Sustainable Agriculture Systems for the Drylands

Proceedings of the International Symposium for Sustainable Dryland Agriculture Systems
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Editors

Gospel Omanya and Dov Pasternak

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Contents

Preface

The long-standing low crop and livestock productivity of arid lands is a major perpetuator of hunger and poverty among communities inhabiting these areas. The constraints to dryland agriculture are intertwined, and include low erratic rainfall, poor soil fertility, water-, wind-, and soil-erosion, land degradation, pests, and inadequate access to agricultural technologies. These are compounded by un-sustainable use of land, eg uncontrolled deforestation for fuelwood, continuous monoculture without rotation, and lack of supportive agriculture policies at both national and international levels. There is a need for participation of all stakeholders to mitigate these constraints for a sustainable and profitable production system. Sustainable agriculture could be looked at as cultivation without reducing the productive potential of the resource base for the future. The symposium was held considering this background. In this respect, I would like to acknowledge its birth to Prof Dov Pasternak who hatched the symposium idea.

This symposium discussed past research findings, experiences and perspectives for sustainable agriculture in the drylands. It aimed to share, identify and formulate sustainable and practical strategies for agriculture systems that are applicable by policy makers, researchers, development workers and farmers in the drylands. The symposium enabled 102 participants from 19 countries in Africa, Asia and Europe to assemble in Niamey, Niger. A total of 25 papers were presented in four themes, namely, Crop Diversification in Agriculture Systems, Soil and Water Management, Crop and Tree Improvement and Productivity, and Building Sustainable Agriculture Production Systems. Following the presentations, a round table discussion was held to draw recommendations towards a sustainable and profitable production system. This book reports the recommendations and proceedings of this symposium. It will be useful to researchers, development officials, policymakers and donors involved in promoting sustainable agriculture for improved livelihoods of farmers. Participants encouraged follow up actions that would assist in the realization of the recommendations.

The Organizing Committee is grateful to the Ministry of Foreign Affairs of Finland and the International Development Research Center (IDRC) for financing the symposium. The logistic and technical support of Dr S Koala and the ICRISAT-Niamey team; Prof D Pasternak, A Schlissel and International Program for Arid Lands Crops (IPALAC); and Dr I Mahamane and the Institut National de Recherches Agronomiques du Niger (INRAN) team is greatly appreciated. Many thanks to Dr S Scherr and Dr S Franzel for their contribution as the Scientific Advisory Committee. The committee extends its appreciation to all symposium participants who made the event fruitful.

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International Symposium for Sustainable Dryland Agriculture Systems
ICRISAT Sahelian Center, Niamey, Niger

June 2005

Chapter 1

Crop Diversification in Agriculture Systems

Moderator: O Youm

Rapporteur: S Abdoussalam

Existing and improved agroforestry systems in low rainfall areas of India

GR Korwar[1] and G Pratibha[1]

Abstract

Agroforestry (AF), the practice of growing trees and crops and/or grasses and legumes together is as old as agriculture in India. The AF systems are more widespread in the low rainfall (arid and semi-arid) rainfed regions of the country. In these regions, usually, animals are an integral part of the agroforestry systems. Generally, these systems are sustainable, but over-harvesting may lead to unsustainability in the systems. Agrisilviculture, silvipasture and agro-horticulture are predominant agroforestry systems of arid regions. The predominant crops are pearl millet (Pennisetum typhoides), *cluster beans* (Cymopsis tetragonaloba), *mung bean* (Vigna mungo) *and moth bean* (V. aconitifolius). *The important grasses are* Cenchrus ciliaris *and Lasiurus sindicus. The important tree species are Propopis cineraria, Acacia senegal, Acacia nilotica, Ziziphus species. The trees are sparsely distributed in the fields. The trees provide fodder, food, fuelwood, shade for animals and crop nutrients.*

Many improved AF systems and practices have been developed on-station and are in the process of extension to the farmers' fields. In the semi-arid regions, the important among these being, intercropping with economic shrubs like curry leaf (Murraya koenigii), *drumsticks* (Moringa oleifera) *and Bixa* (Bixa orellana)*; block plantation of improved genotypes of trees for industrial biomass production, and rotation with crops or intercropping with industrial biomass producing trees. The important tree species for this system are Leucaena leucocephala,* Casuarina *equisetifolia and Eucalyptus tereticornis. Intercropping arable crops in silvi-agriculture and agro-horticulture systems with economic trees like teak* (Tectona grandis), *tamarind* (Tamarindus indicus), *gooseberry* (Emblica officianalis), *custard apple* (Anona squamosa), *mango* (Mangifera indica) *etc are other promising systems making their way to the farmers' fields.*

Introduction

Dryland agriculture is confronted with several problems. Population explosion has brought in marginal and sub-marginal rainfed lands into cultivation posing a serious threat to natural ecosystem. Drylands are fragile and less sustaining lands, resulting in low and uneconomic yields. They are characterized by high soil and climatic variability, excessive degradation of soil, resource poor farmers, etc. Wind and water are the principal factors responsible for degradation (Table 1).

AF is a dynamic ecological based natural resources management practice, that through the integration of trees on farms in agricultural landscape and diversification sustains production for increased social, economic and environmental benefit. Farmers objective of introducing woody perennials in their farming system is not only to cover the risk of crop failures but also to meet the demand for fuel, food, fruit, fodder and small timber. They are essential for meeting the requirements of the ever-increasing population and managing natural resources.

Deforestation and overgrazing are the two principal factors responsible for soil degradation.

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Table 1. Extent of soil degradation (human induced) in India.

Type	Area (m ha)	Geographical Area (%)
Water erosion	148.9	45.3
Wind erosion	13.5	13.5
Chemical	13.8	13.8
Physical	11.6	11.6
Total	187.7	57.1

Source: Sehgal and Abrol (1994).

The livestock, a vital component in the dryland farming systems, plays an important role in imparting sustainability to dryland farming but is often neglected. Farmer's preference is for fruit trees compared to fodder and fuel wood trees and the economics were found to be in favor of agri-horticultural systems compared to arable farming. Apart from fruit, fodder and timber trees alternate choices of high value export oriented crops like medicinal and aromatic crops can be popularized also.

India is divided into different agroclimatic regions, of which, arid and semi-arid regions have harsh environment. The hot Indian arid zone is spread in 31.7 m ha of which major part is in northwestern India and in south India. The major states of arid region in the north are Rajasthan, Gujarat, and southwestern part of Haryana and Punjab and in the south are Karnataka and Andhra Pradesh (Figure 1).

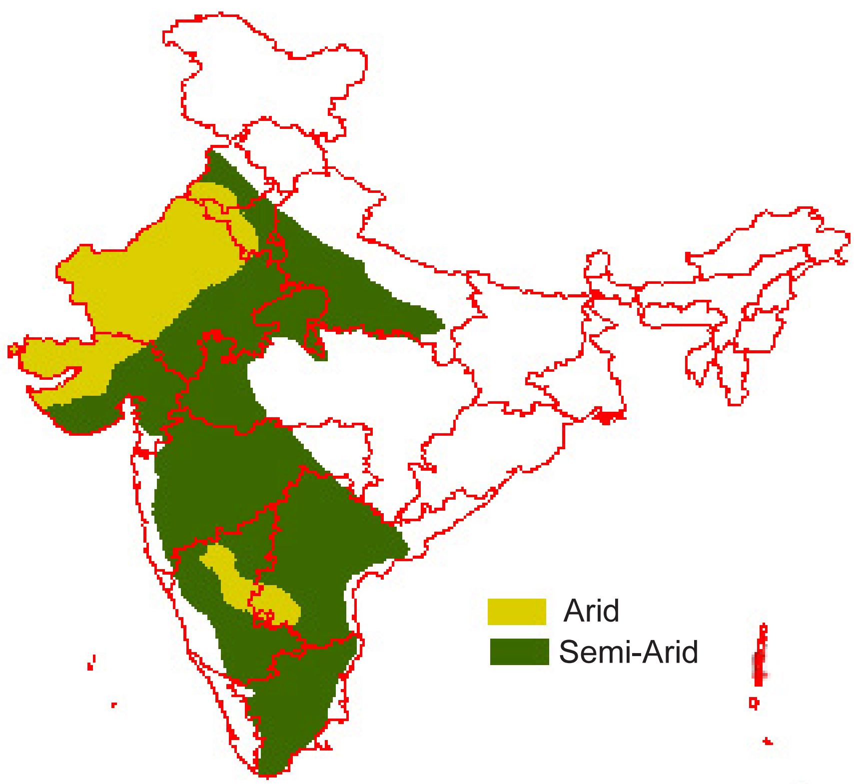

Figure 1. Arid and semi-arid regions in India.

Climate and soil

The key resources that influence the choice of farming enterprise are climate and soil. In northern regions, the monsoon onsets in July and withdraws in second fortnight of September whereas in southern states the monsoon sets in the first fortnight of June and withdraws in second fortnight of November (Ramakrishna et al. 2000). In semi-arid regions, 74% of total precipitation is received through Southwest monsoon. Only 3% is received through Northeast monsoon.

The soils of the region are sandy soils and mixed red and black soils. In some regions soils are moderately strong alkaline and the subsoil is very hard and acts as dry pan in dry regions. The soils of dryland areas are extensively degraded and are of undulating topography. The soils suffer from degradation of one kind or the other. Further degradation of sub-marginal lands can be effectively arrested with trees or their combination with arable crops.

The climatic and soil features of arid regions are very harsh hence the natural vegetation of hyper arid region is sparse with tree species like *Acacia senegal*, *Prosopis cineraria*, *Ziziphus nummularia*, *Albizia spp.* and *Dalbergia sissoo*. The trees are often grown in association with major crops like pearl millet, sorghum, sesame, mung bean, and grasses like *Lasiurus sindicus*. In dry periods the trees and crops suffer from moisture stress than light. Trees have deep root system hence they absorb water from deeper layers compared to crops. In arid and semi-arid environments, AF systems help to provide greater insurance against weather abnormalities.

Methods of Planting

Planting

Establishment of trees is very difficult in these regions. For successful establishment, improving the planting spot can increase the survival and growth of trees. Coupled with timely planting, the saplings establish well before cessation of rains and become hardy enough to pass through the first summer.

The microsite improvement is a form of hydrological intervention for improving point water storage particularly in degraded soils with limited depth and water holding capacity (WHC). In degraded soils, perennial vegetation can be successfully established by restructuring the soil by employing organic and inorganic soil amendments. They improve the water holding capacity that helps in improvement and survival of the plants. The cost of restructuring microsite may be between Indian Rs 8 to10 per pit.

In a study at Central Research Institute for Dryland Agriculture (CRIDA), survival of custard apple increased by 23% with the provision of V shaped micro-catchments (Table 2). In loose textured soils, maintenance of the catchments is required as the structures will disappear soon. In a trial at Jodhpur, a combination of sunken planting with micro-catchments channels leading in to the pits was found to be the best for improving the growth of neem (Gupta et al. 1995).

Table 2. Influence of agronomic interventions on custard apple.

Treatment	Fruit (Numbers)	Height (m)	Survival (%)
No pit mixture	19	2.04	47.40
Pit mixture	20	2.12	40.54
No micro catchment	19	2.07	32.00
Micro catchment	21	2.09	55.00
No ring weeding	15	2.0	20.00
Ring weeding	24	2.15	68.00
No mulching	22	2.03	46.00
Mulching	18	2.12	42.00

Source: Pathak and RamNewaj (2003).

Types of Agroforestry Systems

Alley cropping

In arable lands, to meet the increasing demands it is essential to grow agricultural crops in the alleys formed by rows of trees planted along the contours. Leucaena has been most widely used as hedgerow; the loppings are used for fodder and nutrient recycling.

Growing of crops between the perennial hedges is also a common practice. The hedge is allowed to grow when crop is absent. During cropping season the pruning can be used as mulch to supply N to the arable crops or removed for use as fuel wood, fodder or for other purposes. Short duration crops like sorghum or pearl millet were found to be better suited to such a situation than the long duration crops like castor and pigeon pea. Wider alleys and short cutting heights were found superior under SAT conditions (Korwar 1992). Though several advantages like soil and water conservation were seen (Table 3) in on-station trials (Korwar and Radder 1997), this system has not become popular among the farmers as they did not see any direct economic benefit. Furthermore, stray cattle menace was also very high.

Table 3. Effect on alley cropping on runoff and soil loss.

Treatment	Runoff (mm)		Soil Loss (t ha^{-1})	
	- Prunings	+ Prunings	- Prunings	+ Prunings
Groundnut Sole	43.6	5.5	0.45	0.22
Groundnut/ Leucaena alley system (5 m wide)	30.4	3.0	0.33	0.10
Groundnut/ Leucaena alley system (3 m wide)	19.9	1.4	0.22	0.86
Leucaena Sole	9.1	0.3	0.01	0.02
Standard error (SE)	±4.1	±0.3	±0.04	±0.02

Source: Korwar (1999).

Agrisilviculture system

In this system, the arrangement of annual food crops and woody perennials is such that it enhances productivity and ensures sustainability of land. At the same time it helps to stabilize slopes, minimize erosion and meet some of the farm needs for fuelwood, poles, small timber, fruits, nuts and organic manures. Trees and shrubs planted in the form of hedges and windbreaks also regulate the microclimate. Agrisilviculture combination depends upon the soil, environment, and socioeconomic conditions of the region. In semi-arid and arid regions, the build-up of organic matter is limited and therefore it is important to replenish organic matter supplies every year. In agrisilviculture system nitrogen-fixing trees (NFTs) offer immense possibilities of supplementing the nitrogen requirement of crops grown in association, besides providing rich organic matter and atmospheric nitrogen, improving soil structure, and preventing land degradation. Most of the common nitrogen fixing trees species are *Acacia sps, Albizia, Hardwickia, Dalbergia, Gliricidia, Leucaena, Parkinsonia, Pongamia, Prosopis and Sesbania*. *Prosopis cineraria* - crop mixture is very common in arid regions of Rajasthan, Karnataka and Andhra Pradesh. The leaf is used as fodder in the North where as in the South the leaf is considered sacred. Increased soil fertility under the tree has been reported and recorded. This tree has been reported to increase the crop yields in its vicinity. The Sahelian tree *Faidherbia albida* was tested in on-station trials. The results are not encouraging (Table 4). They are found to compete with the intercrops especially at higher densities (Pratibha and Korwar 1998). Acacia based agrisilvicultural systems is a traditional system of arid regions. Harsh et al. (2000) reported that the returns from the system could be improved by extracting gum by improved methods from the trees. The system gives higher returns than cultivating pearl millet or tree alone (Table 7). *A.senegal* provides seeds that can be used as vegetable. The returns are higher with agrisilviculture system (Table 5, 6 and 7).

Agri-horticultural/ Agri- silvi -horticultural system

In this system, short duration arable crops are raised in the interspaces of fruit trees. A large variety of fruits, vegetables, flowers, plantation/spices crops, medicinal and aromatic plants, and root and tuber crops cover roughly 7% of the cropped area, but contribute more than 18–20% of gross value of the agricultural output. The agricultural crops provide seasonal revenue, while fruit

Table 4. Performance of intercrops in F. albida.

	Crop yields (kg ha^{-1})		Fodder yields (kg ha^{-1})	
Treatment	1995	1996	1995	1996
625 trees ha^{-1}				
Green gram	517	469	3060	3533
Cowpea	25	69	3157	3540
Black gram	325	357	1951	2339
156 trees ha^{-1}				
Green gram	822	763	3543	4387
Cowpea	859	713	3835	4856
Black gram	1146	1083	2341	3490
Sole crop				
Green gram	731	635	2708	3438
Cowpea	999	836	3872	4930
Black gram	901	871	1661	2608

Source: Pratibha and Korwar (1998).

Table 5. Economics of traditional and improved agroforestry systems.

Rain fall (mm)	Traditional Agroforestry		Improved Agroforestry	
	System	**Returns Rs/ha**	**System**	**Returns Rs/ha**
<200	Ziziphus+ Pearl millet (PM) + *Lasiurus sindicus*	2000	Ziziphus budded +PM	15000–20000
<200	*Acacia senegal* + PM + *Lasiurus sindicus*	4000	*Acacia senegal* + PM	8000–10000
200–350	*Prosopis cinararia* + PM + *Lasiurus sindicus*	5000	*Acacia Senegal* + PM	8000–10000

Source: Harsh et al. (2000).

Table 6. Economics of agri-silvicultural model.

Treatments	Gross Returns (Rs/ha) up to 15 years				
	Pearl millet	Wood	Gum	Total (Rs)	Returns Rs/ha/yr
Tree + Crops (*A. tortlis* + Crop)	19200	11200	10520	40920	2728
Sole Trees	22400	-	22400	1493	
Trees used for gum exudation at the age of 12-15 yrs		22400	23040	45440	3029
Sole Pearl millet	24000	-	-	24000	1600

Source: Pathak and RamNewaj (2003).

Table 7. Economics of Acacia senegal + Pearl millet after 11 years in arid regions.

Tree/crops	Tree density/ha	Total returns (Rs)	Returns/year	Benefit/Cost ratio
Acacia senegal	1111 (3m x3m)	129000	11727	3.25
	494 (4.5m x4.5m)	87700	7973	2.21
	277 (6m x 6m)	71400	6490	1.80
Acacia senegal + pearl millet	140 (12m x6m)	63600	5782	1.60
Sole pearl millet		39600	3600	

Source: Pathak and RamNewaj (2003).

trees are managed for 30–35 years giving regular returns of fruit and in some cases fuel wood and fodder from pruned biomass. The acceptability for fruit plants is more compared to fodder or fuel wood. Horticulture in dry lands has a wide scope provided right species and right materials are selected.

The system work best in medium to deep soil with good water holding capacity. Individual farm ponds and supplemental watering in the off-season will certainly improve the scope of fruit farming in drylands. Several fruit trees such as *ber* (*Ziziphus mauritiana*), mango (*Mangifera indica*), pomegranate (*Punica granatum*), custard apple (*Annona squamosa*) and *amla* (*Emblica officinalis*) can be grown successfully under dryland conditions. Hardy species such as tamarind (*Tamarindus indicus*), *jamun* (*Syzygium cumini*), guava (*Psidium guajava*) and *karonda* (*Carissa carandus*) can also be grown in degraded lands. Solanki and Ramneawj (1999) have reported that growing crop with Ziziphus is more profitable than cultivation of sole crops (Table 8).

Table 8. Performance of Ziziphus based system.

Treatment	Yield t ha^{-1}			Gross income (Rs/ha)
	Ziziphus	Inter crop		
		Grain	Fodder	
Ziziphus (Sole)	3.3			10,000
Ziziphus + Sorghum	4.5		1.1	15,222
Ziziphus + cluster bean	1.7	0.4	1.1	8990
Ziziphus + Pearl millet	1.7	0.2	1.8	6620
Ziziphus + mung bean	4.0	0.5	1.4	20460
Standard error (SE)	0.33			980
CD (0.05)	0.94			2830

Source: Solanki and RamNewaj (1999).
CD= critical difference.

Silvi-Pastoral system

Opportunities for augmenting on-farm production and availability of fodder are limited. Hence, community lands can be brought under perennial fodder production systems especially silvi-pastoral systems on marginal lands with different landscapes.

Silvi-pastoral systems are mixed land use systems for forage, livestock, and wood production. They are gaining increasing importance in the developing countries where there are extensive areas of land that cannot be dedicated to conventional agriculture without producing severe, and sometimes, irreversible soil degradation. Silvi-pastoral land use systems are significant where agroforestry, crop-farming systems are not feasible owing to low rainfall and lack of water. The native pastures are not capable of supporting the growing livestock population and introduction of high yielding grass and legumes is essential. The traditional silvi-pastoral systems for different parts of India are presented in the table (Table 9).

Table 9. Silvi-pastoral systems for different regions.

System	Region
Acacia nilotica + natural grass	Arid and semi-arid
Acacia leucophloea + natural grass	Arid and semi-arid
Acacia planiforns + natural grass	Arid and semi-arid
Acacia catechu + natural grass	Arid and semi-arid
Dalbergia sissoo + *bhabar* grass	Shivalik
Prosopis cineraria + grass	Arid Rajasthan
Hardwickia binata + *Sehima nervosum*	Arid and semi-arid
Date palm + natural grass	Arid and semi-arid

Source: Singh et al. (1999).

Silvi-pastoral systems studies at Jhansi by DebRoy and Pathak (1972) revealed that C*enchrus ciliaris* gave higher forage yield than C.*setigerus* in all the treatments. Highest forage yield of 4.19 t ha^{-1} was obtained from C.*ciliaris* under Leucaena at close spacing. In case of *A.tortilis*, the forage production from C.*ciliaris* was 4.19 t ha^{-1} with wider spacing compared to

3.32 t ha^{-1} in closer spacing. The survival of *A.tortilis* was 100% and that of Leucaena varied from 75-94%. The study indicated that it was possible to get 4.3 t ha^{-1} of dry forage yield through proper silvi-pastoral system.

A silvi-pastoral system consisting of the trees such as *Albizia amara* and *L. leucocephala* and grass such as *Chrysopogon fulvus* and pasture legumes *Stylosanthes hamata* + *S. scabra* was established during year 1990 at National Research Centre for Agroforestry (NRCAF) to compare the production potential of established silvi-pasture and natural grassland with respect to biomass and livestock production. The yield of forage leaf, fodder and fuel wood production after four years revealed that under silvi-pastoral system dry forage production was 4.88 t ha^{-1} and fuel wood production was 1.30 t ha^{-1}. Under natural grassland, the dry forage yield was only 3.25 t ha^{-1}. Gain in body weight of goat was higher (28.6 g head^{-1} day^{-1}) under silvi-pastoral system as compared to natural grassland (10.8 g head^{-1} day^{-1}). Similar trends were also found in sheep grazed on natural grassland and silvi-pastoral system.

Experiments conducted at the Indian Grassland and Fodder Research Institute (IGFRI), Jhansi indicated that the total yield of fodder was more when fodder grasses were grown with fodder trees than pure fodder grass cultivation. *Leucaena leucocephala* intercropped with agricultural crops and fodder grasses increases the total yield of food grain, fodder, and fuel (Tiwari 1970; Pathak 1989). Studies conducted at the Central Arid Zone Research Institute (CAZRI), Jodhpur showed that 30-60 trees ha^{-1} in Jodhpur and 104 trees ha^{-1} in Sekhawati (Sikar) grown in association with pearl millet, cluster bean, mung bean and sesame without any adverse effects increased crop productivity during normal and good rainfall years (Gupta and Venkateswarlu 1994). Tree grass combination gave better returns (Table 10) than grass alone (Singh and Singh 1999).

Table 10. Yield and returns of silvi-pastoral systems in arid regions.

System	Yield (t ha^{-1})		Returns (Rs/ha)
	Fuel wood	Grass	
Acacia tortilis (10 x 5 m)	6.0	-	3000
Acacia tortilis (10 x 10 m)	3.2	-	1600
Acacia tortilis + grass (10 x 5 m)	5.0	5.6	3895
Acacia tortilis + grass (10 x 10 m)	2.8	5.3	2793

Source: Singh et al. (1999).

Horti-pastoral system

Currently rapid technological shifts are evidenced in dry farming areas compared to the past. These shifts are driven by market and social factors. Economic returns are in favor of agri-horti systems compared to arable cropping in low marginal rainfall areas. Sheep and goat rearing has also become another option for dryland farmers apart from milch animals. To meet the growing demand for fruits and fodders, horti-pasture system was identified as a potential alternative land use system (Singh and Osman 1995).

Different fruit tree species were evaluated at CRIDA. Survival was highest in Syzygium followed by wood apple, and was least in jack fruit (Table 11) (Osman and Rao 1999). Custard apple was the ideal option since it was not grazed by the cattle and is hardy too. *Ber* is another highly promising plant as it also provides fodder. It is however susceptible to pest infestation.

Table 11. Survival of fruit trees in rainfed areas.

Fruit trees	Survival (%)
Achras zapota	43
Annona squamosa	67
Artocarpus heterophyllus	10
Emblica officinalis	67
Feronia elephantum	90
Mangifera indica	67
Psidium guajava	55
Punica granatum	86
Syzygium cuminii	95
Tamarindus indica	86
Ziziphus mauritiana	73

Source: Singh et al. (1999).

Grasses and legumes associated with hardy fruit trees/top feed species is the panacea for non-arable and cultural wastelands. In horti-pastoral system, there is integration of fruit trees with pasture/grass. To improve wastelands/degraded lands through horti-pastoral system, the first step is to protect them from biotic interference followed by selection of suitable top-feed species, which have fast growth and good coppicing ability, and are highly palatable. In addition, the tree species should have the ability to withstand browsing, trampling and intensive lopping and should be resistant/tolerant to drought and extreme climatic conditions. Survival and growth of different fruit trees under natural rangelands were evaluated at Jhansi. It revealed that tamarind, *chironji*, *amla*, *ber* and pomegranate are promising since they had higher survival than sapota and custard apple. The growth of *amla* was fast (Table12) compared to others. Fruit trees such as *ber* grow very well with pasture as it provides good quality of foliage during the lean period (April-May). *Amla* is best suited for alkali soils. In grass/legume species, guava and custard apple were planted in 1986 at a spacing of 6 X 6 m. Three systems eg, cenchrus, stylo, and no pasture were tested. The results indicated that survival of fruit species is better under no pasture. The trees have more competitive ability with stylo when compared to cenchrus (Table 13).

At Jhansi, growth of Ziziphus was maximum with Cenchrus where as fruit yield increased with legume stylo compared to control and decreased in association with grass (Table 14). Experiments at CRIDA under SAT condition revealed that after five years of planting, fruit yield was negligible. Buffel grass out-yielded stylo and established faster than stylo. Available nitrogen

Table 12. Growth of fruit trees and forage yields under natural grasslands.

Fruit trees	Survival (%)	Height (m)	Collar diameter (cm)	Forage yield t ha^{-1}
Emblica officinalis	93.3	1.63	3.56	4.25
Aegale marmelos	86.6	0.83	1.46	3.30
Ziziphus maurtiana	93.3	1.36	1.56	2.67
Buchanania lanzan	6.6	0.05	0.10	4.38
Punica granatum	80	1.11	2.13	2.53
Tamarindus indicus	100	1.13	2.3	2.74

Source: Singh et al. (1999).

Table 13. Survival and growth of fruit trees in horti-pasture system.

System	Survival (%)	Height (m)		Basal diameter (cm)	
		Years after Planting			
		1	5	1	5
Sole Guava	97	1.61	1.93	2.24	6.33
Guava + Stylo	62	1.60	1.68	2.11	5.06
Guava+ Cenchrus grass	30	1.48	1.65	2.04	4.72
Sole Custard apple	80	1.08	1.90	2.78	6.58
Custard apple + Stylo	65	1.04	1.76	2.45	5.22
Custard apple + Cenchrus grass	10	0.98	1.73	2.08	5.2

Source: Singh et al. (1999).

Table 14. Ziziphus based pasture system.

Treatment	Tree Growth		Fruit Yield kg ha^{-1}	Pasture DMt ha^{-1}
	Height (cm)	Collar Diameter (cm)		
Sole Tree	321	7.28	20.48	-
Tree +Grass	354	8.48	17.74	5.63
Tree + Legume	340	7.69	25.35	4.00
Tree +grass + Legume	314	7.55	22.45	4.32
CD at 5%	NS	NS	3.06	NS

Source: Singh et al. (1999).

DM – Dry matter.

CD – Critical Difference.

NS – Not significant.

was high under pasture compared to no pasture. Among pastures, stylo had higher nitrogen, whereas, there was no change in available P content. Pasture improved the soil aggregate over no pasture systems (Table 15).

Table 15. Influence of horti-pasture system on soil quality.

	Aggregate size		N Kg ha^{-1}		P Kg ha^{-1}	
	0.5-2.0mm		Soil depth		Soil depth	
System	1st Yr	5th Yr	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Sole Guava	37.1	36.7	160	167	5.8	3.6
Guava + Stylo	31.0	67.3	196	223	5.7	3.4
Guava+ Cenchrus grass	38.1	72.1	162	170	5.9	3.5
Sole Custard apple	34.3	34.9	166	169	5.7	3.4
Custard apple + Stylo	32.7	69.7	188	213	5.8	3.2
Custard apple + Cenchrus grass	37.3	74.0	169	175	5.8	3.1

Source: Singh et al. (1999).

Shrubs

Crops are more compatible with short growing shrubs than with trees in drylands. These are well suited to the rainfed regions and they offer less competition with the associated crops. Plantation of economic shrubs and intercropping with arable crops would improve the production and income from rainfed areas, apart from imparting the required stability. Some shrubs that are potential under rainfed conditions are henna, curry leaf, Jatropha, *Simaruba glauca*. Short duration legumes like green gram can be intercropped with curry leaf, bixa, as they would yield 70% of the sole crop. Curry leaf yields about 10,000 kg fresh leaf per hectare from second year. It can yield an additional yield of 250 kg – 3000 kg if the harvested rainwater is recycled to irrigate the plants during off-season. In places where there is demand for fresh leaf this crop is more profitable.

Crop diversification

Diversification of land use systems is a necessary strategy for providing variety of products for meeting varied requirements of the people, insurance against risks caused by weather aberrations and ensure sustainable production of the land on a long-term basis.

Medicinal plants

Some of them are highly tolerant to both biotic as well as abiotic stresses. Hence, rainfed regions offer superior niches for cultivation of such plants. Therefore such plants can be profitably cultivated in drylands more particularly for economic crop diversification. The promising plants for drylands under rainfed conditions having medicinal, aromatic and dye yielding properties are shown in Table 16. However, cultivation of these species on commercial scale will require forward linkages with marketing for obtaining higher returns.

Conclusions

Economics of agroforestry systems

Agroforestry systems perform better than arable crops. Agri-horticulture was most remunerative with benefit cost ratio of 5 as against 2 in agri silviculture and 1.2-1.75 in arable crops (Reddy and Rama Rao 1999). The concepts and strategies associated with agro forestry are rapidly evolving towards the creation of sustainable land uses that enhance farmers' livelihoods, provide commodities for global markets, and mitigate global concerns about environmental degradation. Diversification of tree crops has number of benefits both to the farmer and environment.

Participatory models

Farmers generally are not inclined to take up the cultivation of non-conventional crops or Agroforestry (AF) models in the absence of some success stories. NGOs can demonstrate the practical feasibility and profitability of cultivating such crops involving few progressive farmers. Few such successful examples could build confidence in the farming community and encourage them to take up the cultivation of these new crops. With concerted efforts outlined above, some

Table 16. Promising species for crop diversification.

Botanical Name	Common Name	Economical part	Alkaloid & its Use
Medicinal Plants			
Catharanthus roseus	Periwinkle	Leaves	Vinblastine, vincristine -Anticancer
		Roots	Ajmaciline
Cassia angustifolia	Senna	Leaves,pods	Sennosides-Laxative
Aloe barbadensis	Aloe	Leaves	Aloin- Cosmetics
Withania somnifera	Asgandha	Roots,leaves	Withanoides
Solanum nigrum	Solanum	Berries	Solasidine-steroids
Mucina purieans	Muccina	Seeds	L-dopa-parkinsonia
Aromatic Plants			
Cymbophogon martini	Palmarosa	Flowering herb	Geraniol, Geranial acetate perfumery, cosmetics, soaps, foods
Cymbophogon flexuous	Lemongrass	Leaves	Citral-perfume flavor vitamin A can be isolated. The spent grass can be used as cattle feed, fuel in distillation unit manure
Vetiveria zizanoids	Vetiver	Roots	Vetiverol, Vetiveryl acetate Cooling
Ocimum basilicum	Basil	Inflorescence	Methyl chavicol, Eugenol
O.gratisimum		and leaves	Linalool
O.cannum			Methyl chavicol
O.americanum			
Dyes			
Indigofera tinctoria	Indigo	Leaves	Blue dye – textile
Bixa orallana	Bixa	Seed	Orange – textile & food colorant
Lawsonia innermis	Henna	Leaves	Orange – cosmetic & textile
Hibiscus sabdarifa	Mesta	Calyx	Red-food color
Tagetus errecta	Marigold	Flower	Food color
Carthamus tinctoria	Safflower	Flower	Food color
Simarauba gauca	Paradise tree	Seed	Edible oil
Pongamia pinnata	Karanz	Seed	Non edible
Jatropha curcas	Jatropha	Seed	Non edible

Source: Singh et al. (1999).

good models can be developed. In view of the above, AF models were developed in 6 villages in two districts of AP. The results of the experiments revealed that the farmers are more interested in main field plantation than boundary plantation. Survival of main field plantation was better than the boundary plantation.

Care and maintenance

For successful establishment of perennials in rainfed regions, protection of perennials from stray animals during off-season at least for initial 2-3 years is important. The plants can be fenced with the locally available material, individual tree guards, social or living fences. Before planting the species, live fences can be planned with useful species like *Gliricidia sepium, Agave sisalana,* Jatropha, Prosopis, Lawsonia spp. These species apart from protecting the crops also yield other products like green leaf manure, minor fruits, fodder, fiber, fuel wood etc.

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Identifying wild food plants for sustainable agroforestry through market survey

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Abstract

Local people in the rural area rely heavily on wild plants or semi-domesticated plants for food, medicines, building materials, domestic energy, etc. Food plants are among the most harvested species while plant products for other household uses are increasingly sold in local and urban markets as sources of income.

Market demand of harvested forest products could be one of the major incentives that direct sustainable management programs for natural resources. Plant products sold in urban markets are usually brought from the rural area where they are considered as good source of income from the forest. Good market value also causes a species to be widely harvested and therefore over-harvesting is plausible.

A survey was conducted in five urban markets of Ouagadougou, Burkina Faso, to inventory the wild food plants that have market value. In each of the five markets, sections were visited where legumes and fruits are sold. All wild plant products exhibited for sale were recorded twice, first during the dry season (February-March) and then during the rainy season (August). About 500 sellers of wild food plants were visited each time. During the dry season, 17 local species sold under 24 different product formulas were recorded. During the rainy season, 14 woody species were recorded. Species more frequently sold in both dry and rainy season were Parkia biglobosa, Adansonia digitata, Acacia macrostachya, Bombax costatum and Tamarindus indica. Species sold by many merchants during the dry season only were Ziziphus mauritiana and Detarium microcarpum; while species often sold during the rainy season only were Vitellaria paradoxa, Saba senegalensis and Sclerocarya birrea. The frequency of the recorded plant products in the urban markets suggests that the related species are economically valued in urban areas.

Annual income generated from sales of Vitellaria paradoxa and Parkia biglobosa in Burkina is estimated at US$7.6 million and US$8.3 million respectively. Products from other plants such as Tamarindus indica, Adansonia digitata and Saba senegalensis show good potential for sales in urban markets.

These results contribute to better visualize actual socio-economic importance and potential of non-wood forest products in Burkina Faso. It also suggests that the agroforestry parkland systems under which the species perform are managed to insure sustainable production of the non-wood forest products (NWFPs).

Introduction

The majority of the population of Burkina Faso still uses natural resources to meet basic needs. Apart from crop plants, wild plants are intensively used by the populations in the rural areas as well as in the cities of Burkina Faso as building material, firewood, medicines, for their fruits or vegetables and fodder (Guinko and Pasgo 1992). The contribution of harvesting wild plant products to the welfare of local people is significant (Helmfied 1998). Nevertheless, non-wood

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forest products (NWFPs) often have been overlooked in strategies and programs for forest conservation and management (Crafter et al. 1997).

In this paper, the expression 'wild plants' is used for non-cultivated plants, although some of the species mentioned such as *Parkia biglobosa* and *Vitellaria paradoxa* are commonly regarded as semi-domesticated species. To avoid confusion in the meaning of the concept of NWFP that will be widely used in this paper we adopted the definition worked out by FAO experts. The agreed definition is: "Non-wood forest products consist of goods of biological origin other than wood, as well as services derived from forests and allied land uses" (FAO 1995).

To properly investigate the importance of natural resource to the local people, one should first understand the criteria by which they value these products. This approach is specially needed for rural landscape management including agricultural parklands where most of the recognized useful species grow. A better understanding of the relationship between local people and the natural resources will help in identifying the important functions of the individual species, as well as ecosystem as a whole that management plans should consider. Income generation is an important function of plant resources that is highly appreciated by the inhabitants. As stated by FAO (1995), NWFPs are consumed by varying social levels, from shifting cultivators and subsistence farmers to urban populations. Parts of the harvested products are, therefore, sold in local or urban markets in different forms: fresh, dry (vegetables) or processed (such as the fermented seeds of *Parkia biglobosa* called *soumbala*). Some of the plant products have a real potential to become commercial items. This importance of NWFPs as commercial products seems to be growing due to poverty of the rural communities and the increasing demand from the cities (Ouédraogo et al. 2003).

Many authors have reported the socio-economic importance of some NWFPs in Burkina Faso (FAO 1995; Guinko and Pasgo 1992; Ouédraogo et al. 2003; Nikiema et al. 1997). Daily consumption of fermented *Parkia biglobosa* seeds was estimated to be 3 g person^{-1} day^{-1} in central Burkina Faso (Ouédraogo 1995). Bonkoungou et al. (2002) stated that *Parkia biglobosa* could generate an annual income of US$270 for a household, which is about the price for a total yield in seeds of 20 trees. The shea butter produced from *Vitellaria paradoxa* kernels plays an important socio-economic role in Burkina Faso where it is one of the main export products (FAO 1995; Bonkoungou 2003; Becker and Statz 2003).

The cultural role of the NWFPs and especially of the wild food plants should not be overlooked. Many species are given a central place in traditional ceremonies. During wedding ceremonies, in the Mossi ethnic group from central Burkina Faso, the bride is accompanied to her husband's house with a well-defined set of items that include *soumbala* and dry vegetables. These products in addition to shea butter are also exchanged as women's gifts at special occasions in the region (personal observations).

The wild food plants are specially looked for during the period of food scarcity. During the rainy season, farmers consume the *Vitellaria paradoxa* and *Lannea microcarpa* fruits to complement their daily nutrition. In the mean time, leaves of many other plant species are harvested and cooked as vegetables ie, *Adansonia digitata*, *Ficus gnaphalocarpa*, *Balanites aegyptiaca*, *Crateva religiosa*, *Annona senegalensis*, *Caparis corymbosa*, *Maerua angolensis* (Belem and Guinko 1997; Ouédraogo et al. 2003).

These wild food plants are a valuable contribution to human nutrition by providing vitamins and minerals to the daily diet. The fermented seed of *Parkia biglobosa* is very rich in protein

(Ouédraogo 1995; Hall et al. 1997) and is therefore considered as a valuable condiment. The yellow, floury pulp in which the seeds are embedded contains a high-energy food with up to 60% sugar and 291 mg/100 g of dry matter of C (Maydell von 1983; Booth and Wickens 1988). People of various ages usually eat the néré pulp as couscous, porridge or dried fruits cakes. *Vitellaria paradoxa* is utilized for various products. The shea butter is the most common vegetable fat traditionally used for cooking and for many other purposes (ie, soap making, traditional medicines, etc). Baobab leaves are widely used in the Sahelian regions and are known to be rich in iron (FAO 1995). An excellent beverage rich in vitamin C is made out of is fruit pulp (Bonkoungou et al. 2002). *Ziziphus mauritiana*, which grows in the Sahelian zone, produces tasty and nutritious fruits that are sold in the markets.

The change in land use intensity and the growing pressure on the natural resources suggest that more attention should be paid to the management of those resources (Nikiema et al. 1997). The agroforestry parklands are considered a crop production system in which sound management of biodiversity including the improvement of the productivity of wild food plants can be carried out (Boffa 2000). As such, parkland development influences the availability of NWFP. Most of the common wild food plants species are taken care of by farmers through agroforestry practices. Since agroforestry parklands in the semi-arid areas of West Africa are reported to be degrading (Nikiema 1993; Gijsberg et al. 1994; Boffa 2000) due to continuous land tilling and reduction of fallow periods, the diversity of wild food plants in the area is consequently declining and some valuable plants are disappearing. Rural landscape-management projects that are implemented in most West African countries can contribute to solving this problem by investigating and investing in the management of wild food plants.

Investment in parkland trees will require a set of criteria that give value to each of the potential plant products. One set of criteria that justify the investment is the market potential of the plant resources. This criterion meets the interest of most of the stakeholders, while the issue of the natural resource's ownership should be properly dealt with.

Market information is also useful for estimating the harvesting pressure on natural resources. For example, seeds of *Acacia macrostachya* that are used as a pulse are considered a delicacy in central Burkina Faso. The price of 1 kg of seeds can go up to FCFA 200 in Ouagadougou markets. Due to the growing socio-economic value of this plant, the question whether its management is considered within the agroforestry parklands system in the region becomes more relevant. It seems that the problems of management of other important commercial species have not been adequately integrated in the actual parklands practices; some of these species are *Saba senegalensis*, *Annona senegalensis* and *Detarium microcarpum*. (Nikiema et al. 1997).

The objective of this research was to describe the importance of woody food plants through market survey in the context of the agroforestry parkland management. We have therefore investigated the following subjects:

- Identification of the common commercial woody food plants products.
- Estimation of their availability and price in the dry and rainy seasons.
- Combination of market information and parkland management practices in order to identify agroforestry parkland management issues that will contribute to both income generation for the rural people and sustainable management of natural plant resources.

Method

Study area

The study took place in the capital city of Burkina Faso, Ouagadougou. This area was traditionally occupied by the Mossi tribe, which represents about 40% of the population of the country, but as all African cities, it has a mixed population migrated from all over the country. The city is scattered with markets where the citizens do their daily shopping for food as well as for other goods. Local and imported products are sold in these markets. The markets are organized by sections where similar products are grouped ie, the vegetable section is separated from the cereal section.

Literature survey

Considerable work has been done to assess NWFPs that are commonly used by local population in Burkina Faso and reported by many authors. Gathering this information is a good start for a proper assessment of the socio-economic value of these plant resources. Literature survey provided a basic list of the plants in question (Table 1).

Information reported in the literature is in many cases the result of socio-economic surveys with farmers. Most of these surveys have reported farmer's preferences (Nikiema et al.1997; Belem 2000; Bonkoungou et al. 2002). However when much of the NWFPs are to be sold in the city markets for income generation then the preference study should be conducted in these markets. Results of such a study are instrumental for the future sustainable development of agroforestry systems with the view of optimization of income generation from the NWFPs.

Market survey

The diversity of species being used as food plants was accessed through market surveys. Five urban markets were chosen including the central market of Ouagadougou. The other four markets were chosen in order to cover, as much as possible, the different market places of Ouagadougou. Furthermore, 9 rural markets were surveyed in Zounweogo province.

It appears that the markets' areas are divided into sections according to products exhibited, so if one needs a product the first thing to do is to search for the area in the market designated to it. In each market, all sellers present in the condiments and vegetable sections of the market were surveyed. The number of surveyed sellers varied from 75 to 126 in the city markets and 23 to 4 in the rural markets (Tables 2 and 3).

Results and Discussions

Socio-economic aspects of important species

Many studies ranked important species as perceived by farmers themselves in different places (Nikiema et al. 1997; Belem 2000; Bonkoungou et al. 2002). Table 4 shows species ranked by farmers according to different authors.

Table 1. Diversity of species and food products in the markets: A synthesis from market and literature surveys. (Aubreville 1950; Belem and Guinko 1997; Bosch et al. 2002; Maydell 1983; Guinko and Pasgo 1992; Belem 2000; Ouédraogo et al. 2003).

No	Species	Fruit	Vegetables	Pulses	Vegetable oil	Spice and condiments
1	*Acacia macrostachya*			x		
2	*Adansonia digitata*	x	x			x
3	*Afzelia africana*		x			
4	*Annona senegalensis*		x			
5	*Balanites aegyptiaca*	x	x		x	
6	*Bombax costatum*		x			
7	*Borassus aethiopum*	x				
8	*Boscia senegalensis*	x		x		
9	*Caparis corymbosa*		x			
10	*Celtis integrifolia*		x			
11	*Crateva religiosa*		x			
12	*Detarium microcarpum*	x				
13	*Dialium guineense*	x				
14	*Diospyros mespiliformis*	x				
15	*Ficus sycomorus*					
16	*Gardenia erubescens*	x				
17	*Hyphaene thebaica*	x				
18	*Lannea microcarpa*	x				
19	*Leptadenia hastata*		x			
20	*Maerua crassifolia*		x			
21	*Parkia biglobosa*	x				x
22	*Bauhinia reticulata*		x			
23	*Bauhinia thonningii*		x			
24	*Saba senegalensis*	x				
25	*Sclerocarya birrea*	x				
26	*Strychnos spinosa*	x				
27	*Tamarindus indica*	x				x
28	*Vitellaria paradoxa*	x			x	
29	*Vitex doniana*	x				
30	*Ziziphus mauritiana*	x			x	

Table 2. Number of persons surveyed in the five markets of Ouagadougou in two different seasons of the year.

Market	Dagnoe-yar		Dasasgho-yar		Rodwoko(Central)		Katre-yar		Toessin-yar	
Season	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Gender										
Female	84	109	60	94	76	83	49	76	51	92
Male	42	11	35	20	13	4	26	14	25	19
Total	126	120	95	114	89	87	75	90	76	111

Table 3. Number of persons surveyed in rural markets of Zounweogo province during rainy season.

Village markets	Total surveyed	Number of men	Number of women
Béré	23	1	22
Bindé	23	2	21
Guiba	18	0	18
Kaibo	14	0	14
Kalinga	5	0	5
Nobéré	8	2	6
Sakuiliga	13	0	13
Yakin	4	0	4
Yimasgho	14	1	13
Total	**122**	**6**	**116**

The ranking shows the same tendency of the perceived species importance. *Vitellaria paradoxa* usually comes first generally followed by *Parkia biglobosa*, *Adansonia digitata*, *Tamarindus indica*, *Lannea microcarpa* and *Saba senegalensis*. The presence and the rank of a species depend on the geographic area and the ethnic group concerned. Ouédraogo (1995) reported that the fermented seeds of *Parkia biglobosa* are the most important and the most widely used NWFP in Burkina Faso. According to Bonkoungou et al. (2002), *Parkia biglobosa* products contribute the most to the household annual income in the rural areas, by generating up to US$267 for a household in Sindou village (Burkina Faso). Annual production of Karité (*Vitellaria paradoxa*) kernels in Burkina Faso was estimated to be about 70,000 tons (Becker and Statz 2003).

Diversity of wild food plants in urban markets

As presented in Table 4 a total of 16 woody species products were recorded in the five urban markets. These species cover commodities such as fruits, vegetables, pulses and vegetable oil. Not all species were present in the markets during each of the two recording periods. The results in Table 4 showed that 16 species were recorded during the dry season, 12 species were recorded during the rainy season and 10 species were present during both the dry and the rainy seasons. 24 NWFPs were recorded and some of the species provide up to 3 different products from various parts (leaves, fruits, seeds or flowers). Table 5 shows the frequency of the species in the markets giving the evidence that species such as *Acacia macrostachya*, *Adansonia digitata*, *Bombax costatum*, *Parkia biglobosa*, *Saba senegalensis*, *Tamarindus indica* and *Vitellaria paradoxa* are common commercialized species in Ouagadougou markets.

Table 4. Ranking of food plants species through local survey.

Authors	Bonkoungou et al. (2002)	Nikiema et al. (1997)	Ouédraogo et al. (2003)	Ouédraogo et al. (2003)	Belem (2000)
Regions	Central Burkina	Sanematenga province	North Burkina	Mouhoun region	Sanmatenga province
1	*Vitellaria paradoxa*	*Vitellaria paradoxa*	*Vitellaria paradoxa*	*Vitellaria paradoxa*	*Vitellaria paradoxa*
2	*Parkia biglobosa*	*Adansonia digitata*	*Tamarindus indica*	*Parkia biglobosa*	*Adansonia digitata*
3	*Lannea microcarpa*	*Tamarindus indica*	*Parkia biglobosa*	*Adansonia digitata*	*Bombax costatum*
4	*Tamarindus indica*	*Bombax costatum*	*Adansonia digitata*	*Saba senegalensis*	*Tamarindus indica*
5	*Adansonia digitata*	*Lannea microcarpa*	*Saba senegalensis*	*Detarium microcarpum*	*Balanites aegyptiaca*

Continued

Table 4. *Continued*

6	*Bombax costatum*	*Parkia biglobosa*	*Lannea microcarpa*	*Tamarindus indica*	*Boscia senegalensis*
7	*Balanites aegyptiaca*	*Ziziphus mauritiana*	*Ziziphus mauritiana*	*Lannea microcarpa*	*Lannea microcarpa*
8	*Ziziphus mauritiana*	*Balanites aegyptiaca*	*Bombax costatum*	*Sclerocarya birrea*	*Ziziphus mauritiana*
9	*Diospyros mespiliformis*	*Acacia macrostachya*	*Acacia macrostachya*	*Balanites aegyptiaca*	*Sclerocarya birrea*
10	*Detarium microcarpum*	*Diospyros mespiliformis*	*Balanites aegyptiaca*		*Diospyros mespiliformis*
11	*Sclerocarya birrea*	*Acacia senegal*	*Sclerocarya birrea*		*Ficus gnaphalocarpa*
12	*Saba senegalensis*	*Ximenia americana*	*Diospyros mespiliformis*		*Ximenia americana*
13	*Acacia macrostachya*	*Saba senegalensis*	*Ximenia americana*		
14	*Ficus sycomorus*	*Vitex doniana*	*Boscia senegalensis*		
15		*Strychnos spinosa*			
16		*Boscia senegalensis*			

Table 5. Plant species and their products sold in the markets during the dry (Dry S) and the rainy (Rain S) seasons of the year.

No	Species	Dry S	%	Rain S	%	Number of products	Number of plant parts
1	*Acacia macrostachya*	59	10	40	6.9	1	1
2	*Adansonia digitata*	94	15.9	84	14.4	3	2
3	*Balanites aegyptiaca*	18	3.0	0	0	2	3
4	*Bombax costatum*	96	16.2	62	10.6	1	1
5	*Borassus aethiopum*	8	1.3	0	0	1	1
6	*Detarium microcarpum*	27	4.6	0	0	1	1
7	*Dialium guineense*	8	1.3	4	0.7	1	1
8	*Gardenia erubescens*	2	0.2	29	5.0	1	1
9	*Hyphaene thebaica*	3	0.5	0	0	1	1
10	*Parkia biglobosa*	102	17.3	51	8.8	3	1
11	*Saba senegalensis*	0	0	71	12.2	1	1
12	*Sclerocarya birrea*	4	0.7	23	3.9	1	1
13	*Tamarindus indica*	151	25.5	111	19.0	2	2
14	*Vitellaria paradoxa*	0	0	103	17.7	2	1
15	*Vitex doniana*	2	0.3	0	0	1	1
16	*Ziziphus mauritiana*	17	2.9	4	0.7	2	1
	Total of interviewed	**591**	**100**	**582**	**100**	**24**	

Looking at the social implications of NWFP commercialization we can see from Tables 2 and 3 that women dominate the sales activity. They represent 69% of the sellers during the dry season and 88% during the rainy season in the urban markets. In the rural markets women represent 95% of the sellers during the rainy season.

Most of the species supply products other than food ie, firewood, timber, medicines, forage, soap etc.

The survey in the 5 urban markets revealed the commercialization of 16 wild plant products for human nutrition. These products include 21% leafy vegetables, 88% fruits, 6% pulses, 21% vegetable oil and 19% spices and condiment of the species (Table 7). The survey in the rural markets shows nine products from four different species. (Table 6)

Table 6. Number of persons surveyed in nine rural markets of Zounweogo province during rainy season.

Rural markets	*Adansonia digitata*	*Parkia biglobosa*	*Tamarindus indica*	*Vitellaria paradoxa*
Béré	1	8	2	12
Bindé	-	10	3	10
Guiba	-	6	1	11
Kaibo	-	3	2	9
Kalinga	-	1	-	4
Nobéré	1	2	2	3
Sakuiliga	-	6	1	6
Yakin	-	2	-	2
Yimasgho	-	4	-	10
Total	2	42	11	67
Number of products	1	3	2	3

Table 7. Different plant uses recorded in the urban markets using the commodity groups as defined by Bosch et al. (2002).

No	Species	Fruits	Vegetables	Pulses	Veget. oil	Spices and condiments
1	*Acacia macrostachya*			x		
2	*Adansonia digitata*	x	x			x
3	*Balanites aegyptiaca*	x	x		x	
4	*Bombax costatum*		x			
5	*Borassus aethiopum*	x	x			
6	*Detarium microcarpum*	x				
7	*Dialium guineense*	x				
8	*Gardenia erubescens*	x				
9	*Hyphaene thebaica*	x				
10	*Parkia biglobosa*	x				x
11	*Saba senegalensis*	x				
12	*Sclerocarya birrea*	x			x	
13	*Tamarindus indica*	x				x
14	*Vitellaria paradoxa*	x			x	
15	*Vitex doniana*	x				
16	*Ziziphus mauritiana*	x			x	
	Total	**14**	**4**	**1**	**4**	**3**
	%	**88**	**21**	**6**	**21**	**19**

The NWFPs are sold in the markets using different measurement tools or methods as given in Table 8. The most simple to understand is when the measurement unit is equivalent to one unit of the product ie, one fruit of baobab tree or *Saba senegalensis*. The most common units recorded in the markets are *Laga*, which is about a volume of 2 litres and *Tas* (the French word for 'heap') whose size can vary according to products and prices. One other measurement unit that was recorded is the *Boule*, a rounded portion of the product. The latter unit is used for products that need to be dried (ie, the fermented seeds of *Parkia biglobosa* and the tamarind fruits).

Table 8. Urban market prices of plant products in Ouagadougou.

			Measurement Units			
No	Species	Products	*Laga*(2L can)	*Tas*(heap)	*Boule*(rounded products)	One unit
1	*Acacia macrostachya*	Pulse	600-800	25-50		
2	*Adansonia digitata*	Fruits		100		50
	Adansonia digitata	Vegetables	100	25-50		
3	*Balanites aegyptiaca*	Vegetables	100	25-50		
4	*Bombax costatum*	Vegetables	600	25-50		
5	*Borassus aethiopum*	Fruits				
6	*Detarium microcarpum*	Fruits	100	25-50		
7	*Dialium guineense*	Fruits	500	50-200		
8	*Gardenia erubescens*			25-50		
9	*Hyphaene thebaica*		100	50		25
10	*Parkia biglobosa*	Seeds	500-800			
	Parkia biglobosa	Pulp	50-100	25		
	Parkia biglobosa	Fermented seeds		100-500	25-100	
11	*Saba senegalensis*			25-50		10-25
12	*Sclerocarya birrea*					
13	*Tamarindus indica*	Dried leaves	100-200	50		
	Tamarindus indica	Fruits	500-750			
14	*Vitellaria paradoxa*	Fruits		25-100		
	Vitellaria paradoxa	Butter	500		25	
15	*Vitex doniana*	Fruits		50		
16	*Ziziphus mauritiana*					

The variation in selling units allows sale of most of the products in a wide range of prices starting with unit prices as low as FCFA 10 (US$0.2) as given in Table 8. The use of bags was also observed in some cases but we chose not to mention it in Table 8 because the bags were of different sizes.

Food plants and their occurrence in the agroforestry parklands

Most of the recorded commercialized food plants are present in the parklands as shown by Nikiema et al. (2003). Species such as *Parkia biglobosa* and *Vitellaria paradoxa* are called semi-domesticated because they have been managed in the farmers crop fields for centuries as suggests the physiognomy of the agroforestry parklands. They are also highly valued because of the variety of products they offer and the income one can make from them.

The study shows that most of the recorded commercial species are present in the agroforestry parklands but not necessarily from the same ecological area. Inter-regional and trans-boundary trade also covers many plant products such as *Dialium guineense,* which are harvested from south Soudanian and Guinea savanna vegetation zones and sold in the more arid zones. The species present in the parklands can be considered as secured by farmers, in terms of conservation, since they are semi-domesticated. The following species are integrated in the parkland management systems, *Vitellaria paradoxa*, *Parkia biglobosa*, *Adansonia digitata and Balanites aegyptiac*a.

Market value of species and implications for management

The occurrence of species products in the markets and the commercial value attached to them suggest that the potential for promoting the wild food plants in the central area of Burkina Faso is very significant. Many wild food plants products are present in the urban markets throughout the year (such as the fermented seeds of *Parkia biglobosa*, shea butter, Tamarind, *Dialium guineense*, Baobab leaves etc) other products are seasonal.

The contribution of wild food plants to generate income for poor rural population and especially to the rural women can be impressive. Ouédraogo (1995) estimated the daily consumption of *soumbala* per person in Burkina to be 3 g. The estimated annual consumption of *soumbala* would then be 12,000 tons in Burkina. Considering an average price of FCFA 400 kg^{-1} (US$0.75) (Hall et al. 1997; this paper), the *soumbala* business represents an annual revenue of about FCFA 5 billion (about US$8.3 millions) in Burkina Faso alone. These calculations do not consider external trading with neighboring countries (Ivory Coast, etc) where Burkinabe communities are settled. Information on the contribution of *soumbala* export to the economy of Burkina is difficult to find but necessary for the proper evaluation of the role of wild food plants in the national economy.

Vitellaria paradoxa's butter, internationally known as shea butter, is one of the main export items from Burkina Faso. Bonkoungou (2003) reported the annual income from *Vitellaria paradoxa* to be US$7.6 millions in Burkina Faso.

Based on the yield and income that the wild food plants can bring to farmers, their household economy can be improved by integrating, in a more organized manner, the use of promising wild food plants (*Parkia biglobosa*, *Adansonia digitata*, *Vitellaria paradoxa*, *Tamarindus indica*, *Saba senegalensis*, *etc)* as a source of income. As an example, 10 planted *Parkia biglobosa* trees after 10 years will produce about 25 kg of seeds each meaning 250 kg in total. This production will bring the farmer about US$80 to US$100 every year adding to the annual income from his crop field. Study done by Lamien and Vognan (2001) revealed that Néré and Karité contribute 16 to 27% (equivalent of US$35–37) of the annual income of rural women in Burkina Faso. Examples of farmers in Burkina who have developed income generation through the tree component of their agricultural fields are numerous (personal observations).

Conclusion

Surveying the urban markets provides reliable information on which valuing of local species can be based. Frequency and prices of products in the markets could be used as key criteria to identify candidate species for a market oriented agroforestry system.

Agroforestry parkland management in the future should give priority to proven income-generating species while domestication programs should accompany the promotion process of those species. Marketable species as shown in the present research should be better promoted in the parklands for a more market-oriented agroforestry.

The contribution of wild food plants to the rural household, regional and national level economy is not minor and should not be neglected. As demonstrated in our discussion some of the valuable species can represent up to US $8.3 million a year for producers and traders. Gathering more information on the potential external markets and improving the quality of the products can further expand export markets. Export markets are still to be explored for products such as shea butter that has a growing interest in Europe (Becker and Statz 2003) and America.

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Ber (*Ziziphus mauritiana*) based cropping systems in arid and semi-arid regions

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Abstract

Ber (Ziziphus mauritiana) *is an important crop of the arid and semi arid regions of the world and is capable of producing under severe drought conditions. A system approach rather than monocrop is advised to get maximum productivity per unit area. The system approach not only protects farmers from biotic and abiotic calamities but also provides an economic cushion. Following are some case studies conducted in India on various cropping systems based on ber.*

Introduction

Ber has been found to have an efficient and positive interaction with several crop and plant species like cereals, pulses, oil seeds, vegetables, grasses, forest trees and fruit plants in a composite system under arid and semi arid ecosystem of the country. Different ber-based agroforestry systems are proving their usefulness in improving the socio-economic status of the people in various ecosystems of the country.

Case Studies: Ber-Based Agroforestry Systems

1. Agri-horti system

In rainfed areas of arid and semi-arid India, *kharif* (rainy season) and *rabi* (postrainy season) crops are grown successfully with ber plantations. Here, ber is planted at 6 x 6 m distance and the inter space between two rows is being utilized to raise the crops.Among various crop species, legumes have an edge over the non-legumes in terms of biological nitrogen fixation. Work conducted at the Central Arid Zone Research Institute (CAZRI), Jodhpur has revealed that a farmer can get an additional production of 7.82 q ha^{-1} cluster bean (*Cyamopsis tetragonaloba* (L.) Taub.) when grown with jujube plantation in kharif. Under semi-arid conditions of Pali, Rajasthan, 4.36 q ha^{-1} mung bean (*Vigna radiata* (L.) Wilczek), 10.23 q ha^{-1} cluster bean and 1.88 q ha^{-1} sesame (*Sesamum indicum* L.) can be produced under ber (cv Seb) based farming system during kharif. In aridisols at National Research Centre for Arid Horticulture (NRCAH), Bikaner (annual rainfall of 350-450 mm), nearly 45% area between the ber rows was utilized for raising crops under rainfed conditions during both the seasons. During kharif, leguminous crops (cluster bean, moth bean) for various purposes (such as for green pods and grains) were raised while during rabi, only mustard (for grains) was taken. Cluster bean (cv Durga Bahar) yielded 67.0 q ha^{-1} green pods (yield from only 4500 m^2 area available between ber rows). The grain

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production of the same cultivar was noticed to be 2.25 q ha^{-1}. Cultivar RGC-936 (cluster bean) produced 6.3 q ha^{-1} grain and RMO-40 (moth bean) produced 5.4 q ha^{-1} grain from same area during kharif. During rabi season mustard (Pusa Bold) produced 9.14 q ha^{-1} yield from the same piece of land.

In a case study conducted at a farmers field in Bundelkhand region of Uttar Pradesh by NRC on Agroforestry, revealed that ber-based cropping provides an additional income of Rs 10,000 ha^{-1} from fruits apart from 8.0-9.5 q ha^{-1} yr^{-1} fuel wood and 6.0-8.5 q ha^{-1} yr^{-1} top feed. Among various horticulture based multiple cropping systems tried under rainfed conditions at Godhara, Gujarat, *aonla* (*Emblica officinalis*) and ber-based systems proved the best. *Aonla*-based cropping system gives a higher net income of Rs 28,300 ha^{-1} yr^{-1} while ber-based system gives a net return of Rs 24,900 ha^{-1} yr^{-1} in fifth year of plantation. At marginal lands of Bundelkhand (red gravelly land with 7.7 pH, 0.15% organic carbon, 0.17 m mhos cm^{-1} EC, 0.62 me/100g ESP, 110 kg ha^{-1} available nitrogen, 12.2 kg ha^{-1} phosphorus and 120 kg ha^{-1} potassium) ber-based system provided 8.94-10.72 q ha^{-1} fruit and 0.68-3.74 q ha^{-1} grain from different crops. Black gram was found to be the most suitable inter crop with an average yield of 3.74 q ha^{-1} yr^{-1} in ber-based system. Apart from fruit, ber tree produced 3.85-4.75 q ha^{-1} fuel wood and 0.63-0.72 q ha^{-1} fodder every year. Therefore, it clearly indicates that ber-based agri-horti system has a tremendous potential in arid and semi-arid parts of the country that is mostly rainfed.

2. Horti-horti system

Inter spaces between ber rows have been effectively utilized for various horticultural crops. Apart from leguminous vegetables (cluster bean and cow pea), the inter space has also been utilized for production of drought hardy cucurbits (*mateera*, *kachari* etc) in arid and semi-arid parts of India. Small stature fruit crops such as *karonda*, *phalsa* etc, have also been successfully grown in ber-based cropping system. Work done at the Narendra Dev University of Agriculture and Technology (NDUAT), Faizabad (Table 1) reveals that even fruit crops with larger canopy (guava, *aonla*) can be grown in ber-based farming system.Drought hardy medicinal and aromatic plants and flowers can also be grown under ber-based agroforestry system.

Table 1. Performance of fruit species under ber based cropping system.

Species combination	Cultivars	Plant density	Trunk girth* (cm)	Productivity*(MT ha^{-1})
Ber+Aonla	Umran and NA	100 and 144	39.3	4.0
	7 + Chakaiya		42.1	4.2
Ber+Guava+ Phalsa	Gola, L 49 and	100	42.1	4.5
	Local	144	28.5	5.2
		100	—	0.3

*after 6th year of plantation

3. Horti-pastoral system

The economy of the people in arid region is based on animal husbandry. Ber-based horti-pastoral system in the region provides fodder for the animals and fruits for additional income. Jujube along with grasses can form an ideal combination in animal husbandry based arid ecosystem.

After pruning, the system provides fodder from grasses and leaves, and fruits and fuel from ber plants. At CAZRI, combination of jujube and buffel grass *(Cenchrus ciliaris)* under rainfed condition has provided 8.4 q ha^{-1} grass fodder, in addition to fruit yield. Study also indicates that after 5 years of establishment, growth of jujube plant was more than double while production of dry leaves and pruned wood was more than six times under horti-pastoral system as compared to monocrop.

4. Horti-silvi system

Under ber-based horti-silvi system in arid region of India, selection of suitable tree species is of prime importance. Visualizing a new concept of horti-silvi system where fruit as well as forest species are planted with the aim to act as complimentary to each other. Selection of drought hardy species is essential for extreme arid conditions.

Ber-based horti-silvi system has been found more beneficial at places facing the problem of very high wind velocity in arid region. Plantation of tree species such as *Acacia tortilis*, *Prosopis juliflora*, *Cassia siamea*, *Albizzia lebbek*, *Ziziphus nummularia* etc, as wind breaks all around the orchard and provision of woody tree species preferably leguminous trees *(Prosopis cineraria)* inside the system in a pre defined layout can give better output from the system in adverse soil and climatic conditions. The tree species planted around the system provide fuel or some marginal timber wood, at the same time protect the orchard from hazards of cold and hot winds, as well as generate more income through fruit production while the production of fruits and timber can be achieved from the main plantation. Selection of the tree species can be made as per local demands and its suitability in the region. *Rohida (Tecomella undulata)* commonly known as Desert Teak has been found to be abundant in arid region and therefore, it can be a component in ber-based horti-silvi system. The fodder trees *Leucaena leucocephala*, *Alianthus excelsa* etc, are being selected in areas dominated by animal husbandry.

5. Horti-silvi-pastoral system

This is an ideal system of farming under arid and semi-arid agroclimatic zone. All the three components can be successfully utilized to generate more output for the local habitants under adverse soil and climatic conditions of the region. Besides fruit production, the system checks the degradation of land caused by high wind velocity and rain on one hand and helps in stabilizing the already degraded lands on the other hand. The selection of forest trees and pasture grasses for ber-based horti-silvi-pastoral system entirely depends on soil and climatic conditions of the particular place. At Central Horticultural Experiment Station, Godhara, Gujarat (annual rainfall 700 mm), heavily eroded wasteland having a network of two deep and three medium gullies were brought under agroforestry system and planted with various fruit trees (ber, mango, guava), grasses (*Cenchrus ciliaris* and *Stylosanthes hamata)* and forest trees (*Leucaena leucocephala,* eucalyptus)(Table 2). The area between the gullies was planted with ber, mango and guava using staggered contour trenches to harvest rainwater and to check surface runoff. The highly degraded land within a distance of 6 m from the gully rims was planted with *Leucaena leucocephala* and eucalyptus with a population density of 3000 trees ha^{-1} on either side. *Cenchrus ciliaris* was planted along the gully rims and on the bunds of contour trenches. Besides, fruit trees were intercropped with plants like cow pea (*Vigna unguiculata*), okra (*Abelmoschus esculentus*), cluster bean, brinjal (*Solanum melongena*) and a tropical pasture legume *Stylosanthes hamata*. The collected surface run-off was used for life saving irrigation at critical crop growth stages. In situ grafting in mango and budding in ber gave good establishment even during drought years.

Table 2. Yield of fodder in q ha^{-1} (fresh weight basis).

Year	First	Second	Third
Crop species			
Cenchrus ciliaris	60.00	75.20	107.84
Stylosanthes hamata	31.91	38.88	92.05
Leucaena leucocephala	45.75	56.25	80.50

The system started giving returns from the very first year with a production of 4 q ha^{-1} from ber which increased upto 16 q ha^{-1} in second year and upto 49 q ha^{-1} in the third year with a net return of Rs 1705 ha^{-1} in the second year and Rs 11,599 ha-^{1} in the third year. Besides, the ber trees also provided fuelwood of about 2.2 q ha^{-1} in the second year and 7.5 q ha^{-1} in the third year from the annual pruning. The other fruit trees started giving returns from the third year. The production of pasture grasses from the system is given in Table 5.

After 5 years, the value of timber from eucalyptus was nearly Rs 90,000 ha^{-1}. A comparison of the different intercropping systems with the local practice of growing maize (*Zea mays*) plus pigeon pea (C*ajanus cajan*) by the tribal farmers revealed that ber and cluster bean combination gave the highest net return of Rs 14,630 ha^{-1} (Table 3) and the maize and pigeon pea combination gave the lowest return of Rs 616 ha^{-1}.

Table 3. Comparative performance of different cropping systems.

Intercropping system (ber planted in 1984)	Yieldq ha^{-1} (1986)		Netreturns(Rs ha^{-1})	Yieldq ha^{-1} (1987)		Net returns (Rs ha^{-1})
	Ber	Inter-crop		Ber	Inter-crop	
Ber	16.10	-	1705.00	49.00	-	11,599.00
Ber + Cowpea	16.24	66.12	5685.40	52.16	31.98	13,808.20
Ber + Okra	17.08	69.97	5497.40	47.28	33.91	12,581.20
Ber + Clusterbean	16.20	58.77	4502.00	51.22	42.95	14,630.60
Ber + Brinjal	17.10	82.90	2121.20	50.08	-	11,899.00
Ber + *Stylosanthes*	15.97	31.91	2091.20	47.65	38.88	11,943.68
Maize + Pigeon pea (farmer's practice)	8.00*	3.00	1126.00	5.00*	2.5	616.00

*yield of maize

Thus, it is possible to optimize integrated use of land, water and vegetation not only to obtain sustained productivity from the arid and semi-arid wastelands but also to manage the situation of drought and soil erosion by adopting the ber-based agroforestry systems.

Management Practices

Most parts of the vast arid regions depend on rainwater from the little rainfall.Horticultural production under these conditions is only possible through proper management of rainwater, utilization of the natural biophysical resources, including the hardy plant species, and management of the biotic and abiotic stresses.Watershed management has been used by mankind since antiquity.In India too, the practice seems to be centuries old.The *khadins* or *kharins* in Jaisalmer, which are low lying basins collecting runoff from surrounding rocky catchments for cultivation, are believed to be about 300-500 years old.In the year 1908, 377 *khadins* have been reported to exist around Jaisalmer.

The *in situ* runoff concentration technique is most suited particularly for the fruit crops because (a) being deep rooted they are able to utilize the moisture stored in lower soil layers and can produce optimum crops even in low rainfall year and (b) once established they continue to produce for many years. Extensive research is being carried out in Mexico, Israel, Australia and USA to increase horticultural production by efficient management of watersheds.In India, some work has been done at the CAZRI Jodhpur.Even in the indigenous hardy plant species such as *ker (Capparis decidua)*, *lasoda (Cordia myxa)*, custard apple (*Annona squamosa)* etc, productivity will increase if due consideration is given to watershed management.

The region receives high solar radiation.Multi-storey cropping system models based on fruit trees can be developed to utilize this valuable resource for production of quality fruits.Vegetable, medicinal and aromatic plants can be a component of such models.In high radiation zone, which also has low humidity, the attack of insect pests and diseases is very low.However, conditions of high radiation and temperature coupled with low humidity cause water stress in plants owing to great water losses from soil and plant surface but by following proper soil and water management techniques, optimum productivity can be maintained.

The high summation of heat units especially during the long summer is a valuable resource for development of high total soluble solids in fruit crops such as date palm, grape, etc.Besides, the conditions of high temperature and low humidity help in solar drying of fruits and vegetables.The practice is already common for drying pods of *khejri (sangri- pods of Prosopis cineraria)* and fruits of *kachari* (*Cucumis calossus*) and fruits of ber and date palm.

The sharp fluctuations in day and night temperatures during autumn, spring and summer help in development of sweetness in sweet orange, kinnow, ber and date palm; flesh color and sweetness in pomegranate arils and *mateera* (a land race of watermelon) pulp.Such fluctuations in temperature coupled with high wind velocity can, however, also cause desiccation and heat injury to trees if the orchard is not well managed.

To conserve the moisture losses from the surface of plant and soil, use of mulches, cover crops and anti-transpirants have been used.Black polythene (400 gauge) has been found to be an effective mulch material in ber, pomegranate, date palm and *aonla* orchards.Some local weeds like *bui (Aerva tomentosa)*, *sarkanda (Saccharum munja)* etc, are effective live mulch materials.Anti-transpirants like 10% Kaolin and 10^{-3}M PMA have been found effective to check moisture losses from plant surface resulting in increased fruit production in pomegranate. The arid region also has some hilly and saline stagnated lands and a few loamy patches besides the large expanse of sandy area.Horticultural production is possible in these lands by following suitable techniques.

In vegetable crops also, optimum production is possible by adopting techniques of moisture conservation and runoff concentration. Bottle gourd, sponge gourd, round gourd, long melon and cluster bean can be sown during early July with the onset of monsoon so that flowering and fruiting take place during the period from beginning of August to the end of October. These crops can be grown even when the rains are delayed until early August. With further delay in rains, there is very little possibility of their rainfed production. Bitter gourd, snap melon, *kachari*, okra and cowpea can be used if monsoon starts by the middle of July. With further delay in the onset of monsoon, there is very little possibility of growing these crops. The vegetable crops like tomato, brinjal, chillies, cauliflower and onion can also be used in drylands by runoff concentration technique provided the seedlings are kept ready in the nursery for transplanting in the field with the onset of rains in early July. The nursery, however, must have irrigation facilities.After plantation in the field, irrigation may not be required except in case of an extremely drought year.A technique has been developed at the CAZRI, Jodhpur that provides micro-catchment of inverted 'V' shape with 6% slope and 4.5 m^2 area to accumulate runoff into a pit appreciably by bentonite clay barrier at the bottom of the pit.

Chapter 2

Soil and Water Management

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Participatory land use analysis for semi-arid regions in Kenya: A nutrient monitoring approach

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Abstract

This paper presents a study on nutrient dynamics of typical farms in arid and semi-arid areas in Kenya, using the nutrient monitoring (NUTMON) research approach for assessing nutrient flows and stocks and their effects on financial performance. Systematic collection of information on farm management practices using structured questionnaires allowed quantification of material flows, with emphasis on soil nutrients and cash flows. Based on data collected on inputs into the farm, outputs out of the farm and internal nutrient flows, financial performance indicators are calculated at the farm enterprise level, using the NUTMON toolbox. Participatory soil sampling and laboratory analysis were carried out to determine total N, P, K and carbon stocks in the topsoil layer. Feedback to the farmers was given on the soil analysis results, on the basis of graphs containing the average values for each of the elements (N, P, K and carbon), to identify priorities in alleviating nutrient deficiencies and determine appropriate integrated nutrient management strategies to address soil fertility problems. This led to formulation of a research agenda to combat nutrient constraints during the experimental design workshop. Farmers do associate poor crop yields with poor soil nutrient status and did recognize the relevant symptoms, but not at the level of individual nutrients.

Averaged for all farms sampled, total nutrient balances, ie including inputs and outputs over the farm gate, as well as exchange with the environment, such as biological (nitrogen) fixation, leaching and/or volatilization, for N, P and K were negative. The losses in the total balances were mainly due to leaching and erosion, processes that are not under direct control of the farmers. Average net farm income was negative for the clusters operating entirely under rainfed conditions (Kionyweni, Enkorika) and positive for the cluster where irrigation facilities are available (Matuu). In Matuu more than 60% of the farm households have incomes above the rural poverty line, while 90% are below that level in Enkorika.

Introduction

The rapid increase in Kenya's population has led to three major developments. Firstly, rural-urban migration in search of job opportunities, leaving much of the burden of farming to the rural women and children (most of whom also attend school); secondly, out-migration from the high potential to medium and low rainfall areas (arid and semi-arid lands (ASAL)) in search of new farmland and thirdly, the increased pressure on the land necessitating intensification of land use, leading to continuous cultivation, often without the necessary external inputs, such as plant nutrients to sustain its productivity. Consequently, soil nutrient contents have declined, leading to reduced soil fertility and environmental degradation (Okalebo et al.1996; Murage et al. 2000).

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Introduction of crop production technologies, developed in and adapted to the high potential areas, into ASALs appeared difficult and sometimes destructive because of the unfavorable agro-ecological conditions. Rainfall is unreliable, both in terms of quantity and distribution, while the soils are fragile and because of their sandy texture, susceptible to erosion and leaching (Mutiso 1991). The gradual decline in crop production and associated soil cover have aggravated the vicious circle through further nutrient losses as a result of erosion and leaching. As a consequence, therefore, Kenyan ASALs are currently characterized by low-productive and non-sustainable agro-ecosystems that seriously threaten the livelihoods of their population.

Although introduction of improved technologies in agriculture has significantly increased productivity, many small farmers in marginal and fragile environments have hardly profited (Conway and Barbier 1990). Low adoption rates of technologies, developed by research institutes and offered to farmers, indicate the need for a more client-driven approach. In response to this need, participation has become a key element in attempts to improve understanding between researchers and farmers (Defoer 2000). In recent years, new research methods and approaches have been developed that have put participation, action research, and adult education at the forefront in attempts to support disempowered people. To the wider body of development programs, projects and initiatives, these approaches represent a significant departure from standard practice. Extractive research is being complemented, and sometimes replaced, by investigation and analysis in close cooperation with the local population.

This paper is based on a study on 'Nutrient stocks and nutrient flows in Kenya's arid and semi-arid lands (NUTSAL)' with the objectives of: (a) to identify, in close cooperation with the farmers, the major constraints faced by small scale farm households in the ASALs of Kenya, with special emphasis on nutrient balances; (b) to identify, through participatory design and testing, alternative production techniques that will alleviate the constraints and contribute to implementation of more sustainable agricultural production systems. This is a follow up of nutrient monitoring (NUTMON) projects carried out in the high potential areas, investigating nutrient balances in smallholder farms, with the aim of determining their agroecological sustainability (De Jager et al. 1998a; De Jager et al. 1998b; Van den Bosch et al. 1998a; Van den Bosch et al. 1998b).

Materials and Methods

The NUTMON methodology (Vlaming et al. 1997; Van den Bosch et al. 2001) was applied. In this methodology, two major phases can be distinguished: (1) diagnosis and analysis of existing farm and nutrient management systems, (2) participatory learning and action research phase. In the participatory diagnostic phase, the current situation with respect to natural resources, socio-economic environment and farm management and its influence on resource flows and economic performance is assessed. In this phase, a variety of tools is used, ranging from generally applied tools such as natural resource flow mapping, transect walks and farmers' soil maps, to a specially developed quantitative monitoring tool, the NUTMON toolbox (Van den Bosch et al. 2001) to assess nutrient flows and financial performance indicators. Monitoring takes place at plot and farm household levels, where most of the decisions on nutrient management take place. Influences of processes at lower scales (for instance leaching and denitrification) are incorporated in the farm level approach through transfer functions. Monitoring sessions take place at least twice per season; shortly after planting and at harvesting time. The diagnostic phase also serves to create farm household awareness of nutrient management aspects, as the basis for formulation, in a joint effort of scientists, extension officers and farmers, of a research and development agenda.

The results of the diagnostic phase form the basis for the participatory technology development phase, in which appropriate technologies, especially with respect to nutrient management, are designed and investigated in on-farm trials. Possible options for experimentation are identified in consultation with the participating and other interested farmers and ranked. The performance of these technologies is monitored, and their consequences for the resource and financial flow indicators assessed. On the basis of these indicators, the most attractive innovations are selected. Farmers, extension officers and researchers are fully involved in this identification and implementation process and therefore both indigenous knowledge and scientific knowledge are incorporated in technology development and testing.

Participatory farm selection, inventory and biophysical characterization

Study area and farm selection

The study area comprised agroecological zones IV and V (Jaetzold and Schmidt 1983) of Machakos and Kajiado districts of Kenya. In the area, three sites were selected Matuu, Kionyweni (Machakos) and Enkorika (Kajiado). Mean annual rainfall in the area is less than 600 mm in two rainy seasons (bimodal) with very high inter-annual variability.

Farms were selected through participatory methods (Defoer and Budelman 2000) involving farmers, extension officers, scientists and other stakeholders such as NGOs. An initial one-day village meeting (baraza) was held in each of the study sites, attended by all these stakeholders, including the assistant chief and village elders. Farmers were asked to provide criteria, which they use to distinguish between good and poor soil fertility management practices. Subsequently, the farmers classified each other in three categories of management groups, based on these criteria.

Inventory

The NUTMON-methodology is based on systematic collection of information from the farm household on farm practices and farm management, which allows quantification of flows of material (with emphasis on the nutrients nitrogen (N), phosphorus (P) and potassium (K)) and cash through the system. Information collection starts with the *farm inventory*, repeated before each crop cycle. The distinguished flows are quantified in various ways (Van den Bosch et al. 2001). Firstly, flows directly related to farm management are quantified through information collected from the members of the farm household on inputs into and outputs out of the units (chemical and organic fertilizer use, harvest of crop and animal products, redistribution of crop residues and farmyard manure). N, P and K contents of the 'nutrient carriers' are determined in the laboratory, prices are determined directly during the interview or collected during a separate survey. Secondly, flows that cannot easily be quantified by the farmer (such as intake during outside grazing and manure excretion of different types of animals) are estimated by means of a simple sub-model. A third group of flows (atmospheric deposition, gaseous losses, leaching and erosion) is quantified on the basis of off-site knowledge using pedo-transfer functions (Tietje and Tapkenhinrichs 1993). Based largely on the same information, financial performance indicators are calculated at the farm household level.

Biophysical characterization

During the inventory, a 'farm sketch' is produced that visualizes the spatial distribution of the various units distinguished. The farm household is characterized in terms of available labor and consumer units. Available land resources are specified in terms of both, farm section units (FSU-land units with more or less 'stable' soil characteristics) and primary production units (PPU-land units dedicated to production of a certain commodity in a given season). Capital goods are specified, such as hoe(s), plough(s), wheelbarrow(s), etc. Animals at the farm, secondary production units (SPU) are defined in terms of Animal Management Groups, ie groups of animals (generally) of the same species that are managed by the farm household as one unit in terms of feeding, confinement, grazing, etc. If relevant, within a Management Group, allowance can be made for different age groups, such as milking cows, heifers and calves. The presence of redistribution units such as bomas (night corrals), manure heaps, and compost pits is recorded. In addition, the Household (HH) is defined as the labor supply and consumption unit, the Stock, representing a temporary store for staple crops (cereals and pulses), crop residues (for cattle feeding) and/or chemical fertilizer for future use and finally the 'external world' (EXT), consisting of markets, neighbors and/or other families, serving as a source of and/or destination for flows, that as externalities (not on-farm) are not monitored.

Methods to qualitatively assess natural resource qualities and natural resource flows are part of the farm inventory, implemented in close collaboration with farm household members. These methods include drawing farm soil maps, including local names and characteristics of the soils, and nutrient flow maps visualizing flows of nutrients within the farm and with the environment. The soil nutrient stock of a farm is defined as the total quantity of the nutrient in the top 30 cm of the soil profile. A number of soil samples per farm, depending on farm size and heterogeneity of soils, are taken for laboratory analysis. As the basis for formulation of alternative production techniques, farmers had to be made aware of the concept of nutrient deficiency and the consequences for crop growth and production, for which a meeting was organized for discussion of soil analysis results.

Monitoring sessions take place at farm level at least twice per season, shortly after planting and after harvest, to obtain yield information. Material flows, livestock dynamics, labor use, services acquired from outside and their costs, are recorded. Data collected are entered into a database for which a special program, NUTSHELL, is fed that computes nutrient balances, gross margins, etc.

Results and Discussion

Farmer management groups and farm selection

The farmers identified the following practices as indicators of good soil fertility management,

- Application of animal manure
- Deep and appropriate tillage
- Optimum crop spacing
- Construction of bench terraces for soil and water conservation
- Planting in pure stands to avoid competition for water
- Timely and early planting
- Early weeding
- Ridging, especially when weeding with oxen
- Appropriate crop rotation
- Retaining 'good' selected seeds (those that use their own or local seeds) or use of appropriate varieties (those that use seed from outside)
- Knowledge and proper use of fertilizer
- Proper planning of farm activities
- Crop protection (chemical)
- Keeping farm records

They considered that high-level soil fertility managers did use at least three-quarters of the selected practices, medium-level about half and low-level managers less than one quarter. Each of the farmers names was then read from card and classified by majority vote in one of the categories,

- High level soil fertility management group;
- Medium level soil fertility management group;
- Low-level soil fertility management group.

From each of the three categories, subsequently, ten farmers were selected considered able and willing to participate in the NUTSAL study.

The criteria identified by the farmers indicate that they perceived good soil management in terms of strategies geared mainly to soil fertility and water management. In these dryland conditions, farmers did not see fertilizer application as an important practice because of the risks that were perceived. A more detailed description of the selection process and its results is given in Gachimbi et al. (2002).

Soil analysis

Farmers' soil map

To capture farmers' perceptions on soil fertility status and soil fertility management, a soil map was drawn along with the farmers. The soil map was used as a basis for identification of FSUs, for which the local name was indicated, and for soil sampling. Eventually, the farmer-drawn map and soil analysis results were used in the problem analysis and prioritization of topics for technology development and on-farm testing. In Figure 1, an example of these farmers' maps is presented.

Soil samples were collected from the farm section units identified, which were analyzed for

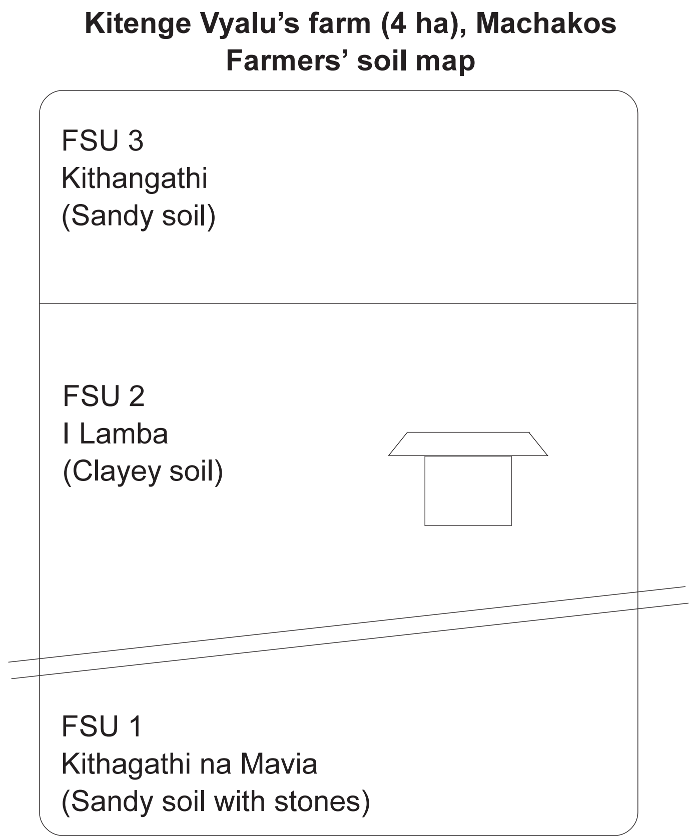

Figure 1. Map showing various farm section units (FSU).

soil chemical and physical characteristics in the laboratory. In Table 1, an example is given of a complete set of soil characteristics for one of the farmers in Kionyweni.

Table 1. Soil analysis results and classification.

Farmer's name: Ndambuki Kyalo
Location: Kionyweni

Soil type (farmers' classification)	Texture class	pH	Organic carbon (%)	P (ppm)	N(%)	K (me%)	Sand (%)	Silt (%)	Clay (%)
Nthangathi	Sandy clay loam	6.0	0.62	22	0.06	0.14	64	10	26
Nthangathi na Kitune	Sandy loam	6.6	0.27	5	0.05	0.26	78	12	10

Soil nutrient status and feedback to the farmers

Feedback on soil analysis results was performed in a combined meeting of farmers, extension officers and researchers in each of the clusters. In the meeting, first the concept of nutrient deficiency in plants was illustrated using simple examples. It appeared that farmers could easily identify a range of symptoms associated with 'poor soil fertility', such as reddish purplish leaves, yellowish green leaves, stunted crops, low quality maize cobs, low weed cover, compaction of the soil, and weak roots. However, they could not identify the relation between deficiencies of individual nutrient elements and deficiency symptoms. Subsequently, the results of the soil analyses for the elements nitrogen (N), phosphorus (P), potassium (K) and carbon (C) were discussed on the basis of graphs, as illustrated in Figure 2. These graphs contain, for each farm in each farmer management group, the average values for each of the elements. When a farmer had identified more than one FSU, these were sampled and analyzed separately, but average values for the whole farm are shown in Figure 3. To put the measured values in perspective, they are expressed as a percentage of the value identified by the extension service as 'agronomically adequate' (Mehlich et al. 1964). As an example, the data for the three management groups in Kionyweni, that are representative for the majority of the results obtained, are discussed here.

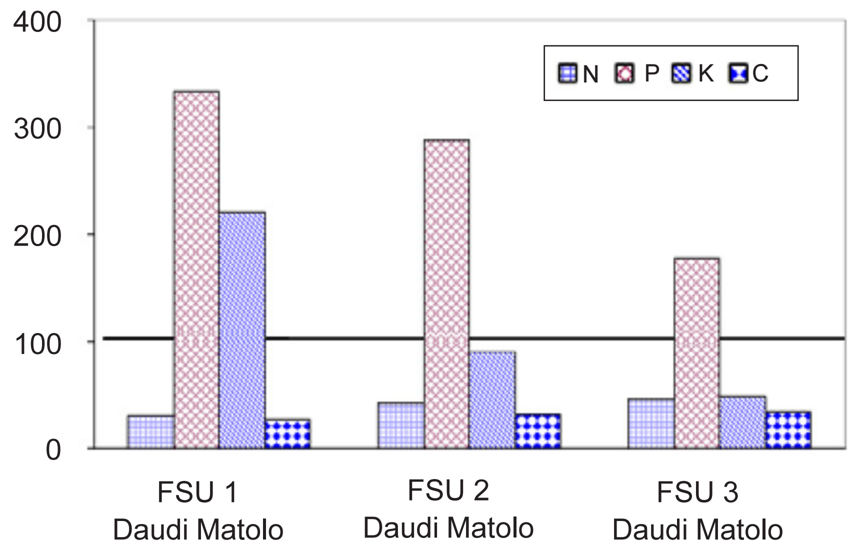

Figure 2. Soil sample farm report-Soil sample results of Daudi Matolo's farm.

Figure 3 shows that even in this high management group, the soil-N values are all well below 50% of the 'adequate' level, and that the variation among the farm households is relatively small. Figure 3 illustrates that the variability in soil P-levels among the farmers is much larger (a factor 3.5 between the lowest and the highest value) and that, on average the values are well above 50% of the 'adequate' level, with more than half the values exceeding the 75% point. Potassium levels in all the farms are agronomically adequate due to soil inherent potassium potential, except in one case. A combination of N- and P-values is typical for situations where soil fertility management to a large extent revolves around application of animal manure, since nitrogen is very mobile in the system and very susceptible to losses during storage and application of manure (Lekasi et al. 2001). Hence, a large proportion of the nitrogen in animal manure is lost before and during application, and therefore hardly contributes to the soil nitrogen store. Phosphorus on the other hand is far less susceptible to losses, and a substantial proportion of the element contained in animal manure is therefore added to the soil store. Potassium is abundantly available in all

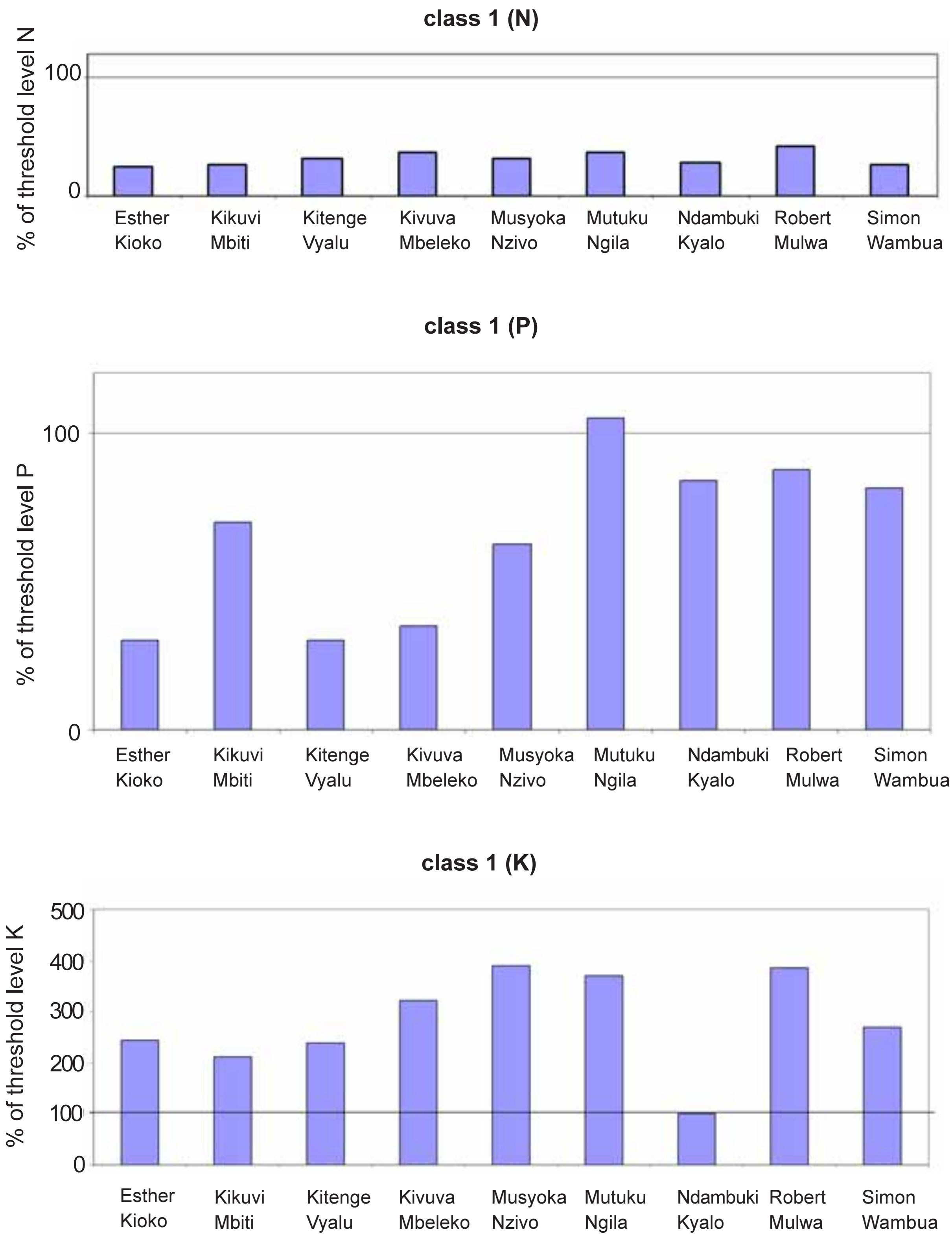

Figure 3. Soil sample farm reports; Kionyweni cluster nitrogen, phosphorus and potassium levels for the high fertility management group; 100% is 'agronomically adequate' (see text for explanation).

soils, with values varying between 2 and 4 times the 'adequate' level. The organic carbon levels in the soil are again variable, with a factor 2.5 between the lowest and the highest value. All values are well below the level considered 'adequate' from an agronomic point of view. This is an interesting observation in view of the argument put forward to explain the difference in N- and P-levels. The relatively low C-levels suggest that the organic components in the animal manure must have been largely decomposed, under the relatively favorable conditions for microbial action, ie relatively high temperatures and sufficient moisture in the upper soil layer.

Following discussion of these results with the farmers (Figure 4), the group was sub-divided in sub-groups of 10 farmers each, to discuss the possibilities for improvement in soil fertility management, as a first step towards participatory technology development, the subsequent step in the participatory learning and action research (PLAR). Each of the farmers was presented with the detailed data for each of his/her FSUs, allowing comparison and discussion during the sub-group meetings. Reporting from the sub-groups, as the last item of the meeting, revealed that farmers suggested improving fertility by adding manure (FYM), terracing and/or spreading termite mound soil or ant hills (since these insects bring nutrient-rich soil up from deeper soil layers). Addition of inorganic fertilizer and crop rotation also may contribute to solving soil fertility problem. The suggestions, at this stage, did not really yield innovative techniques, but they did form a solid basis for development of appropriate technologies.

Figure 4. Feedback of soil analysis results to the farmers.

Farm nutrient balances

When averaged for all farms, total nutrient balances for N and P were negative (Figure 5) in the Matuu and Kionyweni clusters in Machakos and Enkorika in Kajiado. Partial balances, that in the NUTMON-methodology represent 'farm-gate' balances, were positive, except those for N and K in Matuu (Figure 6), leading to the conclusion that losses in the overall balance are mainly due to the hard-to-quantify flows. These losses (gaseous losses, ie denitrification and volatilization, leaching and erosion) are mainly due to leaching in Matuu and erosion in Kionyweni and Enkorika. Leaching losses are proportional to the quantity of water moving through the profile. Hence in Matuu, where irrigation facilities are available, next to rainfall, irrigation contributes to these losses. However, in most of the farms monitored, the redistribution units, in which manure is stored, were neither covered nor had a concrete floor. Hence, losses of nitrogen from these units through leaching and volatilization are appreciable (Lekasi et al. 2001; Van Gemen 1998). Phosphorus is neither subject to leaching nor to gaseous losses, while substantial leaching losses of potassium do take place. Erosion for all three elements represents appreciable loss in all three clusters. In Kajiado, cattle are herded on the rangeland, while crops, mainly cultivated for subsistence, are fertilized with animal manure produced on-farm; hence imports into the farm are very low.

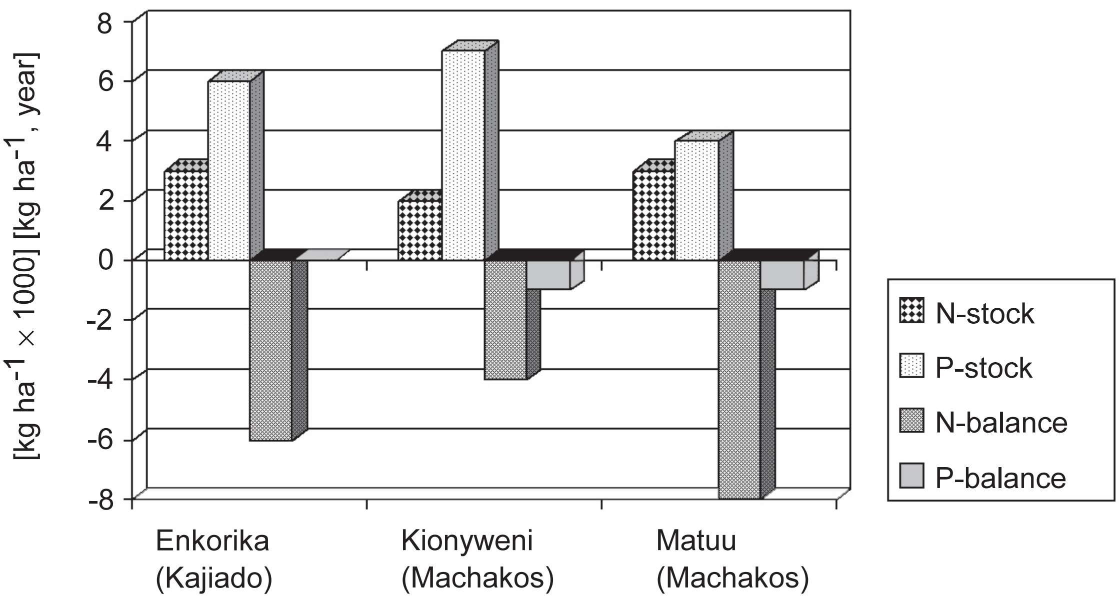

Figure 5. Nutrient stocks and average total farm nutrient balances for the Matuu, Kionyweni and Enkorika clusters.

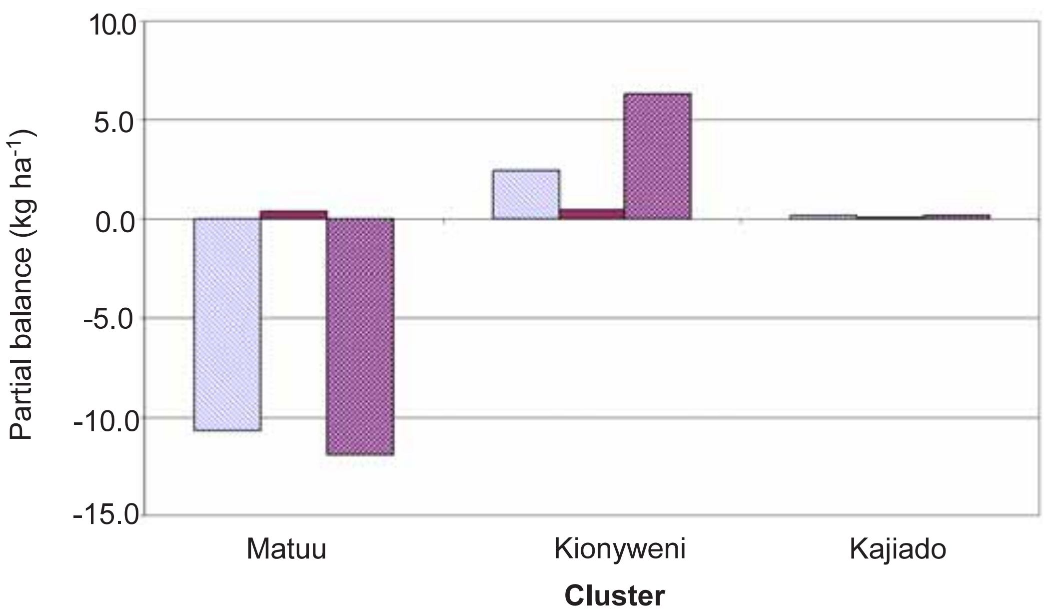

Figure 6. Average farm partial nutrient balances (kg ha^{-1}) for the Matuu, Kionyweni and Enkorika clusters.

Financial indicators for the three sites

Average net farm income is highest in Matuu at US$2,156 per year, as a result of commercially oriented irrigated agriculture and as low as US$713 in Kionyweni and US$250 in Kajiado. Total gross margin is high in Matuu (US$625) and low in Kionyweni (US$50) and Kajiado (US$ 46). Average farm net cash flow is negative and varies between US$75 (Kionyweni) and US$413 (Matuu). No off-farm income was reported in Kionyweni and Kajiado. In Matuu, arable crops constitute the major source of income, as also shown by the high market share (23%) compared to 1.4% in Kionyweni and 0% in Kajiado.

Overall rural poverty level in Kenya as adopted by the Ministry of Finance and Planning is US$16 per adult equivalent per month (ie US$12 for food requirements and US$4 for basic non-food requirements) (CBS 2000). With more than 60% of the participating farm household members in the study area living below the absolute rural poverty level (Table 2), and with most of the farm labor requirements being met by family labor, there is a need to increase productivity in the areas to increase the farm earnings per consumer unit and returns to labor.

Table 2. Farm income levels in Matuu, Kionyweni and Enkorika clusters in comparison to poverty levels.

		Percentage of farms with observed income level			
	No. of Farms	Y< US$ 15	Y> US$15	Average(US$/CU)	Range
Matuu	28	36	64	48	20 to 451
Kionyweni	26	85	15	3	43 to 44
Enkorika	8	87	13	9	34 to 95

NB: CU -Consumer Unit. (in adult equivalents)
Y - Earnings per consumer unit

In Matuu, more than 60% of the family members (expressed in adult equivalents) have an income above the absolute rural poverty level, while in Enkorika almost 90% is below that level. In Kionyweni, average income was lowest (US$3 per consumer unit).

Conclusions

The NUTMON methodology appears a suitable and appropriate tool for the diagnostic phase of Farming System Analysis and Design in Arid and Semi-Arid Lands (ASAL) of Kenya. The participatory inventory and monitoring procedures, applied in this phase, involved the farmers in the analysis of their own situation and created awareness about the processes and flows associated with the nutrient balances and the associated deterioration of their natural resource base. Farmers recognized this decline in soil fertility on their farms, but the climatic uncertainty and the current economic conditions make it almost impossible to modify that situation.

The feedback, through farmers' workshops, of the results of soil analyses and the discussion on possible solutions for the identified problems, creates confidence that in the participatory learning and action phase, farmers will be equally involved and willing to adopt suggested adaptations.

The results of the quantitative analyses of nutrient balances at farm level confirm the results from earlier work in the high-potential areas of Kenya and elsewhere in East Africa, as well as those from drier regions in West Africa, that, in general, farm balances for all three macro nutrients (nitrogen, phosphorus and potassium) are negative. However, the figures are low as rainfall was well below the long-term average. Moreover, the negative balances appear to be mainly the result of losses that cannot be easily controlled by the farmer, ie erosion, denitrification and leaching, the hard-to-quantify flows.

The financial indicators show that in the purely rainfed systems farm income in this – relatively dry – year was below the poverty level, and that only in the cluster where irrigation facilities are available a reasonable income could be generated.

Acknowledgements

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Durabilité du système zaï dans la zone nord du Burkina Faso: Etude des flux de matières organiques dans l'exploitation

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Résume

La production agricole des pays au sud du Sahara a du mal à supporter la croissance démographique. Les raisons de cette situation portent essentiellement sur une dégradation continue des ressources naturelles. Dans la zone Nord du Burkina Faso, les producteurs au cours des années 1980 ont adopté des techniques de conservation des eaux et des sols (CES) leur permettant de restaurer la fertilité des sols dégradés. L'adoption de ces techniques a été suivie par une adoption systématique de production de matière organique. L'utilisation de ces techniques CES a permis la récupération de plusieurs dizaine d'hectares. Cependant, la durabilité de ces systèmes dépend de plusieurs facteurs dont le plus important reste la disponibilité de la matière organique.

En vue de donner des indications sur les flux de matière organique et l'importance de chaque flux au sein des exploitations agricoles, des travaux ont été conduits dans la zone Nord du Burkina Faso pendant les années 1999 et 2002. De ces travaux, il apparaît que les résidus de récoltes occupent une place de choix dans la production de la matière organique et il est indispensable de proposer des modes de gestion permettant une meilleure rentabilisation de cette source de matière organique. De plus il est ressorti que la paille sauvage intervient très peu dans les exploitations agricoles ce qui pourrait constituer une piste pour une augmentation de la productivité globale de matière organique des exploitations. La mise en oeuvre de stratégie de gestion durable de matière organique dans les exploitations permettra une durabilité des systèmes de production.

Abstract

Crop production in sub-Saharan countries has difficulties to support population growth. The reason for the following situation is a continuous degradation of natural resources.

In northern Burkina Faso, farmers have rapidly adopted traditional soil and water conservation (SWC) techniques in order to restore the fertility of degraded soils.

The adoption of these techniques was followed by a systematic adoption of organic matter production. Using these techniques, farmers were able to recover thousands of degraded lands. However, the sustainability of the system depends on many factors and the most important one is the availability of organic resource.

In order to give indication on the flux of organic resources through the cropping system and the importance of each flux, experiments were executed in northern Burkina in 1999 and 2002.

The results showed that cereal residues are the most important source or organic matter and it is essential to propose management system for more efficient use of that source of organic matter. The results also showed that natural bush residues were not integrated enough in the organic matter production system when they could represent an important source of organic matter. Taking into account these remarks could lead to the sustainability of the cropping system in the Sahel.

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Introduction

Le Burkina Faso, pays sahélien connaît depuis plusieurs décennies une accélération de la dégradation de ses ressources naturelles, ce qui limite fortement le développement des productions agro-sylvo-pastorales (Pontanier et al. 1995; Thiombiano 2000). Cette situation est imputable à plusieurs facteurs dont les importants demeurent sans conteste la précarité des conditions climatiques, la forte croissance démographique et la baisse continue de la fertilité des sols.

En effet, le pays a connu de nombreuses sécheresses récurrentes et on note aujourd'hui une diminution globale de la pluviométrie. Ainsi, les moyennes inter annuelles de la zone soudano-sahelienne, supérieures à 700 mm avant 1966, n'ont été que de 424 mm sur la période 1982-1986 (Lamachère et Serpantié 1992).

La conséquence de ces sécheresses répétées et l'inadaptation des pratiques d'exploitation des ressources naturelles ont eu pour conséquence une destruction du couvert végétal et une dégradation des ressources en sols suite aux actions conjuguées du vent et de la pluie.

Les sols, auparavant mis en jachère pour retrouver leurs qualités, sont exploités de façon continue et quelquefois sans une rotation des cultures. Cette exploitation minière des ressources fortement consommatrices de ressources naturelles, vise à compenser la diminution des rendements et entraîne de ce fait un appauvrissement des sols rarement compensé par un apport de fertilisants. L'extension des superficies cultivées à des terres marginales ne pouvant fournir que de faibles rendements (Roose 1994) et actuellement l'un des facteurs les plus importants de la dégradation des terroirs (Vlaar 1992).

Les fortes intensités de pluies ont entraîné sur les sols mal protégés la formation de croûtes de battance ou de pellicules très peu perméables augmentant ainsi les risques de ruissellement et d'érosion. Ces sols encroûtés appelés *Zippelé* dans la langue locale ont occupé alors une grande partie des zones cultivables créant ainsi des problèmes de disponibilité en terre fertile. En réponse à cette situation, certains producteurs ont préfèré la solution de la migration à la recherche de terres plus fertiles.

A partir des années 1980, les producteurs ont adopté plusieurs techniques de conservation des eaux et des sols en vue de lutter contre la dégradation des sols. Parmi ces techniques, le *zaï o*u cuvette de semis, reste celle qui a connu le plus de succès tant sur le plan agronomique que socio économique. L'adoption de cette technique a permis la récupération de plusieurs millier d'hectares (Ouedraogo et Kaboré 1996). L'adoption de la technique a été accompagnée par une adoption systématique de techniques de production de la matière organique; indispensable dans la réalisation de la technique du zai.

La technique du zai a fait l'objet de plusieurs travaux notamment en ce qui concerne sa caractérisation. Cependant aucun travail n'a fait mention des conditions de durabilité et de pérennisation de la technique. La variable matière organique apparue comme élément central dans la réussite de la technique n'a été regardée que sous l'angle de la parcelle. Cependant, plusieurs processus se sont avérés nécessaires avant son utilisation dans la parcelle. La rationalité des producteurs dans l'utilisation de la matière organique et les différents flux de matière organique dans l'exploitation sont des aspects qui permettront de donner des indications sur la longévité du système.

Le présent article apporte sa contribution dans l'étude de la durabilité du système zai surtout en ce qui concerne sa variable matière organique. Il se fixe également pour objectif de donner des pistes de reflexion afin de permettre une rationalisation et une meilleure valorisation de la matière organique dans les exploitations agricoles.

Matériel et Méthodes

Les travaux ont été conduits dans la zone Nord du Burkina dans la province du Yatenga. Le climat est de type soudano sahélien avec une longue saison sèche (octobre à mai) et une courte saison humide (juin à septembre). La zone d'étude est traversée par les isohyètes 400, 500 et 600 mm.

De façon générale les sols de la zone sont peu propices à l'agriculture et on rencontre quatre principaux groupes de sols à savoir les sols minéraux bruts, les sols ferrugineux tropicaux lessivés, les sols peu évolués et les lithosols sur cuirasse et sur granite. 30% du terroir est impropre à l'agriculture pendant que les 60% restant sont soumis à une exploitation minière. Le terroir est saturé avec une densité de population d'environ 63 habitants au kilomètre carré.

La principale activité est l'agriculture et en activité secondaire les populations de la zone d'étude pratiquent le petit commerce.

Les producteurs ayant participé aux travaux sont au nombre de douze (12) repartis dans quatre villages dont deux (2) à Bogoya, quatre (4) à Soumyaga, deux (2) à Komsilga et quatre (4) à Soumyaga. Ces producteurs ont été choisis de concert avec une ONG, (ORFA) sur la base de leur savoir-faire en matière de l'utilisation de la technique du zaï.

En méthodologie trois types d'outils ont été utilisés, ce sont:

- le questionnaire afin de collecter les informations chiffrées sur les variables structurelles de chacune des exploitations (statut foncier, nombre de personnes actives, présentes, le cheptel disponible, les superficies totales des champs et celles aménagées en zaï, l'équipement agricole, etc.);
- les mesures directes servant de vérification des informations fournies par le producteur (Tableau 1).

Le diagramme de flux a été élaboré en se basant sur un diagramme simplifié proposé aux producteurs et amélioré au fur et à mesure sur propositions des producteurs eux-mêmes. Les méthodes et unités de mesure de chaque élément du flux ont été définies et étalonnés avec les producteurs afin d'obtenir des renseignements comparables pour l'ensemble des situations. Le Tableau 1 donne les unités de mesure utilisées.

Pour l'estimation de la quantité de compost susceptible d'être produite par chaque exploitation les dimensions des fosses ont été mesurées et des échantillons ont été prélevés dans chaque fosse. Cet échantillon est ensuite pesé à l'état frais et ensuite à l'état demi-sec ceci après exposition au soleil. Cet état demi-sec correspond à la forme sous laquelle les producteurs appliquent la matière organique dans les poquets zaï.

Pour l'estimation de la quantité de fumier produite par animal nous nous sommes référés aux travaux de Lehouerou (1980 a) et Kaasschietier et Coulibaly (1995). Nous avons admis que 0,5 UBT (1UBT = 1,5 bovins = 10 ovins = 12 caprins = 2 ânes = 1 cheval) pouvait ingérer 3,125 kg de matière sèche par jour dont 1,3 kg serait issus des résidus céréaliers. C'est sur cette base, que les quantités de résidus mises à la disposition du cheptel par jour ainsi que la durée moyenne d'utilisation des stockés pour chaque exploitation ont été estimées.

Tableau 1. Méthodes et unités de mesure de flux de sources de matière organique destiné au zaï selon leur nature.

Nature de la source	Lieu de mesure	Outil ou unité de mesure	Périodicité des mesures
Résidus de récolte	Au champ	Charrette ou bottes et une = 50 bottes	Chaque fois que le charrette producteur apporte à la maison
Fumier	Au champ et à la maison (fumier de petits ruminants et crotte d'ânes)	Charrette et brouette	2 fois/mois
Ordures ménagères	A la maison	Poubelles ou brouettes	2 fois/mois
Paille sauvage et matière végétale	En brousse	Bottes	Chaque fois que le producteur apporte à la maison
Argile, cendre, Phosphate naturel	A la maison	Brouettes, pelle ou sac	Chaque fois que ça existe

Résultats et Discussions

Caractérisation des flux de matière organique et composition des matières organiques entrant dans la fabrication du compost

La représentation par les producteurs des flux de matière organique dans leur système de production montre trois (3) flux principaux de matière organique en direction des exploitations (figure 1). La matière organique des concessions sera ensuite utilisée pour la production de compost destinée aux champs. Les sources de matière organique en dehors de ces flux reste selon les producteurs très limitées. La Figure 1 représente le diagramme type de flux de matières organiques au sein des exploitations agricoles dans la zone Nord du Burkina Faso.

De la Figure 1, il ressort que la finalité de ces flux de matière organique est la production de compost indispensable pour la production agricole dans la zone. En effet, dans cette zone les producteurs ont adopté le système zaï ou poquets de semis et une des exigences de cette technique est l'utilisation de compost bien décomposé dans les poquets de semis. Afin d'obtenir des composts de bonne qualité, les producteurs ont adopté une structuration des différentes sources de matières organiques pour permettre une meilleure libération des éléments minéraux. La Figure 2 nous donne la structure des apports organiques entrant dans la fabrication du compost.

De cette représentation il ressort que le fumier constitue la plus grande proportion de matière organique utilisée dans la fabrication de compost dans les exploitations agricoles. Cela montre l'importance du bétail au sein de ces exploitations. En effet, chaque exploitation possède un petit élevage où se trouve mélangé des petits et des grands ruminants. Les animaux initialement confiés aux éleveurs sont récupérés et gardés par les producteurs eux-mêmes. Cette situation a engendré une transformation dans la gestion des résidus de culture. En effet, les résidus de culture jadis abandonnés sur les parcelles sont de nos jours entièrement enlevés et transportés à la maison pour l'alimentation du bétail. Les sols sont alors exposés aux effets du

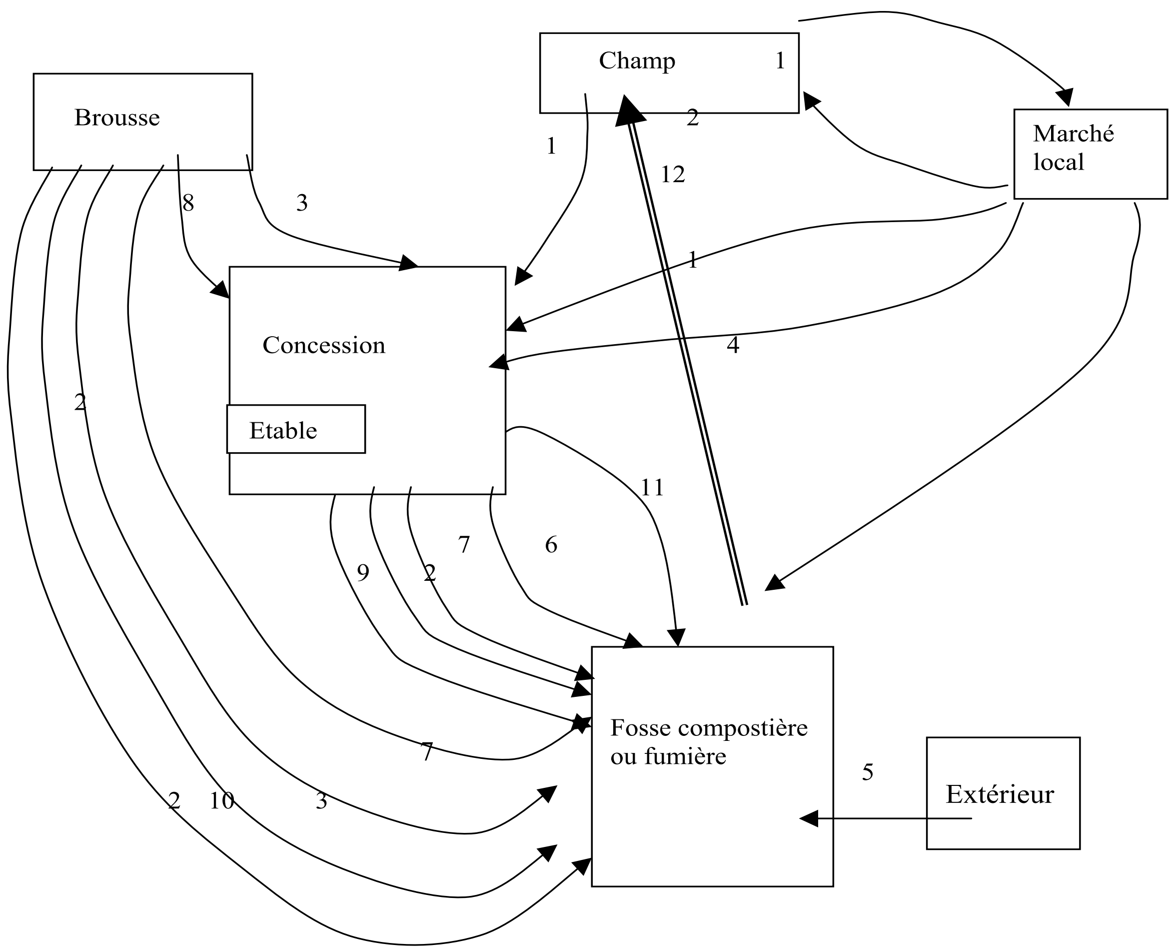

Figure 1. Diagramme de flux de sources de matière organique élaboré par 12 paysans innovateurs.

1 = Résidus de récolte, 2 = Fumier de gros ou de petits ruminants, 3 = Paille sauvage, 4 = Sous produits Agro-alimentaires, 5 = Burkina – Phosphate (en don), 6 = Ordures ménagères, 7 = Eau (catalyseur), 8 = Bois, 9 = Cendre, 10 = Argile, 11 = Litière + crottes d'ânes, 12 = Compost

climat (vent, eau et soleil) mais retrouvent leur fertilité en début de saison avec l'apport de la matière organique. Cependant, la composition du fumier varie énormément en fonction de l'espèce animale, l'âge des animaux et le régime alimentaire (Falisse et Lambert, 1994). Les producteurs sont conscients de cette variabilité de la qualité des fumiers et soutiennent que le fumier des petits ruminants est le plus riche. A l'opposé, les crottes d'âne sont beaucoup moins fertiles que les autres déjections animales. La contribution du fumier à la production de compost devient très variable en fonction des substrats en présence d'où toute la complexité du conseil technique sur les doses de matière organique à utiliser dans les parcelles.

Le suivi des différentes proportions de matière organique entrant dans la fabrication de compost a permis de noter cette importance du fumier dans la fabrication du compost. La Figure 3 montre les quantités de matière organique mise en jeu selon les sources.

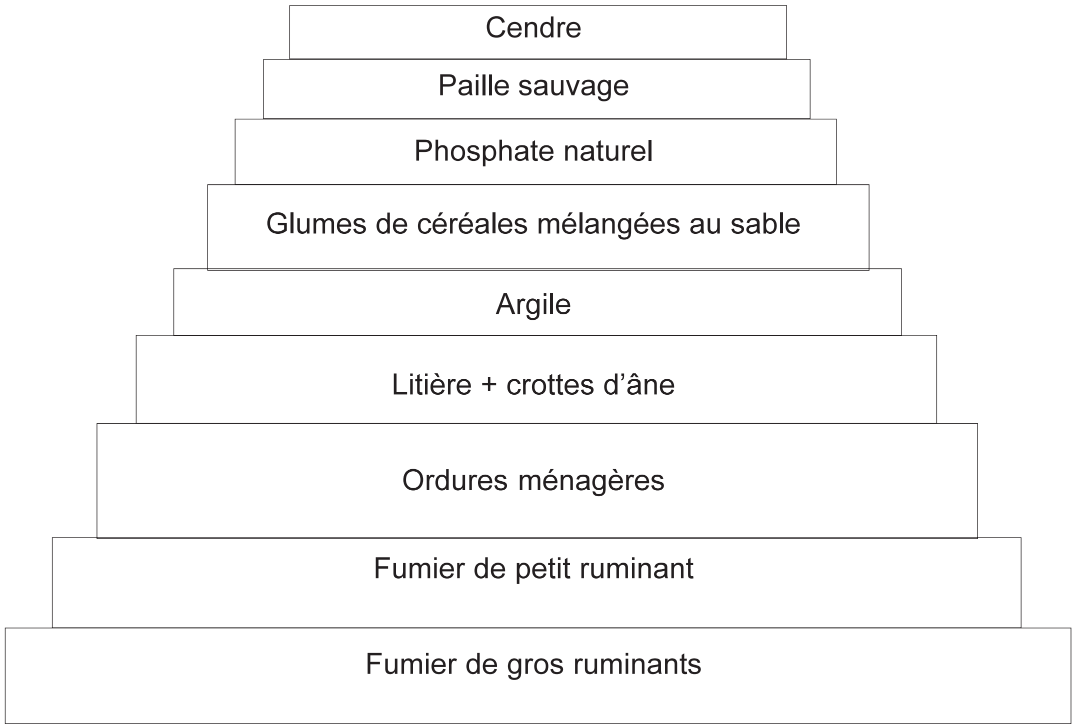

Figure 2. Structure des composantes agro-biologiques du compost destiné au zaï, description des producteurs de la zone Nord du Burkina Faso, 2003. La taille du rectangle représente l'importance de la matière.

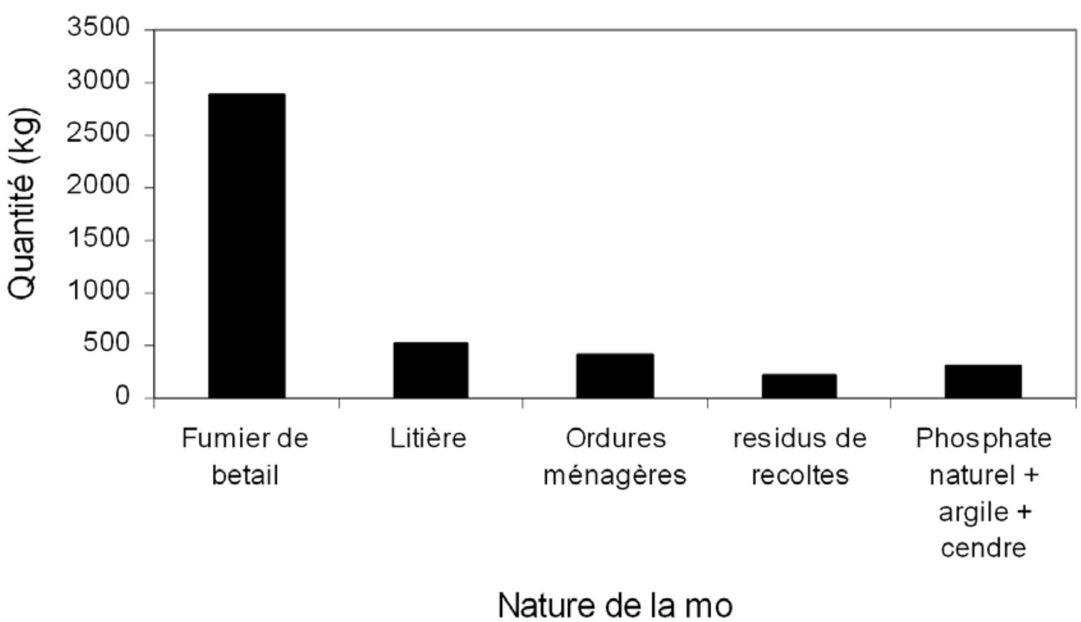

Figure 3. Quantité de matière organique mise en jeu selon les sources, résultat du suivi de 12 producteurs dans la zone nord du Burkina Faso.

Importance des résidus de récolte et contribution dans la production de matière organique

Bien que les résidus de récolte n'apparaissent pas dans la figure 3, ils restent de loin la clef de voûte de la production de matière organique. La production de fumier est fortement influencée par cette variable car la paille sauvage est rarement stockée en saison sèche pour les animaux. La dépendance des exploitations de la zone nord du Burkina Faso vis à vis des ressources fourragères naturelles reste très réduite et se concentre en saison pluvieuse longue seulement de trois mois (juillet à septembre). A l'opposé, les résidus de récoltes (paille de mil et ou de sorgho) sont fortement indispensables en saison sèche. Durant cette période, longue de six à sept mois, les résidus de récoltes sont abondamment utilisés pour l'alimentation des animaux. C'est pourquoi les producteurs procèdent à un ramassage systématique des résidus céréaliers après les récoltes.

Les résidus de récolte peuvent être classés en trois catégories selon les producteurs et ce sont: les résidus de céréales (mil et sorgho), les fanes de légumineuses (arachide et niébé) et les gousses de niébé. Les deux premières catégories sont stockées au sein de la concession ou sur les arbres aux champs sous forme de bottes. Les proportions de chaque catégorie de résidus ont été évaluées au niveau de 12 producteurs. La Figure 4 montre l'importance relative de chaque catégorie de résidus dans la production de fumier. De cette figure, il apparaît que les résidus de céréales sont de loin les plus importantes.

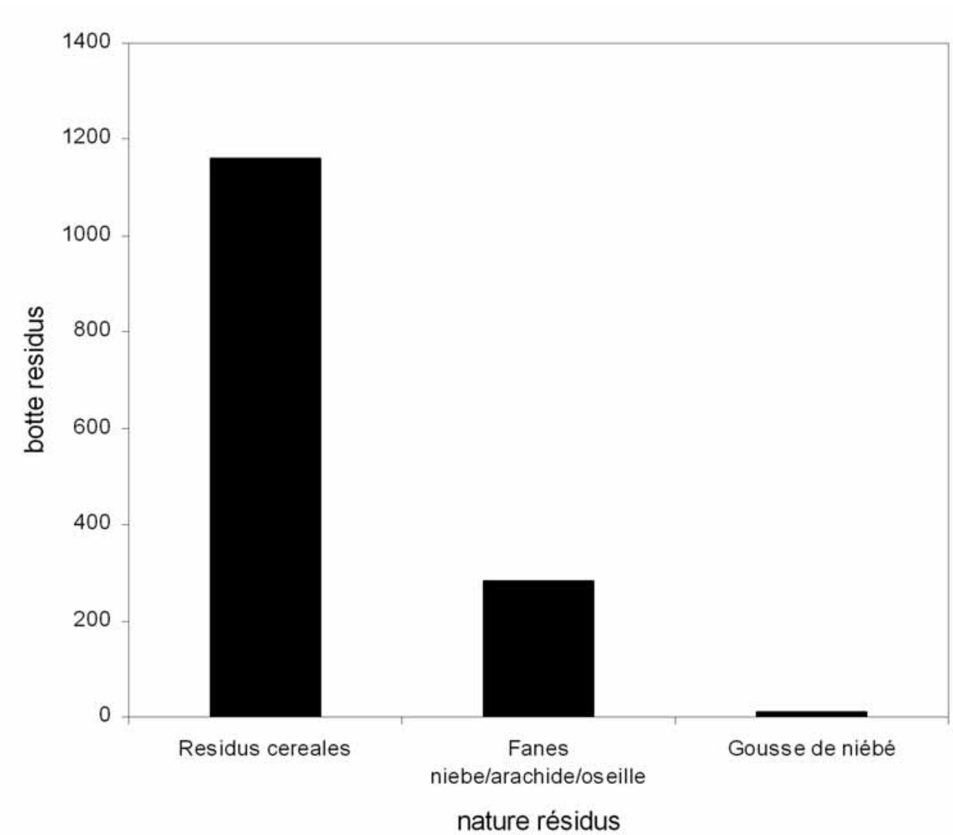

Figure 4. Biomasse des résidus de récolte stockée pour les besoins de production de fumier destiné à la fabrication du compost, résultats de 12 producteurs au Nord du Burkina Faso.

Des figures 1, 2, 3 et 4, il ressort que les résidus de culture ont une très grande importance dans les systèmes de production et suivent un cycle de gestion qui se termine dans les champs. En, effet, les résidus de récolte sont transportés dans les étables pour l'alimentation du bétail. En retour, le fumier et la litière sont utilisés dans les fosses pour la fabrication de compost. Le compost est utilisé dans les champs pour la production agricole

Cependant, plusieurs facteurs sont déterminants dans la production du compost au niveau de l'exploitation. Les facteurs les plus importants indiqués par les producteurs sont la disponibilité en main d'œuvre, la taille du cheptel et la disponibilité en eau. La qualité du compost produit est fortement influencée par ces trois facteurs.

Conclusions et Suggestions

A l'issu de nos travaux, il ressort que la gestion de la matière organique au niveau des exploitations agricoles de la zone nord du Burkian Faso est de plus en plus maîtrisée par les producteurs. Il reste cependant à les accompagner sur les aspects liés à la production et l'utilisation de la biomasse produite au niveau des champs. L'utilisation de hache paille pourrait permettre une réduction du volume des résidus d'où un stockage plus facile. Le développement de variéte de sorgho et de mil fortement productrices de biomasse permettrait de pallier à l'insuffisance de résidus et partant une augmentation de la production de matière organique. Les producteurs devront être également formés sur les techniques d'alimentation et d'entretien du bétail. Dans certaine situation il est apparu des quantités de litières trop importantes non consommées par les animaux. Cela constitue un gaspillage pour le producteur qui dispose de très peu de stock pour rallier les six mois de saison sèche. La qualité de la matière organique est un phénomène très important dans le système de production adopté par les producteurs dans la zone, il serait souhaitable que des travaux de laboratoire se poursuivent sur la caractérisation des différentes matières organiques afin de donner des conseils précis aux producteurs sur les quantités de matière organique à utiliser en fonction des substrat utilisés. Enfin, la végétation sauvage est une source de matière organique peu utilisée par les producteurs de la zone en dehors de la vaine pâture. Les producteurs devront être sensibilisés à adjoindre cette source de matière organique afin de produire suffisamment de compost pour les champs. La mise en œuvre de l'ensemble de ces recommandations permettra d'assurer une durabilité des systèmes de production dans cette zone sahélienne fortement dégradée.

Remerciements

Nous remercions les paysans innovateurs du projet de conservation des eaux et des sols phase 2 (CES II) pour leurs contributions à la conduite de cette activité. Nous sommes également reconnaissant à l'endroit des ONG ORFA et R-MARP pour leur disponibilité et leur active participation au suivi des opérations.

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Main causes of declining soil productivity in Malawi: Effects on agriculture and management technologies employed to alleviate the problems

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Abstract

As an agricultural country, an increased utilization of natural resources has characterized the socio-economic development of Malawi since independence. The population of the country has been growing at a fast rate and population pressure has resulted in excessive deforestation, reduced landholding sizes, reduced crop yields, declined forest cover leading to degradation of soil and water resources, loss of plant and animal habitats, unstable river/stream banks, flush flooding and silting, and lowering of water beds. The conservation and proper use of natural resources are absolutely essential for protecting the environment and ensuring that future populations are healthy and well fed. Agricultural soils are being degraded at an alarming rate by mainly water erosion as a consequence of improper and inappropriate farming practices. Because of these degradative processes there has been a concomitant decline in soil quality, that is, the capacity of the soil to produce adequate yields of healthy and nutritious crops that can resist erosion and ameliorate climatic and environmental stresses on plants. Despite the above highlighted problems, people will have to be fed from the degraded and dwindling resources and this has necessitated a call for concerted efforts in full consultation with farmers to assertively implement soil fertility improvement and soil and water conservation programs for improved agricultural productivity in Malawi. Some of the programs employed to address the problems are contour ridging, use of vetiver grass, soil fertility improvement technologies such as crop residues incorporation, mulching, agroforestry interventions eg, alley cropping of Tephrosia vogelli and Cajanus *cajan, systematic interplanting of Faidherbia albida, under sowing of Tephrosia vogelli and improved fallows. Also ranking high on the programs are land resource surveys and evaluation which are geared towards monitoring effects of various farming activities and inputs to the environment, the results of which can be applied to the management of ecologically similar catchments.*

Introduction

Malawi is a long narrow landlocked country situated between latitudes 9° 22’ and 17° 8’ south of the equator and longitudes 33° 40’ and 35° 55’ east. It has a total area of 11.8 million ha of which 9.4 million ha is land and 2.4 million ha is covered by water.

National Statistical Office, NSO (1987) reported that agriculture is the mainstay of Malawi’s economy, accounting for more than 35% of the Gross Domestic Product (GDP); it employs 80% of the total labor force and contributes about 90% of the domestic export earnings. Approximately 85% of the total population resides in rural areas and derives its livelihood from farming.

The human population of Malawi has been increasing at a high rate estimated at 3.5% per annum. This increase in population has put a very high pressure on the limited land resources. FAO (1998) reported that the nationwide population density is 170 people per square kilometer

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of arable land and over 200 in the densely populated southern region where more than half of the population lives. The result is that over 70% of the households are classified as resource-poor households, with holdings of less than 1.0 ha; of these, over 40% are farming less than 0.5 ha.

Consequences of population pressure

Population pressure has resulted in reduced landholding sizes, reduced crop yields, increased demand for agricultural land thereby making people cultivate on steep and marginal land, excessive deforestation in order to open more land for agriculture and also to fetch fuel wood and poles for construction, decline in forest cover leading to degradation of soil and water resources, loss of plant and animal habitat, unstable river/stream banks, flush flooding and silting, lowering of water beds, and reduction in natural grazing land. Overgrazing has caused formation of gullies, perpetual food shortages, and lean animals that fetch low prices at the market. All of these have affected farmers' income.

Soil degradation in Malawi

Chilimba et al. (1998) described soil degradation as the loss of soil productivity through chemical, physical and biological processes. Chemical degradation is the loss of nutrients through leaching and uptake by plants, increasing acidity and accumulation of toxic elements such as exchangeable aluminum and manganese, which limit soil productivity. Physical degradation involves destruction of soil structure, increase in soil bulk density and a decrease in water holding capacity of the soil and a decrease of infiltration rates.

These physical constraints lead to increased surface runoff, which causes soil erosion. Low levels of organic matter in the soil mainly cause physical degradation. Decline in soil fertility results from the loss of organic matter and chemical nutrients through leaching and the removal of crops and residues, compaction and loss of soil structure and physical erosion of topsoil by rainfall.

Land degradation in Malawi has been acute. Soil erosion currently averages 20 tons ha^{-1} per annum, with rates of more than 50 tons ha^{-1} in many areas. This problem is exacerbated by poor agronomic practices, particularly in marginal lands and steep slopes. Soil erosion is characterized by deteriorating soil structure, reduced moisture retention capacity, depletion of nutrients and organic matter and decreased micro-fauna and flora. All these factors reduce the rooting depth of crops, which decrease yields, especially in drought years.

The basic cause of soil degradation in Malawi is accelerated erosion caused primarily by rainfall on unprotected soil.

Overcultivation is another factor to reckon with. Land is cultivated too frequently. Non-arable or unsuitable land is used for cultivation without sufficient nutrient addition and proper conservation measures.

Also ranking high on the main agents of soil degradation is deforestation due to growing demand for wood and land for agricultural production as a result of rapid population growth. Many of what used to be perennial rivers have little water flowing in them now and others dry up in the dry season.

Overgrazing has also contributed much to this phenomenon. This is a widespread problem and difficult to solve as grazing lands are usually communal, nobody bears responsibility for them. Soil compaction caused by the cattle means reduced water quantity infiltrating into the soil and more loss as runoff. The ability of soil to grow enough grasses is reduced considerably.

Heavy rainstorms in some areas are very erosive and erodible soil suffer most because there is very little time for the soil to absorb the large volume of water. Areas that suffer most are steep slopes exposed due to the removal of vegetation and areas with unconsolidated soil material and cultivated areas.

Soil losses experienced in Malawi are estimated to destroy the productive potential of arable lands within 10-35 years. Continuous cultivation without replenishing the plant nutrients taken up by crops has resulted in a steady decline in soil fertility. The consequence is declining yields of many crops. This general decline in the productivity of the land is the reason for the lack of food security.

Chilimba et al. (1998) documented that in Malawi organic matter content is reported to drop to 59% in the first year of cultivation and nationally crop yields are estimated to be dropping by 2% annually. Past research in soil fertility has focused narrowly on inorganic chemical constituents to the exclusion of the equally important aspects of soil structure and organic matter. Consequently, research on the effects of agriculture on the inherent fertility and structural stability of soils is weak.

Implications of soil degradation on agriculture

There is growing concern within Malawi over the decline in the productive capacity of the country's soil resources as a result of soil erosion and adverse changes in the hydrological, biological, chemical and physical properties of these soils. This problem has resulted in food shortages, reduced exports while increasing food importation that drain foreign exchange reserves. This has had very serious implications on the food security situation and the country's economy.

Bunderson et al. (1995) reported that loss of topsoil has enormous costs to the economy, agriculture and environment, representing an estimated 1-5% of GDP from current production.

Materials and Methods

Technologies towards alleviating the Identified Problems

Several technologies are available to improve soil fertility and crop yields. Use of organic and inorganic fertilizers, agroforestry practices, intercropping legumes with cereals, and crop rotations to improve soil fertility are being demonstrated to farmers.

Use of chemical fertilizers

This is one of the technologies to maintain and replenish soil fertility but most of the farmers are unable to purchase the chemical fertilizers due to their high costs. Kamanga et al. (1999) reported that increased use of hybrid maize and mineral fertilizers are the most promising routes to improved crop yields. Although fertilizers may produce greater maize yields, their use is not widespread because their prices are prohibitive to subsistence farmers.

Soil and water conservation technologies

Having realized the limited potential to expanding and increasing agricultural production and the problems of soil fertility and water conservation, some of the activities undertaken by the country to improve on soil fertility and soil and water conservation for improved agricultural production are as follows:

- Contour Ridging: There are campaigns on contour ridging. Farmers are trained on contour marker ridges using "A" frame as a technology. Contour ridging gives sufficient time for rainwater to infiltrate thereby reducing runoff and increasing the ground water recharging capacity. Bunderson et al. (1995) reported that many agroforestry technologies are best planted on the contour to improve their function and effectiveness. This helps to reduce soil loss and runoff, while improving water infiltration. They go on to say that the nature of these concerns demands a catchment-area approach by the entire community; otherwise the efforts may be compromised. For cultivated land, the first task is to delineate and build contour marker ridges throughout the catchment. Crop ridges are then aligned to the contour lines.
- Vetiver grass and Napier Grass: Strips of deep-rooted perennial bunch of grasses planted along the contours of farmers' fields produce an effective barrier against erosion and runoff. With proper spacing and management, natural terraces can form between the contour strips as soil is moved from the upper side to the lower end behind the grass strip. Vetiver grass *(Vetiveria zizanioides)* and Napier grass (*Pennisetum purpureum*) are promoted as tools for soil conservation by planting on the contour. Napier is commonly used as fodder for cattle while vetiver is unpalatable to livestock.
- Rehabilitation of Degraded Land: Degraded land is rehabilitated to put it back into production. Farmers are provided with knowledge through extension personnel on how to establish hedges using grasses like vetiver and nitrogen fixing trees like *Tephrosea vogelli*.

Soil fertility improvement technologies

A number of interventions geared towards improving soil fertility are disseminated to smallholder farmers. This is a response to unaffordable inorganic fertilizer prices to most farmers and other soil structural problems.

- Organic Matter Utilization: This is in the form of ordinary *khola* manure, incorporation of crop residues and compost manure, all with undetermined nutrient endowment. Promotion of compost manure features high in this program.

Agroforestry interventions

Agroforestry systems offer opportunities for realizing higher productivity, more dependable economic return, and a greater diversity of outputs and benefits on a sustainable basis. The appeal of agroforestry lies in the multipurpose use of woody plants as well as their products. Some tree species play a vital role in sustaining and improving crop yields by helping to improve soil structure and fertility, reducing soil erosion and providing shade etc.

Malawi has intensified agroforestry interventions in order to improve food security, agricultural sustainability and the conservation of the natural resource base by addressing common problems faced by smallholder farmers. These technologies have particularly been taken on board to address problems of small farm holdings and lack of land for agricultural expansion, low or declining soil fertility and crop yields, increasing soil erosion and water runoff on steep slopes, animal nutrition problem and inadequate fodder, shortage of fuel wood and building materials, accelerated deforestation, and overgrazing including rising costs of farm inputs coupled with limited credit opportunities.

Systematic interplanting of *Faidherbia albida* on smallholder farms

Faidherbia albida is a large leguminous tree indigenous to Malawi. Its distinctive feature is leaf growth in the dry season and shedding at the start of the rainy season. Cereal crops such as maize, sorghum and pearl millet have been cultivated continuously under *Faidherbia albida* in many parts of Africa with no significant reductions in yields or additions of fertilizers. Yields under the canopy are 50-250% higher than adjacent areas away from the canopy. The tree also provides abundant quality fodder during the dry season mainly in the form of pods, which may average over 100 kg per tree (Ministry of Agriculture 1994).

Munthali et al. (1994) reports that *Faidherbia albida* is perhaps the most important multipurpose tree species for agroforestry. Traditionally, it has been retained in farmers' field care because of its ameliorative effects on the soil and its positive effects on crop yields. It grows naturally in parts of silvicultural zones which make up to 48% of the total land area in Malawi.

Alley cropping

Alley cropping or hedgerow intercropping is the cultivation of annual crops such as maize between hedgerows of woody plants. This improves soil fertility and crop yields, improves the efficiency of chemical fertilizers so that application rates can be reduced. Hedges are pruned two or three times during the year to prevent shading of the crop, and to provide leaf biomass for organic manure and mulch. Mulching this material into the crop alleys adds nutrients and organic matter to the topsoil, suppresses weeds and decreases erosion and runoff. Pruned branches also provide fuel wood or act as racks for hanging tobacco. The foliage of some species makes excellent fodder. The hedges in alley cropping are generally fast growing, high yielding leguminous shrubs and trees with nutrient-rich foliage and the recommended species are *Leucaena leucocephala*, *Senna spectabilis*, *Tephrosea vogelli*, *Sesbania sesban a*nd *Gliricidia sepium*.

Systematic tree intercropping

Population pressure has resulted in a steady decline in abundance and diversity of certain trees; consequently, their value to farmers is being lost. Farmers are encouraged to protect naturally regenerating trees in their fields to help reverse these degrading trends. The trees being promoted are those that are naturally adapted to various areas. This technology builds upon traditional agroforestry practices by planting more systematically to reduce problems of deforestation and continuous monocropping. Virtually any type of tree can be planted depending on the needs and priorities of the farmer. *Faidherbia albida* is one of the indigenous species that is commonly left in the field or allowed to regenerate naturally. Other tree species are fruit trees such as mango, banana, peach etc.

Short-term fallows

These incorporate fast growing trees and shrubs to speed up soil restoration with secondary wood products. The best species are those that enhance soil fertility by fixing nitrogen and by establishing ground cover quickly. This technology is advantageous in that it requires little labor and management, but small land holdings may limit its application. Short-lived shrubs such as *Cajanus cajan*, *Sesbania sesban* or *Tephrosea vogellii* are best suited for this technology. Short or late planted crops like ground nuts, soy beans, sweet potatoes and cassava may be grown with the shrubs for the first year while the trees are still small. Cultivation is then abandoned, allowing the trees to grow. After 2-3 years, the trees are cut to ground level before the onset of the next season. Their root system and foliage improve soil fertility. Woody material can be used as fire wood or tobacco ties. Cultivation is then resumed with restored fertility.

Land Resource Surveys and Evaluation

- Environmental Monitoring: This program was initiated to monitor the effects of various farming activities and inputs to the environment, the results of which can be applied to the management of ecologically similar catchment areas.
- Land Husbandry Extension: In order to increase adoption of the activities geared towards improving soil fertility status, a number of extension tools have been utilized which include campaigns, on farm demonstrations, training and field tours.

Results and Discussion

Potential of agroforestry technologies in Malawi

According to an experiment conducted at Bunda College by Kwapata (1994), it was found out that 10 t ha^{-1} of fresh Leucaena leaf biomass is just as effective as inorganic fertilizer N applied at the rate of 100 kg ha^{-1}. It was also discovered that a single application of Leucaena leaf biomass is as efficient as two split applications. High maize yields require an application of about 100 kg N ha^{-1}. However, the increasing cost of inorganic fertilizer has led to the inability of many rural farmers to apply less than the recommended rates of fertilizer application. The consequences are declining maize yields due to low soil fertility. These results are encouraging because they are moving towards low cost technologies that produce the same good yields.

Incorporation of Leucaena leaf biomass increases maize grain yields. This is important for smallholder farmers who cannot afford to purchase inorganic fertilizers. In addition, substantial added benefits of fodder and firewood can be realized from Leucaena hedges. These research findings hold promise for solving some of the problems of declining crop production in Malawi.

In an experiment carried out by Kamanga et al. (1999), it was found that yield benefits obtained from the legume systems with mineral N fertilizers are sufficient to overcome food insecurity of many households, particularly within smaller landholdings.

Table 1 illustrates the domestic impact of yields resulting from legume interplanting. The legume trees used in this system were Sesbania, Tephrosea and Pigeon pea and were interplanted with Maize. The Sesbania interplanting with 48 kg N ha^{-1} of mineral fertilizer provided sufficient food for the average family of 5.8 people from 1 ha and also resulted in a surplus of 20% that the household could market. Tephrosea also exhibited similar benefits of producing sufficient food with 6% surplus. Pigeon pea and maize interplanting produced 87% and 83% respectively, of the household maize requirements. However, the same interplantings without inorganic fertilizer provided insufficient food for the household.

An amount of 43% of the total food required would be realized from Sesbania with 40%, 25% and 24% from Tephrosea, Pigeon pea and maize interplanting, respectively.

Table 1. Maize yield and food security from the legume based systems for 1998.

System	Yield	Maize	% Maize Produced Production(kg ha^{-1})	% Maize Difference
Sesbania+48 kg N ha^{-1}	2937	1644.7	120	+20
Sesbania biomass only	1055	590.8	43	57
Tephrosea+48 kg N ha^{-1}	2592	1451.5	106	+6
Tephrosea biomass only	978	547.7	40	60
Pigeonpea+48 kg N ha^{-1}	2122	1188.3	87	13
Pigeonpea biomass only	621	347.8	25	75
Maize + 48 kg N ha^{-1}	2032	1137.9	83	17
Maize stover only	584	327.0	24	76

Conclusion

Declining soil productivity is the main cause of food insecurity in Malawi. Population pressure on land resources is still growing. Nevertheless, the people will have to be fed from the degraded and dwindling resources. And this has necessitated a call for concerted efforts in problem identification and efforts in full consultation with farmers to assertively implement soil fertility and soil and water conservation technologies for improved agricultural productivity in the country in order to ensure that every household is food secure. However, the adoption of these technologies has not been very remarkable because of, among other problems, lack of funds to run the programs to their successful continuity and completion and insufficient germplasm for soil fertility improvement programs.

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Farmer innovations in mitigating water and nutrient deficiencies in rain fed agriculture: Lessons from African Conservation Tillage joint pilot activities in Zimbabwe, Zambia and South Africa

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Abstract

Over 95% of food production in southern Africa comes from rain dependent dry land farming. With fundamental limitations in the use of the normally high cost irrigation systems, rain-fed agriculture remains critically important in these areas now and in the foreseeable future. On one hand with the annual regional population increase averaging 2.3%, and on the other hand agriculture production/ productivity at best stagnant, the region is faced with unprecedented demands for agricultural outputs (food and industrial raw materials). Agriculture comes out as key in all the efforts to address food security and poverty in the region.

However, after three to four decades of focused interventions on agriculture (seed, fertilizers, mechanization, marketing, etc), it is now being realized that land quality is a critical factor in achieving and maintaining high agricultural productivity. One critical element of soil quality is water, which has in recent decades shown signs of increasing unpredictability and changes in its patterns.

This paper details the last three years of farmer innovations and practices in addressing the issue of sustainable use of natural resources in agriculture with particular focus on better rainwater management and increased water use efficiency. The focus is on three project areas (Zambia, Zimbabwe and South Africa) where the African Conservation Tillage Network (ACT), with local partner institutions, has managed farmer support-facilitation "efforts" in developing and disseminating sustainable farming practices.

The paper also discusses technical and institutional challenges limiting widespread adoption of conservation agriculture (CA) in these circumstances.

Introduction

Increasing inability among most governments and social systems in southern Africa to provide for basic needs of their people has brought rising pressure on agriculture. This is about food security just as much as it is about agriculture's role in economic development, poverty alleviation, and improving living standards, especially in rural areas.

The rise in agricultural output recorded in much of the region in the 1960s and 70s, has in the last two decades reversed into decline or at best stagnated. In most Southern African Development Communities (SADC) countries, the once average grain yields of 2 to 3 t ha^{-1} (still far below potential) in smallholder systems has declined to under 1 t ha^{-1}. In Zambia, national maize yield averages have declined from about 2.4 t ha^{-1} in 1991 to less than 1.4 t ha^{-1} in 1999 (Bwalya and Mulenga 2002). Farmers "mourn" that their harvest now is not even enough for

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their subsistence needs, while 15 – 20 years ago they harvested from the same fields enough to feed the household with some surplus to sell, despite now using improved seed and just about the same quantities of fertilizers.

Reasons for yield decline are many, complex, and varying from location to location. However, one factor that threads through most situations is the degradation of agricultural lands. Qualitative assessments of available data suggest that about 20–30% of Africa's lands are severely degraded due to agricultural activity (Garcia-Torres et al. 2000; FAO 2000; McNeely et al. 2001). This degradation has not just resulted in low farm yields, but also left farming systems (directly responsible for the livelihood of over 55% of southern Africa's 145 million population) highly vulnerable to even minor distortions in weather patterns. Cases of mass starvation as a result of either drought (1982, 1983, 1987, 1992, 1995, 1998, 2001) or floods (Malawi – 1998–99 and 2001–02 seasons) have become all-too frequent in the region with relief food aid more a norm than an exception.

Much of the degradation relates directly to the way agriculture has been practiced. These are practices that have evolved over many decades coming to be characterized essentially by removal of crop residue; complete soil disturbance, commonly referred to as tillage or ploughing; mechanical weeding; inorganic fertilizer use; and monocropping. One critical element of soil quality adversely affected by soil degradation is available water. Even with what appears to be more erratic rainfall in recent years, water stress seems to be constraining crop productivity more than ever before. This is essentially due to the lower ability of the soils to store water and increasing tendency for most of it to flow away in the process called erosion.

General situation

Southern Africa's climate is characteristically tropical semi-arid to arid with some relatively wet to dry humid zones in the northern areas of the region. Most parts receive below 500 mm annual rainfall during 4–5 months of the year. Temperatures range from 15 ^{0}C to 35 ^{0}C with evapotranspiration in almost all areas higher than precipitation for 8 to 10 months of the year.

Socio-economic and cultural circumstances in the region are very diverse. One predominant feature, however, is the rural-subsistence-agriculture based communities, with farming decision-making driven more by survival needs than economic rationalization.

Monomodal rainfall and no irrigation means that they can harvest only once a year. In all the three pilot areas, the main crop is maize. Sometimes, some of the crop is sold for cash. The grain sold does not necessarily represent surplus, as a household may sell the little they have to enable them to address their immediate cash needs. In South Africa, migrant remittances and pension monies are significant and sometimes the only dependable sources of income for most households. In all the three areas, ownership of cattle and hence draft animals is very little – averaging about 2 to 3 households in every 10. Most, however, would have goats and chicken, which often come in handy in converting to cash.

In the last decade, both socio-economic and cultural factors and climatic circumstances, which are by no means static, have come to bear on agriculture performance with largely adverse effects. It is also important to put in context that these communities have in the last decade been subjected to effects of economic liberalization and privatization - collapse of the input-output marketing systems, withdrawal of seed/fertilizer subsidies, and phasing out of government supported agricultural (input) loans. In the same period, the communities have seen growing impact of the effects of HIV-Aids, for instance, on available farm labor, declining remittances, and growing responsibilities in terms of caring for sick and orphans.

This paper focuses on three scenarios from within southern Africa – Siavonga district in southern Zambia, Chivi district in southern Zimbabwe and Limpopo Province in northern South Africa. In all these areas, the term "conservation" in relation to agriculture is not new. Traditional farming practices allowed and/or facilitated some form of replenishment of the soil-water quality (fertility); eg furrowing and inter-cropping. The areas also have a history of soil and water conservation practices enforced by government legislation. These have mainly been soil surface physical structures essentially meant to control surface water erosion – more from the soil loss point of view.

However, both science and on-farm experiences now show that these practices are inadequate in providing for a system that is sustainable at the same time high yielding. The rainfall and temperature situation in much of the Sub-continent, as in these three locations, gives less chance for tillage (complete soil inversion and loosening) based cropping systems to be sustainable.

Materials and Methods

The project intervention areas

Tables 1, 2 and 3 give brief descriptions of the main characteristics of the three project areas.

Table 1. Characteristics of the two pilot sites in Sianvoga, Zambia.

Character	Simamba Community	Chikanzaya Community
1. Peoples	Tonga and Goba tribes Number of households: 550 in Simamba and 846 in Chikanzaya; average household size of six.Settled in villages comprising more than one family; Family based on extended relationships.Family linkages and interactions stronger than community-village interactions.	
2. Survival strategies	Subsistence farming. Major crops in terms of area involved and production are (in order of significance) sorghum, maize and millet.	Subsistence farming.Major crops in terms of area involved and production are (in order of priority) maize, sorghum, groundnut & vegetables (irrigated).
	Other survival activities include: Goats (food and source of income). Brewing and selling beer (women). Gathering and selling wild fruits and tubers (women and children).Remittances.	Other survival activities include:Selling of excess crop produce.Brewing and selling beer (women).Gathering and selling wild fruits and tubers (women and children).Cattle selling and remittances.
3. Land	All land is traditional under authority of chief/headman. However, for all practical purposes, most land worth of settlement and farming is in the hands of families - the responsible family unit has the critical decision in allocation of land than the chief/headman. The chief/headman is only informed as a matter of formality.Land in terms of use could be classified as:Arable land, normally away from the household settlements;Settled lands, ie the villages. There is an increasing trend to crop the field around the households (reason – fertile soils);Grazing land (mostly noted as infertile is normally designated as communal land under the direct control of chief/ headman).	

Continued

Table 1. *Continued*

Character	Simamba Community	Chikanzaya Community
4.Soil Fertility	Poor to very poor on most "old" fields. Such fields are being abandoned in preference for new fields (new clearing) often in marginal areas. In Simamba, farmers do not normally use inorganic fertilizers. The few owning cattle do use kraal manure. Farmers' interpretation of soil fertility is related to water (rain) availability; as long as there is sufficient rain, it is believed that they would have a good crop. In Chikanzaya, inorganic fertilizers have been used especially in the maize crop.	
5. Climate	Rainfall: Annual average range is 300 to 600 mm in the period Nov. to March. In the last 20 years, rain has been above average only in four seasons.	Rainfall: Annual average of 650 mm (400 to 800 mm) during the period October to April
	Above average rain is good for recharging the water table but brings with it weed problems, water logging in low lying fields which may still cause low yields.	In the last 7 years, the area has had two years (seasons) of abnormally high rainfall and one critically below normal rains.
	Temperatures: lowest (June-July) at 20° C and highest (October) at an average of 38° C.	Temperatures range from about 15° C in June (coolest) to over 30° C in October (warmest).

Table 2. Characteristics of the pilot site in Masvingo – Zimbabwe.

1. Survival	Major constraints to crop production in the communities include: Vulnerability to frequent droughts (climatic strategies extremes), Soil erosion and poor soil fertility, Limited/lack of technological information, Poor support infrastructure and inadequate labor.
2.Land and other resources	Land degradation in the smallholder farming sector of Zimbabwe poses a major threat to crop productivity.Farming systems mostly based on crop and livestock production. Most households have dry land fields and a garden. The fields are used for seasonal production of crops such as maize, groundnuts, sunflower and small grains. Majority of the smallholder farmers have less than 5 hectares of arable land. About a third of the families have no cattle and draught power is generally in short supply.
3. Soil Fertility	Soils in much of the intervention area are derived from granites, with coarse-textured sandy surface horizons, occasionally overlaying a clayey subsurface layer.Also characterized by low cation exchange capacity and low pH ranges of between 4.2 and 4.8 (0.01 M calcium chloride). Available soil nitrogen usually below 30 ppm implying a low N availability. Soil phosphorus is also usually below 25 ppm resulting in deficiency to plants.Fields have been cultivated for 40- 60 years with little or no mineral fertilizers. Low in organic matter (0.3 to 0.5%) compared to virgin soils (1 to 1.2%). Consequently, the soils have a weak structure, making them highly susceptible to crusting, compaction and erosion and very poor moisture retention capacity. The soils require substantial nutrient inputs to maintain even low levels of production.
4. Climate	Semi-arid marginal areas with 300 – 600 mm annual rainfall coming mainly in the period November to April. High variability both in terms of duration/timing and amounts; with drought risk of one in every five years and excessive flooding, one in every ten years. Temperature average 30° C in the dry hot period and 25° C in the wet season. Humidity is very low with very high evapotranspiration.

Table 3. Characteristics of the pilot site in Limpopo – South Africa.	
1. Peoples	The Limpopo Province is in the north east of South Africa. The Province has borders with Zimbabwe, Mozambique and Botswana. The Province has a population of 4,929,368 (All figures from Statistics South Africa, A Stats in brief 2000) and covers an area of 123,910 sq km. The project is targeting resource-poor farmers in the former homelands of Limpopo Province who are predominantly women working in groups. Potentially up to 1,600 households in the Province could be involved. About 77% of the households in the area are considered female headed, the majority due to husbands being away in migrant labor.
2. Survival strategies	Off-farm incomes and pension schemes enable many to practice a relatively high-input farming based on mineral fertilizers, commercial seeds and mechanized tillage. However, due to numerous environmental constraints and inappropriate practices, yields are still extremely poor. Food security is still a critical element in the communities' livelihood. The agriculture sector is the largest employer in the Limpopo Province outside government. However farmers face very poor conditions, live with tenure insecurity.
3. Land	The landscape of this area is dominated by steep undulating hills, which are traversed by very deeply incised rivers.
4. Soil Fertility	The soils are generally infertile, unstable and highly erodible.
5. Climate	The area is highly drought prone. Wet season lasts about 4 – 5 months (Nov to April). The average annual rainfall ranges from 400 mm (Mbahela in Vembe district in the north) to 750 mm (Spitzkop in Capricorn district). Most of the rainfall is in the form of highly erosive intense thunderstorms. The rainfall also tends to be highly variable both within and between seasons.

The project intervention thrust

The three areas have had project interventions promoting conservation agriculture (CA) for several years before ACT got involved as an add-on intervention. Programs in Limpopo and Siavonga, implemented by the departments of Agriculture in the areas, have had German Technical Cooperation (GTZ) support (Based in Limpopo Province since 1998 and the Food Security Agriculture Support Programme in Siavonga since 2001). In Zimbabwe, the community has been participating in an Ministry of Agriculture's Agricultural Research and Extension Department (AREX) soil and water intervention project since 1995. Table 4 gives the aims and main thrust of the CA interventions in the three areas.

Involvement of the African Conservation Tillage Network (ACT)

ACT joined the three programs (Limpopo in 2000, Siavonga in 2001 and Zimbabwe in 2000) under a pilot arrangement. ACTs input to the programs was designed to focus on:

- Facilitating exposure of staff/farmers to CA options.
- Enhancing farmers/staff access to CA information.
- Strengthening farmers/staff capabilities in on-farm experimentation and participatory dissemination approaches.
- Development of in-built process for capturing and documentation of lessons (approaches, technical options, impact).
- Facilitating multi-sectorial collaboration especially as concerns private sector involvement.

Table 4. Aims, Objectives and main features in the Project interventions.

Location	Aim and Objectives	Main project features
Zimbabwe Chivi ward; Masvingo Province – southern Zimbabwe	On-farm identification, adaptation and promotion of improved soil and water management among smallholder farmers in arid regions of southern Zimbabwe.	1.Training support in community organization and group dynamics. 2. Exchange of experiences through formal and informal farm visits, meetings and competitions. 3. Technical support through introduction and advise on technical CA options. 4. Farmer innovations.
South Africa Limpopo Province - northern South Africa	Enhance dissemination and adoption of CA technologies in smallholdings with primary focus on women farmers. Farmer/community mobilization and strengthening of group dynamics. Identification and/or adaptation of CA technological options Farmer/staff training.	1. Development and strengthening of farmer organizational capacities. 2.Involvement/partnerships with relevant stakeholders (public, private and NGO). 3. Awareness raising and demonstration of technical options. 4. Farmer experimentation. 5. Process monitoring (technical options and approaches) and sharing of innovations and end of season evaluations and re-planning.
Zambia Siavonga District - southern Zambia	To promote technological options in soil and water management for sustainable and productive farming. Capacity building for local staff in supporting development and adoption of conservation farming practices.	1.Technical options for CA (water harvesting, management; reduced tillage; Organic Matter (OM) build up). 2. Farmer empowerment and facilitate their participation in the development and dissemination of CA practices.

ACTs involvement in on-farm programs is driven by the Network's desire to identify and build farm level experiences to show case development, adoption, and impact of CA in defined circumstances in Africa. Other than adding on the value of capturing experiences/ lessons, ACT does not, however, implement on-farm pilot programs by itself.

Intervention methodology and approach

In all the three areas, farmer mobilization and support in strengthening group dynamics has been an integral element of the project support.

In Zimbabwe, the community now has self-sustaining farmer groups through which farmers in the area are interacting to learn more about sustainable farming practices. The same is true in Zambia and South Africa. In South Africa, the groups have, by default, turned out to be essentially women groups due to the fact that most households in the communities are female headed with majority of them having their men working in urban centers.

The Project support element on farmer participation processes, group dynamics and empowerment, and facilitating farmer innovations is based on two key principles. These are,

Principle 1 - It is the farmers who will decide and act for adoption to occur.

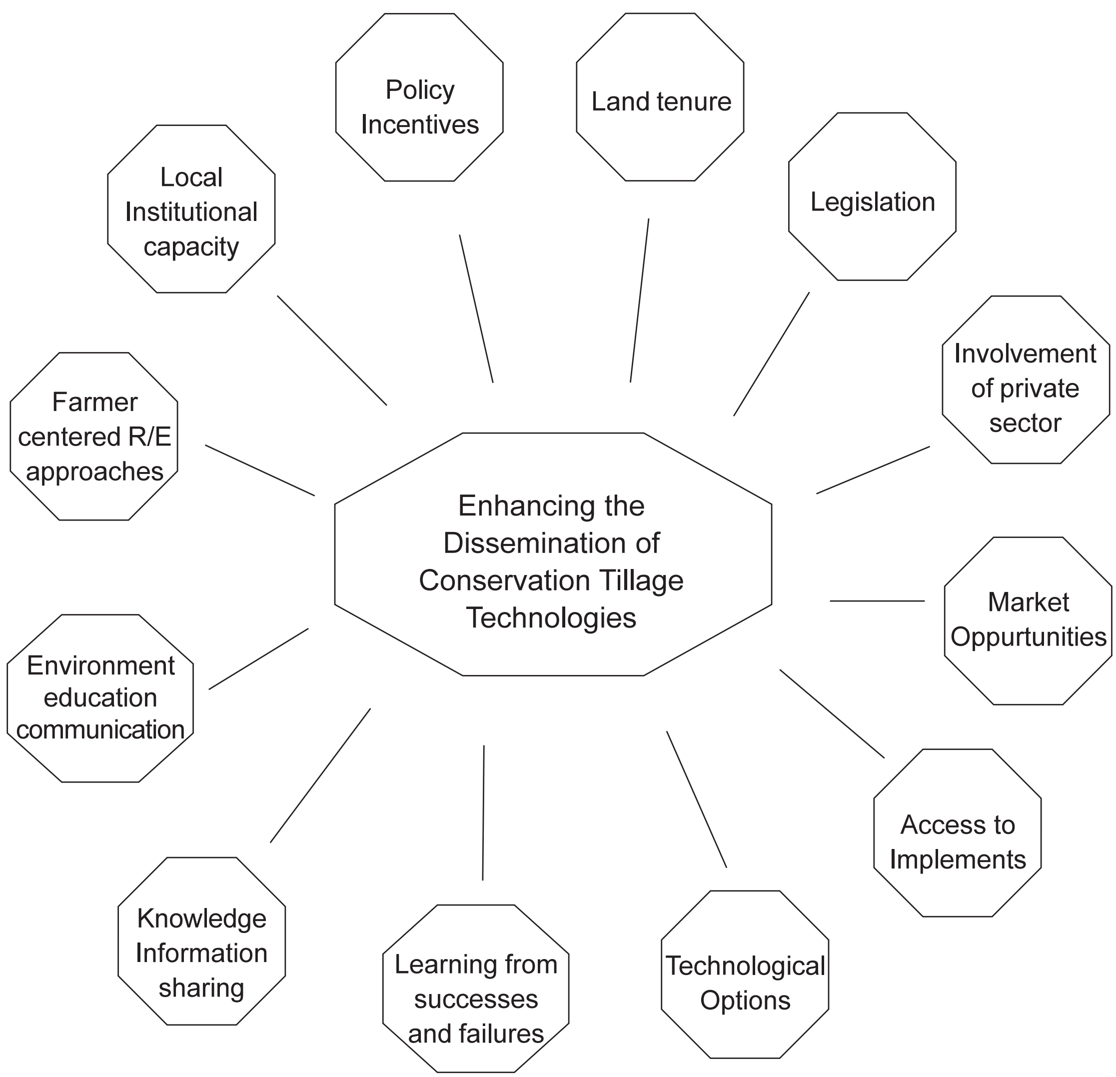
Principle 2 - Issues and circumstances farmers have to deal with are complex, varied and dynamic.

These principles have ensured that the project intervention processes (both in content and methodology) place the farmers in the "driving seat" and participation has been meaningful.

Intervention process

i. The first key element of project intervention is to bring interested farmers together (mainly strengthening existing groups) and facilitate them to start critical analysis of issues related to productivity, resources inputs, etc. Discussions linking agricultural performance to livelihood issues such as poverty and level of income, food security, and socio-economic status of the households, generated a lot of energy even in South Africa where the households have a relatively steady income from pensions and remittances. The analysis wheel is one of the tools used here. Each indicated aspect in the wheel is discussed to identify how it relates to the adoption of CA in the area and also its possible links (affects/effects) on the other factors in the wheel.

ii. Identifying and prioritizing problems constraining agricultural performance. Discussions in step one above were facilitated (at farmers' own pace) into ultimately highlighting the key root causes. The facilitation at this stage also included strengthening farmers' understanding and appreciation of the concept and application of sustainable use of natural resources. The facilitation also helped channel the generated "energy" into "desire to do something".



iii. With this desire, the project moved on to exposing the farmers to possible options in addressing the soil fertility issues. This was done through (a) specialized training, (b) farmer-to-farmer visits, (c) field days/demonstrations (in some cases held by innovating farmers within the area). This process enabled farmers to make informed choices when it came to deciding the action plan.

iv. Now aimed with "new" information/knowledge and with the desire to work out solutions, the process facilitated them into developing action plans. The main characteristics of these action plans include,

- Build within the context of the household production-consumption systems, ie the plan does not become an extra "external" undertaking.
- It had to be understood and operated as a plan for the household (for the group) and not a plan for the project or Ministry of Agriculture.
- Long-term perspective, while ensuring short-term needs, eg immediate food needs, resource commitments are also taken into account.
- Even though with a strong learning element, the plan had to be "real", ie not just an experiment but coming within the households' production and consumption systems.
- Allow and reward innovativeness.
- Enable farmers to see and understand what is going on at every stage with chance to reflect on and share experiences.
- That was a plan not the same as using new seed and use of fertilizers or equipment, it was a plan fundamentally about the way to farm.

Chart 1 gives the main benchmarks in the process being described above.

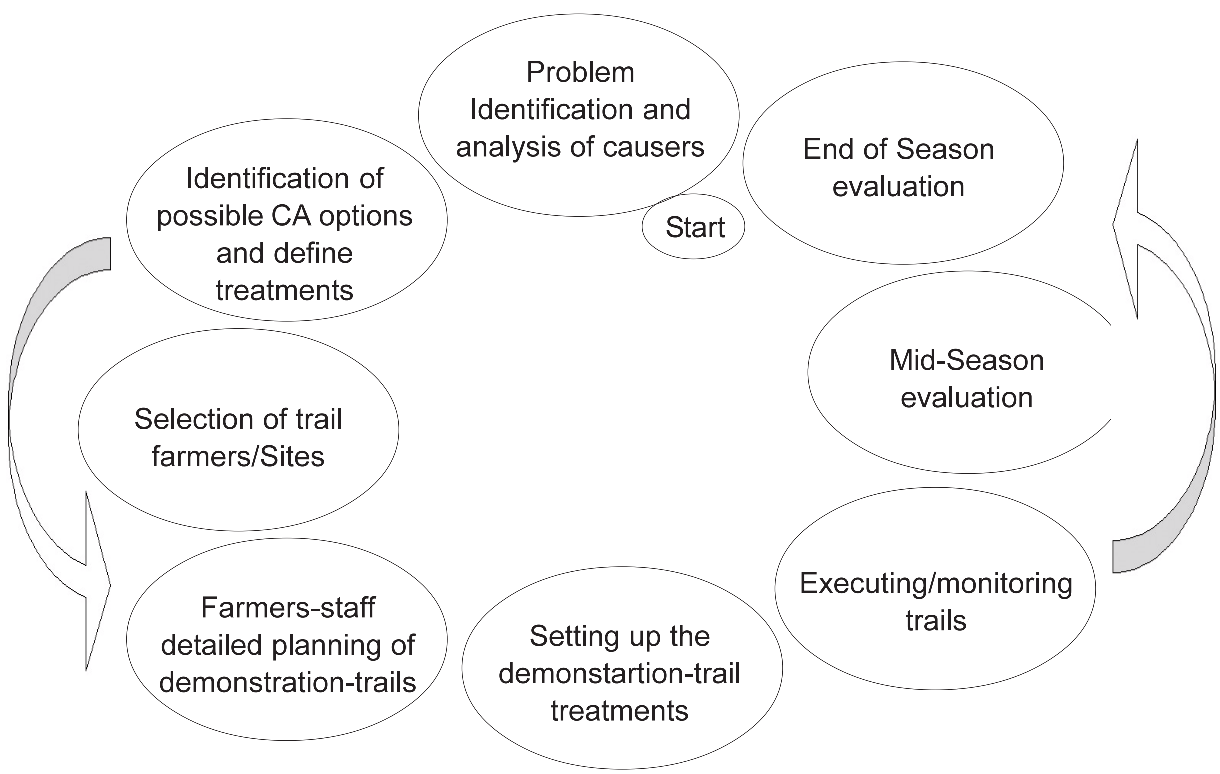


Chart 1. Conceptual framework for the dissemination of conservation tillage technologies.

Farmer innovations in dealing with declining productivity

Most fields were severely degraded at the start of the project. The next option for many households was to abandon such fields and shift to new (not necessarily virgin) lands. However, with rising land pressures this increasingly meant moving into marginal lands such as on hillsides and in preserved dambos (wet lands). After the analysis stage of the process, key problem areas were identified. These are presented in Chart 2.

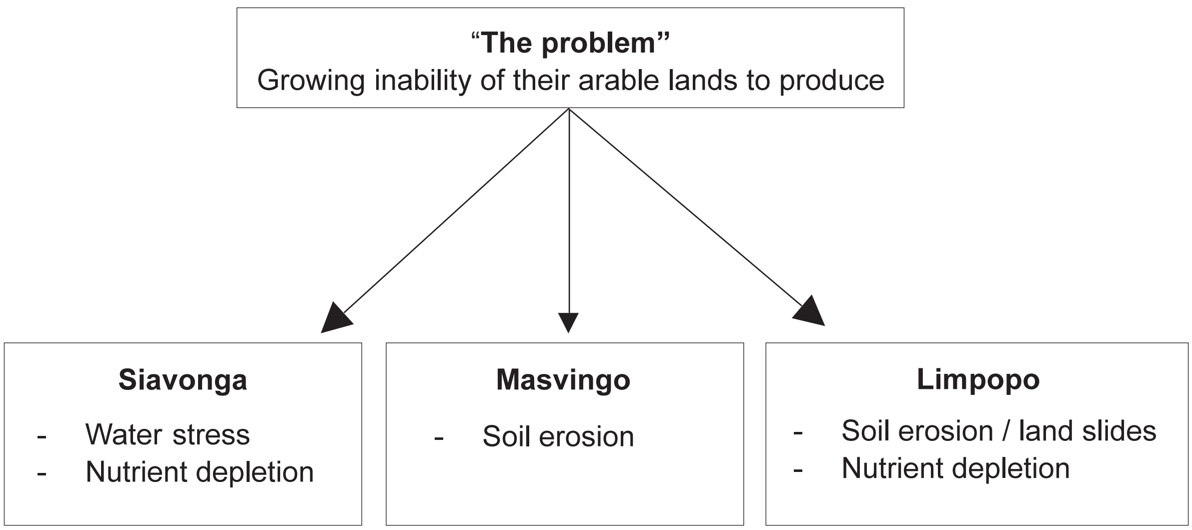


Chart 2. Key constraints limiting agricultural productivity as identified in the three communities.

Technological options adapted/adopted

Some factors/issues also coming out in farmer discussions were that,

- The areas where water stress was identified as a major constraint to productivity (average 400 mm annual rainfall) are the same areas with extensive problem of gullies and erosion.
- Reduced tillage was identified as an option, however, in most cases, households that shifted to reduced tillage (basins, ripping) had disastrous results. This was in fields later found to be compacted or having plough pan.
- Weeds; how to deal with weeds in a reduced tillage situation was a big problem which discouraged or even abandoned adoption.

As a result of these factors, the groups developed a three-stage process in the build up to what may be referred to as sustainable farming.

1. Stage one - This could also be described as a transition phase. This stage involved identification and eliminating symptoms of degradation. This often was soil compaction and hard pan problems.

This stage turned out to be very critical in the success of the adoption process. Key options at this stage related to breaking of the hard pan and beginning to leave residue on the surface (Chart 3). Essentially, this meant starting with some practices to harvest and manage rainwater. The effect on yield was immediate and astounding. In all the three pilot sites, grain yields at least doubled to about 2 to 3 t h^{-1} in the very first year of application, with the effects more pronounced the more compacted the fields were.

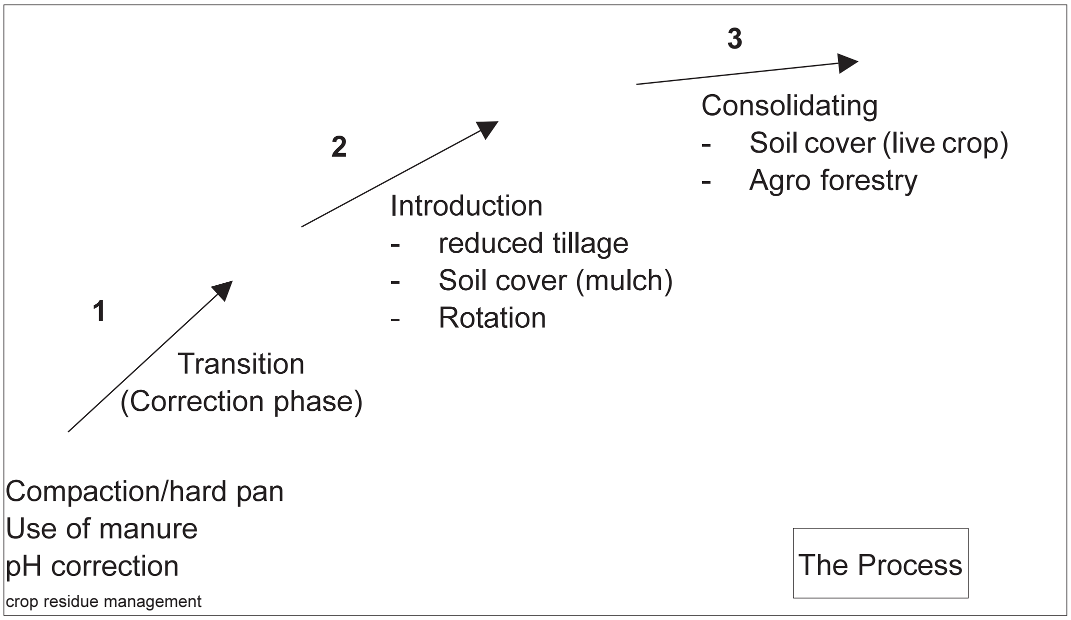


Chart 3. A 3-stage process of building up sustainable farming.

However, the groups noticed that in the second and subsequent years the yields did not change any more, in fact it was apparent that something had to be done to effect any further increase in yields, let alone sustaining the levels achieved. This led into the second stage.

2. Stage two: This coming in from the second and third year or even later, involved introduction of more land management and agronomic options. These include soil cover initially by crop residue mulch and later some legume cover crops in either rotation or intercropping practices; use of organic (composite/kraal manure) fertilizers additional to inorganic fertilizers; and some agroforestry.

The focus at this stage was to enhance the rebuilding of soil structure and replenishment of organic matter and nutrients. This included building the soil's capacity to retain the water now able to infiltrate.

3. Stage three: is mainly about consolidating adoption. One element still an issue at this stage is soil cover, especially use of live cover crops. In the three locations, use of cover crops still has many limitations. These include,
   - What crop to grow and availability of seed for such crops (one critical element in deciding what crop to grow appears to be its (potential) uses – should have some human food value).
   - Management of the cover crop (what time to plant, in relation to the main crop; planting density; "clearing" of the cover crop, etc)

With a November to April rainy season (ie cropping period), Table 5 describes the work patterns through the year for a typical household. The options are described in Table 6.

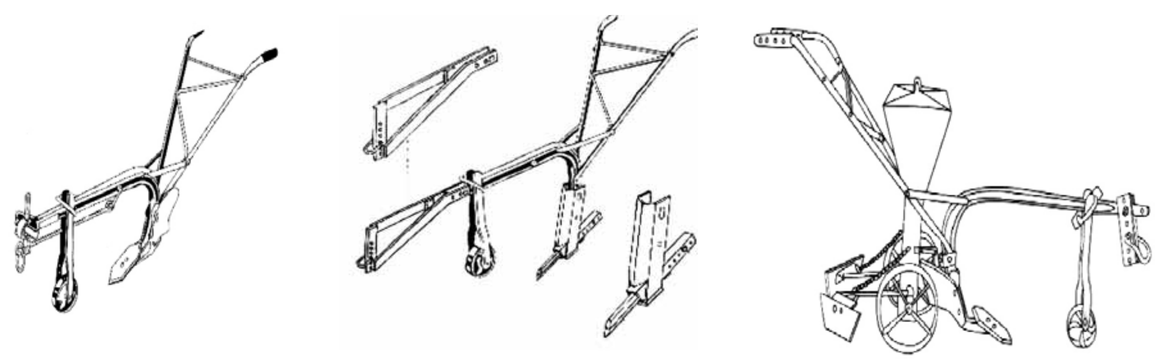
Table 5. Work systems through the year for a typical household.

April to Oct	- Shortly after harvesting, making of basins or ripping starts going on until late October. - Under some social communally acceptable arrangements, livestock is kept away from crop fields or allowed controlled access.
Oct to Nov	- Once the basins or ripped furrows are made, kraal manure and basal fertilizer are applied and slightly covered. Where lime is recommended it is also applied. - Before planting can be done some slashing of grass and crop residue is done (also helpful in weed control)
Nov to Dec	- Planting is done just before the on-set or with the start of rain - In cases of using ripper-planters, the ripping and planting is done at this stage as one operation.
Dec to Jan	- Weeding (hand weeding using a hoe) starts immediately as the weeds begin to emerge and is continued as frequently as desired until crop is big. - Use of herbicides is uncommon. - Relay legume crops (cover crops) eg beans are inter-planted.
Jan to March	- Top dressing fertilizer may be applied. - Weeding may be continued.

Appropriate implements for CA application

Experience in these projects underpinned the importance of access to right farm tools and implements. Basic farm implements available in these communities are the hand hoe and the single mouldboard plough for households with draft animal.

It has, hence, been critical that farmers are availed access to implement options in their quest to decide what/how to apply sustainable farming options. Figure 1 gives some CA related equipment coming up in the region:



Magoye Ripper
- Animal drawn.
- Attachment on the "green" beam.
- Has low angle tine to keep draft and wear of the tine to minimum.
- Used for making planting furrows in unploughed fields.
- Depending on spacing, could go up to 0.5 ha hr^{-1}.

Palabana Sub-soiler (deep ripper)
- Animal drawn.
- Attachment on the "green" beam.
- Used for deep furrowing (up to 30 cm).
- Useful for initial rehabilitation of fields with compacted soils or hard pan.

Palabana ripper-planter
- Same as the ripper, except has a planter attachment as well.
- Allows ripping (ie making of the planting furrows) and planting in one operation (also fertilizing).
- Work rate between 0.15 to 0.25 ha hr^{-1}.

Figure 1. CA related equipment.

Table 6. Range of SWC technologies that have been adopted or tested by farmers in the pilot villages.

Stage	Technological option	Effect of the option	Application of the option	Case example(s)
Transition	Sub-soiling: Basins	Breaking the hard/plough pan and general soil loosening.	Done in the dry season (dry soil) and hence requires more energy, some difficulty for the farmers. Basins are dug using a hoe normally have to go below the plough layer/pan.	Siavonga in Zambia
	Sub-soiling: Ripping/ deep ripping	Breaking the hard/ plough pan and general soil loosening	Households with access to draft animals use ripper or sub-soiler to effect some sub-soiling. Also best done when soil is dry, hence, high energy demands.	Siavonga; Thohoyandou – Limpopo
	Infiltration pits	Effective in capturing heavy down pours.	Dug along the waterways within and on the boundaries of the fields. Fruit tress are later planted in these pits	Masvingo
	No burning of crop residue Controlled grazing	Results in crop residue being available in the field (surface) especially at the on-set of the rains	Based on community interests and agreements. More of a social issue.	Touyaudou-Limpopo
	Stone bunds / earth bags	Disrupt/slow down water flow; hence water is held in the field longer permitting infiltration and hence reduced runoff (erosion control) Effective for rill control/ reclamation	Cheap, conserves soil; may allow water to slip through; Labor intensive; Easily damaged, needs to be combined with another technology.	Polokwane-Limpopo
	Use of manure (composite and/ or animal)	Nutrient replenishment; soil structure improvement; organic matter build-up	Kraal manure: applied in bands on the side of the planting basin	All the sites
	Surface water control features	Initial "holding" of water on the surface to allow infiltration hence reduce flow (erosion)	Vetiver/ Napier grass strips; stone bunds; contours	Limpopo
Introduction	Direct planting (reduced tillage)	Critical to various other elements of CA – no soil disturbance; surface residue.Also eliminates the huge cost of tillage	Multi-purpose, does not produce seeds, easy to propagate Not easily available locally, nursery needs care, not effective in the first two years	Masvingo
	Rotations/intercropping	Soil fertility; allows pest and disease control; crop diversification and incorporation of legumes into the system	Three seasons rotations involving cereal and legumes.	Masvingo
	Soil cover (crop residue mulch)	Soil cover especially at the on-set of the rains	Community level agreements on livestock grazing	Masvingo; Limpopo
Consolidation	Agroforestry	Soil fertility; crop diversification; and organic matter replenishment		Limpopo
	Soil cover (live crops)	Mucuna; *Dolichos lablab*		Limpopo

Results and Discussions

Effects – impact

Scientific assessment of the long-term effects and impact of CA practices on basic soil-water characteristics (related to soil fertility) and ultimately on livelihoods is yet to be done in the project areas. However, what has been largely noted especially from farmers' testimonies have been immediate to short-medium term effects on timeliness, reduction in labor input and indeed better yields at lesser cost.

It is apparent that the risk of farming is reduced as yields stabilize and the impacts of wet or dry years, even of real natural disasters like floods and drought, are measurably reduced. Households applying CA come out more food secure and this is one factor convincing other households to adopt CA.

These benefits also impact on the general rural communities. In Limpopo Province, government provided resources in the early 1990s for "rehabilitation" of gullies. In most cases, the gabions were washed away the very next year or water just moved to begin development of a gully in another place. With the application of CA (Table 7) in a more holistic – catchment – approach, water is not flowing as before and problem of gullies seem to have simply disappeared.

Table 7. Applications of some CA practices among participating farmers in Ward 25, Chivi District, Zimbabwe.

	Number of practicing households		
Technology/ Innovation	2000-2001	2001-2002	% uptake
Strip Cropping	59	73	24
Mulch Ripping	27	38	41
Fanya Juu	25	31	24
Tied Ridging	19	26	37
Infiltration Pits	53	70	32
Composting	63	77	22
Vertiver Grass	63	78	24
Tree Planting in Fanya Juu	5	11	120
Stone Bunds	51	76	49

Some lessons from the interventions

Building farmers' understanding of some basic science to explain why yield (soil fertility) is declining or can decline is one critical starting point in empowering farmers as innovators and partners in the development of technically, socio-culturally, and ecologically appropriate farming practices. Some basic science aspects covered were,

1. Tillage – why tillage? short/long-term impacts/implications (cost, effect on soil quality, etc).
2. Natural processes related to crop production (water cycle, nutrient cycle, etc).
3. Why soil cover?
4. How do rotations effect soil quality and crop yields?
5. What is soil organic matter; how does it affect plant nutrient availability and soil moisture?

Although interpretations and definitions vary, and probably rightly so, the term "Conservation Agriculture" is generally understood as the 'way' of farming defined by the following principles,

- Direct seeding, ie reduced or no tillage.
- Maintenance of soil cover (live or dead vegetal material on the soil surface).
- Water harvesting and retention.
- Crop rotations (intercropping).
- Soil organic matter replenishment.

It is important in CA promotion work to allow farmers to first explore their own ways to apply these principles. Two factors are crucial here,

- It may not be feasible to introduce application of all the principles at once. Farmers should be allowed to select the most feasible and viable "entry point". This may vary even between two neighboring households. It is always important to "enter" at the point with the minimum risks to the farmer/household.
- There would be several options to attain and one principle and, hence, the most appropriate option would have to be ascertained by in-situ trials.

The multi-disciplinary approach in this intervention also underlined the fact that sustainable agriculture development is an integral component of general economic development and calls for a holistic and systems approach. All agricultural development strategies and activities, whether in agronomy, soil science, mechanization, etc must be compatible in order to synergistically interact in such a way as to conserve, minimize degradation or better still enhance the resource base.

What is new/different in the new thrust

The following are some of the factors raised as characteristically different in this thrust,

- Increasing acknowledgement that soil is more than just a medium for crop production.
- Done in the context of reduced/no tillage.
- Rainfall systems and patterns different now than two decades ago.
- Holistic and integrated approach including collaborations/partnerships.
- On-farm (in-situ) development-adaptation of technologies.
- New farmer and extension staff roles and responsibilities.

Challenges to the adoption of CA in intervention areas

Experiences in promoting CA in smallholder dryland farming systems in the three communities has highlighted a number of factors (both in technical options/practices and in dissemination strategies/approaches) which would be important,

- Africa (farmers) has to "internalize" the concept of CA that is defined and understood within the context of the climatic, physical, socio-economic and cultural factors unique to the area/peoples.
- Adoption of CA calls for radical adjustments among all players and stakeholders (not just farmers) (will need direct interventions and incentives).· Taking care of long time needs and concerns while being mindful of immediate welfare/relief needs of farmer-rural communities.
- Relating CA to human development goals – poverty reduction, food security, mitigating the effects of HIV-Aids.

- Awareness on possible options and technologies to address the problem – Even after having been aware of the adverse effects of tillage on the soil in addition to its huge costs, many smallholder farmers in the communities have come to view ploughing (complete soil disturbance) as a necessary evil as there are not aware of any alternatives. Therefore, relevant and appropriate information support and exposure would greatly induce and motivate farmers to “venture” into alternative systems.
- Allow time.

Challenges at application – adoption level

- Develop farmer ownership of process and outputs.
- Mitigation of the risks/opportunity cost in the short term that farmers have to take up in adopting CA.
- With the level of degradation on most arable fields, an elaborate transition is inevitable in setting the “stage” for effective application of “CA” practices.
- Technical options – Soil cover especially in arid-semi land.
- Ensure that options are available for weed control.
- Appropriate implements/tools.

Factors to be taken into account to realize widespread adoption

- Character of agriculture – Still largely driven by subsistence aspirations; large in numbers of household units, but with small (under 1 hectare) plots per household. This is important in understanding basis and rationale for farmers’ decisions to adopt or not to adopt.
- Awareness and appreciation of the problem – It is critical that the process is based on a solid and genuine awareness and appreciation of the “problem/s” and related causes by a critical mass of stakeholders. Central to this are the farming communities.
- Identify and be sensitive to issues of compatibility or conflicts of new practices with existing cultural habits and traditions. It is best to allow the farmers deal with them.
- Farmers’ accessibility to necessary inputs, key here has been seed, farm power sources and related implements.
- Public good and public sector commitment – Important element in ensuring supportive policies for CA and financing.
- Crop-livestock integration – Communal grazing has generally tended to limit the adoption of mulch-tillage-systems in the smallholder sector.

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Increasing research impacts through low-cost soil fertility management options for Africa's drought-prone areas

John Dimes[1], Steve Twomlow[1], Joseph Rusike[1], Bruno Gerard[2], Ramadjita Tabo[2], Ade Freeman[3] and JDH Keatinge[4]

Abstract

Soil fertility depletion on smallholder farms has been identified throughout Africa as the fundamental biophysical cause of declining per capita food production. The overriding cause of this low productivity is a lack of investment in soil fertility by smallholder farmers, especially investment in inorganic fertilizer. The low adoption of improved fertility management methods is attributable to several reasons, including (a) inappropriate recommendations that fail to consider rainfall risks, capital and resource constraints or marketing costs faced by smallholder farmers, (b) blanket recommendations that overlook the variability of farming objectives that typifies smallholder farming systems and (c) inappropriate marketing of fertilizers to smallholder farmers.

International Crops Research Institute for the Semi-Arid Tropics and other International Research Centers and National Agricultural Research and Extensions Services have been developing strategies to encourage farmer investments in fertility management through a program that includes farmer participatory research, risk analysis using crop systems simulation and market linkages. The focus of this research has been low rates of inorganic fertilizer, either alone or in combination with animal manure. This paper introduces the rationale for promoting small doses of fertilizer to resource-poor farmers; presents simulated and on-farm results testing low rates of fertilizer, and describes market developments that help smallholder farmers in dry regions better access inorganic fertilizer.

Introduction

Soil fertility depletion on smallholder farms has been identified (Sanchez et al. 1996; Keatinge et al. 2001) throughout Africa as the fundamental biophysical cause of declining per capita food production. Even in semi-arid regions it is more often insufficient nutrients and not rainfall that is the primary constraint to increased production in smallholder farming systems. (Hilhorst and Muchena 2000; Dimes 2002). The current situation exists despite the release and relatively widespread uptake of improved crop varieties. The overriding cause of the low productivity in African agriculture is a lack of investment in soil fertility by smallholder farmers. Use of inorganic fertilizer is almost non-existent (a mere 8 kg ha^{-1} in sub-Saharan Africa compared to 100 kg ha^{-1} for the World, 120 kg ha^{-1} for Asia and 70 kg ha^{-1} for India alone) and farmers with access to manure commonly do not use it on their croplands because of its poor quality and/or labor shortages for handling (Probert et al. 1995; Ahmed et al. 1997).

There are several reasons why adoption of improved fertility management methods has been poor in Africa. Firstly, small-scale farmers have largely ignored official recommendations promoting near-optimal inputs of fertilizer application and virtually none use the recommended

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levels of application (Table 1). Typically, recommendations fail to consider rainfall risks, capital and resource constraints or marketing costs faced by smallholder farmers. Consequently, the suggested application rates are too high and therefore too expensive and too risky, especially in more drought-prone regions. Nor do they account for the variability of farming objectives that typifies smallholder farming systems, especially the focus on food security with limited resources and minimal risk and the relative returns and returns of other investment options available to the farmer compared to that for fertility investments. Moreover, inorganic fertilizer is rarely available in local markets (Manyong et al. 2002). As a result, adoption rates are low, grain yields and per capita food production are declining and food security is worsening, particularly in Africa's extensive semi-arid areas (FAOStat 2001).

Table 1. Typical fertilizer use in sub-Saharan Africa (data for Zimbabwe SAT, Rusike, unpublished data).

	% of farmers using	Application rate (approx)	Recommended rate
Inorganic fertilizer	5	50 kg ha^{-1}	250-350 kg ha^{-1}
Manure	40	4 t ha^{-1}	20-40 t ha^{-1}

Since the early 1990s, scientists from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in collaboration with other International Research Centers and National Agricultural Research and Extension Services (NARES), have been developing strategies to encourage farmer investments in fertility management through a program that includes farmer participatory research, risk analysis using crop systems simulation, and market linkages (Rohrbach 1999; Muehlig-Versen et al. 2003; Rusike et al. 2003). The focus of this research has been low rates of inorganic fertilizer, either alone or in combination with animal manure. This paper introduces the rationale for promoting small doses of fertilizer to resource-poor farmers, presents simulated and on-farm results testing low rates of fertilizer, and describes market developments that help smallholder farmers in dry regions better access inorganic fertilizers.

Re-interpreting soil fertility recommendations

The underlying problem of existing fertilizer recommendations given to resource–poor farmers is illustrated in Figure 1. The recommendations are generally too high, being aimed at agro-climatic production optima that are realistically only affordable by the wealthiest of farmers. Farmers' application rates generally lie at the lower end of the response curve (Figure 1), reflecting their limited resources to invest and risk management perspective since the highest marginal returns are at the lower input levels. Hence, lower recommendations are more likely to be adopted by farmers in the first instance because they are more affordable, and in the case of drier regions, the higher marginal returns offset the risks of poor crop yields due to inadequate rainfall. Hence, lower rates will increase the likelihood of positive outcomes from farmer experimentation, thereby encouraging further investment in the technology (ie, moving to higher application rates or purchasing other types of fertilizer).

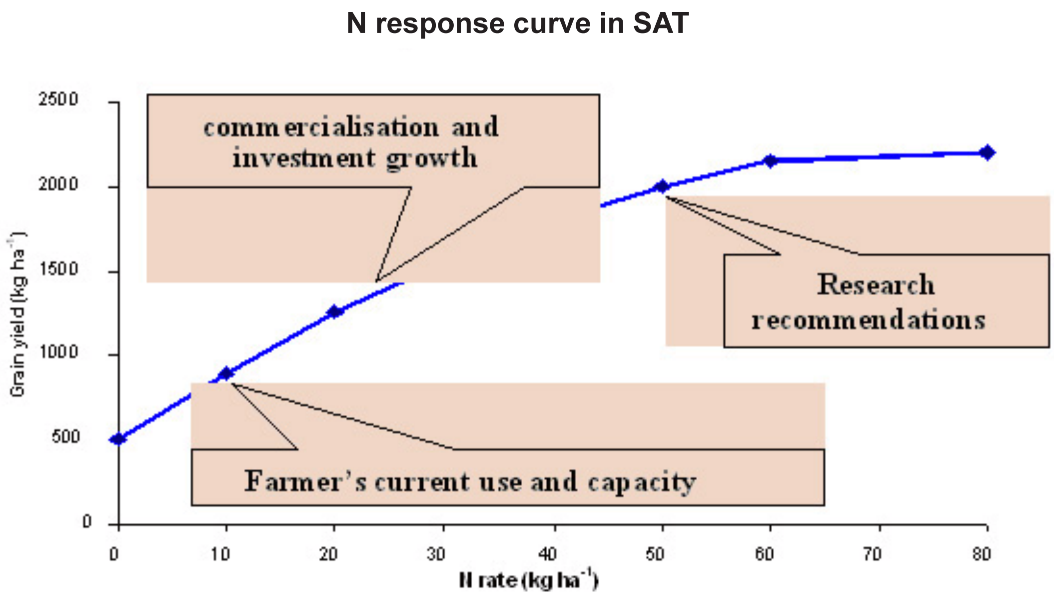


Figure 1. A typical fertilizer N response curve in relation to researcher recommendations, existing capacity of smallholder farmers to invest, and growth path for increased use.

Quantifying climatic risk of fertilizer options using simulation modeling

Simulation models provide a means to test, without expensive and time-consuming field trials, the risk and returns to various rates of fertilizer application across seasons and locations. These tools are increasingly being used to analyse a range of crop fertility management issues in African smallholder farming systems (Keating et al. 1991; Thornton et al. 1995; Shamudzarira et al. 1999; Bontkes and Wopereis 2003). Figure 2 shows the results of a simulation analysis of maize grain yield in the drought-prone Masvingo province of Zimbabwe in various years (using historical rainfall data) under various fertilizer application rates. The simulation tool used in this case is Agricultural Production Systems Simulator (APSIM) (Keating et al. 2002).

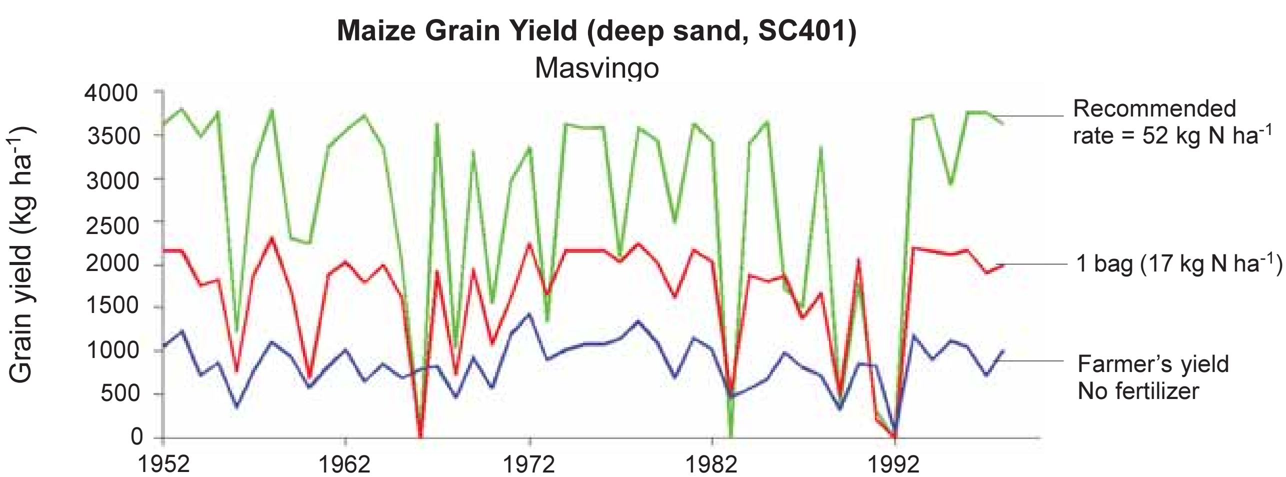


Figure 2. Simulated maize yield (cultivar SC401) on a deep sand soil at Masvingo, Zimbabwe, for climate records 1952 to 1998 and N inputs of 0, 17 and 52 kg N ha^{-1}.

With no fertilizer inputs, simulated yields reflect the current low levels obtained by farmers, while the addition of only 1 bag ha^{-1} of ammonium nitrate fertilizer (17 kg N ha^{-1}) is sufficient to double yields in most seasons. Application of the recommended fertilizer rate (3 bags ha^{-1} or 51 kg N ha^{-1}) can substantially further increase yield in some seasons, but the additional response is very uncertain compared to that for the lower application rate. These results provide illustrative rationale for researchers and extension agents to re-align fertilizer recommendations for drier regions lower down the nitrogen response curve (Figure 1) in order to match farmers' investment capacity and risk aversion.

Applying simulation in combination with economic analyses (in this case a partial budget) and across agro-ecological regions can provide further insights into the spatial applicability of fertilizer recommendations. Table 2 shows the Zimbabwean Dollar ($Z) return in maize grain production per $Z invested in N fertilizer (2000 prices) for simulated crops on a deep sand at Harare, Masvingo and Beitbridge comparing 1 bag ha^{-1} (17 kg N ha^{-1}) and the recommended rate of 3 bags ha^{-1} (51 kg N ha^{-1}). For the high rainfall zone (Harare), returns on fertilizer investments are high ($Z8-9 per $Z invested) and stable (data not shown) with slight difference between the recommended and lower rate of application. For the drier cropping region (Masvingo), the expected returns decrease relative to the wetter zone and there is a much higher return for the low rate (Z$7.6 per Z$1) compared to the recommended rate (Z$5.8 per Z$1). In the case of Beitbridge, there were a few years where simulated yield showed a good response to N fertilizer but for most years, there were no yield advantage to N application (data not shown). Consequently returns on fertilizer investments are extremely variable, with many years showing losses on the invested capital at this location. The average return on investment in this environment was low for both fertilizer application rates, but still more favorable for the low rate.

Table 2. Benefit-cost ratio of N fertilizer applications to maize in 3 cropping regions of Zimbabwe.

Location	Annual rainfall (1951-91, mm)	Benefit-Cost ratio (Z$ return/Z$ invested, average based on 40 years of simulated yields)	
		Low N rate (17 kg N ha^{-1})	Recommended N rate (52 kg N ha^{-1})
Harare	860	9.1	8.2
Masvingo	650	7.6	5.8
Beitbridge	340	2.6	1.1

Performance of low rates of fertilizer under farmer conditions

Analysis using a simulation approach can provide indications of the potential profitability and risk of using inorganic fertilizer in drought prone regions but there is an important caveat that applies to these results – they do not always include important agronomic factors (weeds and pests, other nutrient deficiencies, soil physical properties) or household resource constraints (capital, labor and draft power) that influence the efficiency of fertilizer use under farmer management conditions. In western and southern Africa, ICRISAT and partners have been using farmer participatory research to test low rates of fertilizer and animal manures

Materials and Methods

The work reported in this paper concentrates on examining the profitability of low rates of N or P fertilizer, either alone or in combination with manure in the drier regions of Zimbabwe and Niger. Farmers were provided fertilizers (to apply on 200 to 600 m^2 plots) and seed for improved pearl millet, sorghum or maize varieties and legumes (groundnut, cowpea). The on-farm trials were managed by farmers and varied from simple paired plots (local practice versus fertilizer amendment) to a set of 5 treatments. In all cases, the on-farm trials are un-replicated and individual farm treatment results have been used as replication for statistical analysis. The treatments tested by farmers differ significantly according to the objectives pursued in the two regions (Table 3). In southern Africa, the treatments tended to focus on alternative investment choices for use of inorganic fertilizer in the cropping system, whereas in West Africa, the research has retained a balanced nutrient focus for cereal production.

Table 3. Type of on-farm soil fertility trials implemented in southern and West Africa.

Trials conducted in southern Africa	Trials conducted in West Africa
1. Low N x weeding interactions	DAP and NPK at low rates (4-9 kg nutrient ha^{-1})
2. Farmyard manure with and without 9 kg N ha^{-1}	Topdressing DAP with Urea at low rates
3.N response curves starting at 10 kg N ha^{-1}	Topdressing NPK with Urea at low rates
4.Low rates of inorganic P (5 kg P ha^{-1}) for legumes	
5.Differing P sources for legumes (NPK, SSP, manure)	

Results

On-farm experimentation with farmers in drier regions of Zimbabwe has confirmed the profitability of low rates of N fertilizer, either alone or in combination with manure. In fact, trials conducted over two seasons in Shurugwi, Zishavane, Beitbridge, Gwanda and Mberengwa on heavy and light textured soils, clearly showed little increase in crop response to N fertilizer top dressing beyond 30 kg of Ammonium Nitrate (AN) per ha, the equivalent of only 10.5 kg N ha^{-1} (Figure 3). The return on investment at this level for these farmer-managed trials was as high as Z$10: Z$1 (D Saunders, pers. comm.).

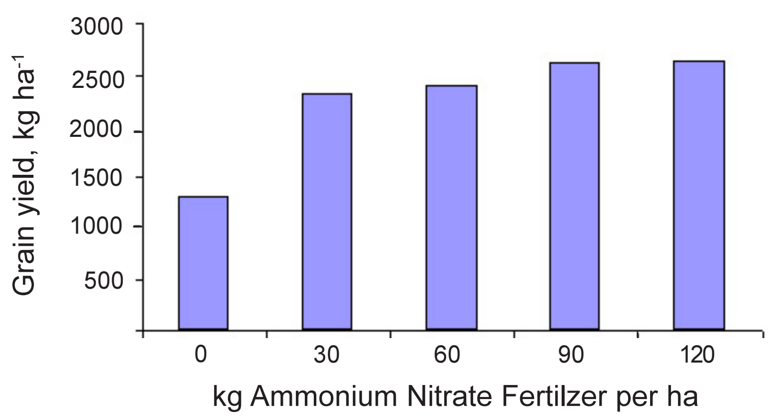


Figure 3. Response of maize to increasing levels of N fertilizer in dry areas of Zimbabwe (mean grain yields across 9 sites in 1999/2000 and 2000/2001 cropping seasons. Source: SDARMP project).

In Niger, the results of micro-dosing trials have been similarly dramatic in increasing grain yields (Figure 4). Across a wide range of farmers and agro-ecological environments, the average yields were higher in all treatments where fertilizers were applied using the micro-dosing technology (Table 4). However, the significant difference ($p<0.05$) in yields was found only between using the DAP alone and the control. Other treatments such as the treatment 'DAP and side dressing with Urea' or the NPK alone where not significantly different from the control.

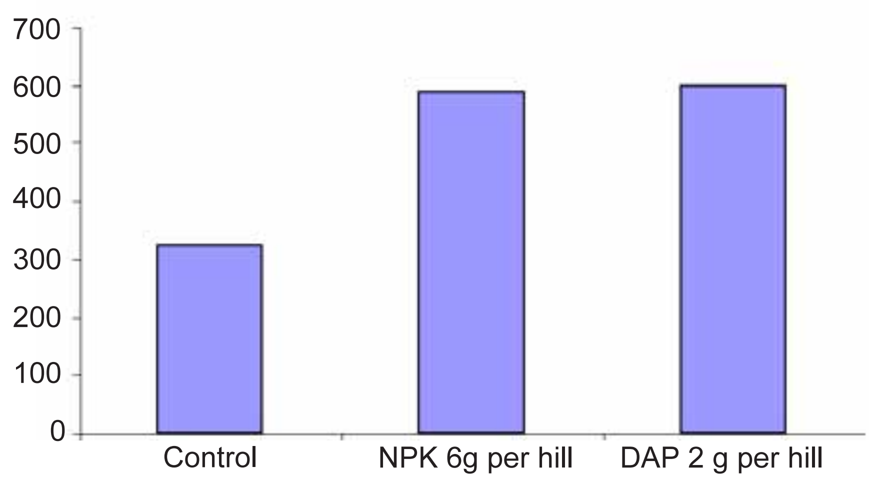


Figure 4. Millet grain yield response to hill placement of fertilizer in Niger (mean response of 406 on-farm trials between 1999 and 2001).

Table 4. Millet yield by treatment in on-farm demonstrations as reported by farmers in Niger.

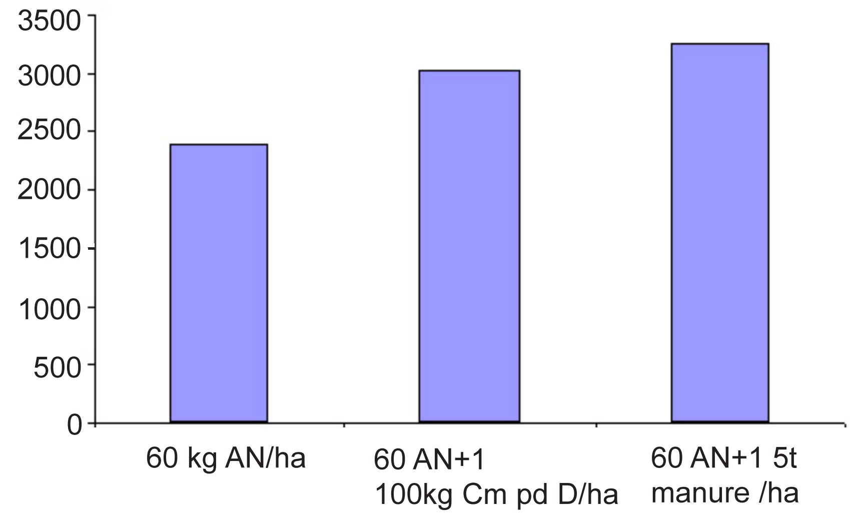
	No of farmers	Mean	Std	Std error	Minimum	Maximum
Control	86	453	523	56	0	2260
DAP	132	735	644	56	0	2400
DAP+UREA	25	593	603	121	0	2100
NPK (15-15-15)	33	574	598	104	0	1975

Animal manure is a source of both N and P and a majority of smallholder farmers in dry regions have access to this resource. On-farm experimentation in Zimbabwe has shown that farm-yard manure can be used as a replacement for basal fertilizer, and at rates of application in line with the amounts typically available on smallholder farms (Figure 5a). Increasing the responses to manure can be achieved when a small top dressing of N (1/2 bag of AN or 9 kg N ha^{-1}) is applied at the 5 to 6 leaf stage of cereal crops and this benefit can be seen even in seasons of severe moisture stress as occurred in 2001/02 in Zimbabwe (Figure 5b).

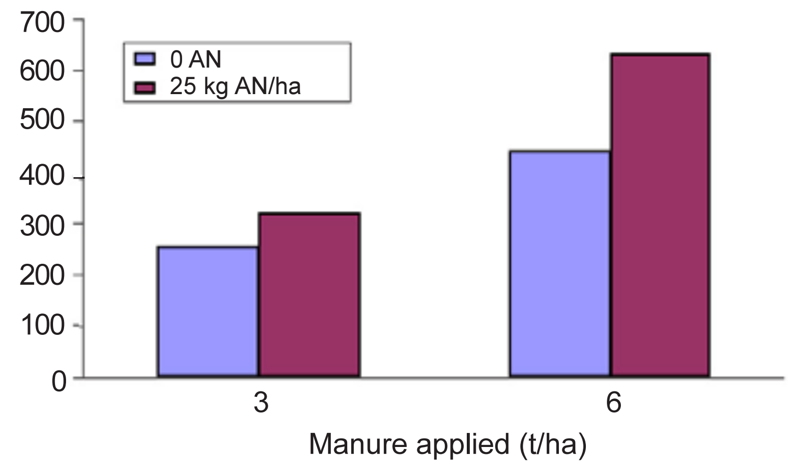
Market linkages

Small packs of fertilizer

ICRISAT research programs have begun work with retailers and non-government organizations throughout Africa to package and sell fertilizer in smaller bags rather than the standard 50 kg bag,



(a) Mean response at 9 sites in 99/00, 00/01



(b) Tsholotsho, 01/02

Figure 5. Grain response of maize to combinations of AN fertilizer with (a) P fertilizer sources: Compound D and manure, (b) 2 rates of applied manure (Sources: SDARMP and ICRISAT-Bulawayo).

to enhance rural retail sales. In Kenya, it has been demonstrated that fertilizer use can be dramatically increased simply by selling it in small packs (Freeman and Omiti 2003). In Zimbabwe, ICRISAT has pilot tested marketing of small 20 kg packs of fertilizer through rural retailers in the marginal rainfall areas during the 2000/01, 2001/02, and 2002/03 cropping seasons. Traders were selected from business centers within the neighborhood of Farmer Field schools; trained in fertilizer product knowledge, handling and storage, demand forecasting, inventory control and cash flow management; and supported to sell on consignment, small packs of fertilizers. With a good start to the season and information dissemination through Farmer Field Schools, traders made good sales, demonstrating that there is a demand for fertilizer by small-scale farmers in dry areas.

A survey of 50 households that purchased fertilizers from the rural retailers conducted at the end of the 2001/02 cropping season showed that most of the farmers bought fertilizers because they were convinced that it improves yields and they had learnt about this while conducting trials. Farmers purchased fertilizer from experimental retailers because they were within walking distance, credit sales were offered, fertilizer was not available in other shops, transaction costs were low and farmers had seen the fertilizer there and decided to purchase it. Farmers found out that fertilizer was available through community meetings and gatherings, local shops, extension agents and the radio. We are gaining the view that farmers face a severe information constraint in judging the marginal costs and returns of fertilizer, and that they are undervaluing the returns to small quantities of fertilizers.

Support for agro-dealers

Small-scale village traders are often the farmers' main source of information on fertilizer use. To strengthen the small-pack program, the project provides training to agro-dealers located in areas where on-farm experiments are being run. This training (implemented by NGOs and supported by Rockefeller) has included information on fertilizer type, methods of application and application rates. Private fertilizer companies working with the project give traders fertilizer on credit, where formerly they had to pay cash down. The result – traders are more willing to stock and promote small-pack fertilizer and more knowledgeable about application rates and methods. Farmers benefit from better availability and better information.

A survey of 220 rural traders was carried out in Zimbabwe to assess opportunities and constraints to targeting the delivery of new agricultural technologies, advice, credit and marketing services through dealers in order to increase smallholder technology adoption, productivity, incomes and food security. The study found that most rural traders are family businesses owned by retired civil servants. The businesses focus on fast moving consumer goods. About half are engaged in the sale of farm inputs: seed, farm equipment and spare parts. The study identified that to expand rural trader participation, traders need to improve their inventory management and offer credit to farmers and manufacturers need to deliver the inputs and offer better trade credit, discounts and technical support.

Warrantage and credit schemes

Few subsistence farmers have the cash to buy fertilizer and credit is very rarely available. In West Africa, ICRISAT is collaborating with the FAO's *Project Intrants* to promote *warrantage*, an inventory credit scheme that facilitates farmer involvement in market trading. In this scheme, farmers pool their surplus harvest product and store it at local grain storage facilities provided with FAO support. Farmers can add to this pool by buying additional grain at harvest when prices are low. The grain is stored during the dry season and sold as the new season approaches and grain prices are rising. The farmer groups then use the profits to buy fertilizer. Recent survey results indicate that about 42% of the farmers that have participated in ICRISATs micro-dosing trials have obtained fertilizers on credit or cash through input shops designed and implemented by the Projet-Intrants.

Conclusions

Results reported here present initial evidence that low fertilizer rates provide smallholder farmers with affordable and profitable fertility options for increasing food production in drought-prone regions. Importantly, and perhaps surprisingly to some, the on-farm trials have clearly demonstrated that response to very small amounts of fertilizer are measurable, even under farmer conditions (Figures 3 and 4). However, as stated earlier, and as shown in Table 4 for West Africa, household resource constraints can influence the efficiency of fertilizer use under farmer management conditions and pose challenges for promoting the technology. Broad-scale testing of the technology in southern Africa is currently underway in conjunction with NGOs (eg, COSV in Hwange, Zimbabwe). This program is designed to implement more appropriate trial design for testing small doses of fertilizer, conduct farmer training and closer monitoring of farmer management as means of overcoming these challenges.

A further concern is the sustainability of such low levels of fertilizer, especially when only a single nutrient is being promoted (and adopted) as having the highest payoff for farmers severely limited investment capacity. But this concern must be counterbalanced by the reality that existing low levels of fertility investment by smallholder farmers is even more damaging to the sustainability of the soil resource, and in turn, farmer livelihoods.

These concerns aside, the soil fertility research reported in this paper is a move away from the traditional approach of seeking bio-physical 'optima' as a basis for recommendation. Instead, this research has started to explore technology options that allow farmers with limited resources and in risky environments to achieve the next increment in productivity. Hence, this approach has a focus on incremental change and a basket of options rather than optimal solutions. An important part of this has to do with how research questions are formulated. For example, traditional fertilizer research asks: how much fertilizer should a farmer apply to maximize yield? We ask a different question. If the farmer can afford only a small quantity of fertilizer – how should this be used (what kind of fertilizer? applied to which crop? how and when?) to maximize returns on this investment?

Key to this approach has been the participation of farmers in testing and evaluating the technology options and the use of crop simulation modeling and economic analysis to quantify climatic and market risk for a range of biophysical and management conditions. A further important aspect has been the linking of technology development to market development, with the view that farmers can only be encouraged to invest in fertility management if the knowledge and products are available at an affordable cost and output markets are accessible to provide the investment incentive.

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Water harvesting for increasing rainwater productivity and combating land degradation: The case of North Kordofan State, Western Sudan

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Abstract

Fundamental constraint limiting both agricultural and livestock production for traditional producers in Kordofan region of Western Sudan is an insufficient and at times inappropriate use of their resource base.

Location wise, large parts of Kordofan lie in the arid and semi-arid zones and its northern parts border the Sahara Desert. Consequently, the region is subjected to the menace of droughts. Rainfall is characterized by high variability and recurrent droughts; the water balance is in deficit except only in August.

The main impacts of droughts and desertification are reflected in the following: decline in soil fertility, low crop productivity, deterioration of rangeland and forest areas, decline in under ground water and movement of sand dunes.

The region is dominated by sedentary cultivators and nomads. Although most of the people practice a mixture of several different land use types; four main land use types can be distinguished:

- *Small-scale rain-fed cultivation: This is of mainly millet, sesame, groundnut and roselle on sandy soils. Sorghum cultivation is practiced on more fine-textured soils. Crop cultivation is mainly practiced as shifting cultivation with tree fallow. The famous one is Acacia senegal-bush fallow on sandy soils.*
- *Gum Arabic production from Acacia senegal. The tree is the most appreciated species not only for gum Arabic but also for its ameliorative effects on soil fertility and provision of fuel wood, building materials and livestock feeds.*
- *Livestock rearing; mainly camel, cattle, sheep and goats by traditional nomadic groups; cattle and sheep by commercial nomadic groups; and domestic animals, mainly cattle and goats by the sedentary cultivators.*
- *Tree rotation: is shortened as no more land is available to perform such a system; continuous cultivation of the same fields has become a common practice. This has led to the decline in land productivity. Food production is affected by overused sandy soils and the problematic sandy clay soils with their hardpan and crusty surface. The erratic rainfall, which falls in storms, is lost as high volume runoff.*

When considering the environmental damage that had inflicted the region as a result of successive droughts, deforestation, overgrazing, and the current extensive use of the resource base to meet the needs of growing population, the sustainability of this system is questionable. Desertification has been seen as caused by over-use (through grazing and cultivation) of nutrient-poor soils in a hot, arid climate. This over use of soil without adequate fallowing causes erosion of soil and the invasion of sand, as well as the changes of species composition of rangelands with less nutritious annual species increasing in relation to more nutritious perennial species. This has dictated the need for a rational approach to tackle the problems of food shortage and land degradation, through the application of rainwater harvesting and to demonstrate its' potential benefits to land users.

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This paper highlights the efforts of Land & Water Research Stations at El-Obeid Research Station in dealing with the problems of rainwater productivity, through measures, which are targeting a rational use of land and water and spreading them among farmers.

Water harvesting is a cornerstone in our endeavors to increase water productivity. In situ water harvesting is irrelevant in an area with rainfall less than 400 mm; the only choice here was micro catchments. A system of parallel earth bunds was constructed along contour lines. The distance between the earth bunds was 15 to 20 m according to slope gradient. The minimum 1:1 catchment's area was observed to induce runoff. Characteristics of the catchment's area play a major role in the volume of runoff. A bare soil has a coefficient that differs from those of cultivated areas. Considerations have to be given to those characteristics of the catchment's area and also other elements of agronomic practices. Early maturing varieties have been used; optimum plant population, timely weeding and thinning were observed.

The results of these efforts revealed that food production could be increased through water productivity by water harvesting and agronomic practices. Disseminations of those efforts were essential. In that context, educational plots have been implemented with full participation of farmers.

Results revealed that with water harvesting, yield could be tripled and even quadrupled compared to traditional cultivation. This will certainly lead to more environmentally sound practices and the release of the more degraded sandy soils which are depleting the process of crop cultivation and also the farmer could concentrate more in a limited, but highly productive land. Land degradation caused by over using of the impoverished sandy soils will be alleviated.

Introduction

A fundamental constraint limiting both agricultural and livestock production for traditional producers in Kordofan region of Western Sudan is an insufficient and at times inappropriate use of their resource base [El-Obeid Agricultural Research Station, 1998]. This has dictated the need for a rational approach to tackle the problems of food shortage and land degradation.

Location wise, large parts of Kordofan lie in the arid and semi-arid zones and its northern parts are bordering the Sahara Desert, (Harrison and Jackson, 1958). Consequently, the region is subjected to the menace of droughts, desertification and desert encroachment.

(Sudan Meteorological Department Reports, 1960-1990). The northern parts of the region lie in the desert and semi-desert, the central parts in the low rainfall savanna and the southern parts in high rainfall savanna. The soil varies from sandy and non-cracking sandy clays in the north and the west to cracking clays in the south [M.Bakhet Said, A. Babiker, 1975]. The population of the region is 3.75 m (Sudan National Census, 1993) of which 63% is rural, 24% nomads and 13% urban. Animal population is estimated at 4.5-5 m animal unit.

Land use

Rainfall varies considerably over the extensive area of the sandy soils. The area covered by the sandy soils can be divided into three zones:

- The northern zone with rainfall less than 250 mm. This zone is usually used by nomadic pastoralists.
- The central zone with rainfall ranging between 250 and 400 mm. This is a cropping zone and the main crops grown here are sesame (*Sesamum orientalis)*, millet (*Pennisetum typhoidum*), sorghum, groundnuts and rosella.

- The third zone with rainfall between 400 and 500 mm and with cracking clay soil. Main crops are cotton, sorghum and sesame. Area wise, this zone is very limited.

Crop cultivation is mainly practiced as shifting cultivation with tree fallow. The famous one is gum Arabic (*Acacia senegal*) - bush fallow on sandy soils. With the increase of food need and the decline of gum Arabic prices, farmers are compelled to deviate from this practice and tend to cultivate the same piece of land more frequently. As no more land is available to perform such a system, the tree rotation is shortened; continuous cultivation of the same fields becomes a common practice. This has led to declined land productivity and food production (Olsson 1983). The removal of the tree component subjects the sandy soils to serious translocation and rapid degradation.

The ability of the sandy soils to supply plant nutrients was very much affected by the removal of tree components, which are the main sources of organic matter. Over cultivation with the decrease of rainfall in recent years has no doubt resulted in increase in wind erosion, encroachment of the desert on arable land and consequently food insecurity . The problem of drought and desertification has deep roots in Kordofan since the early 20th century [Darag A.1984]. Over the years the region's natural resources have been subjected to serious deterioration as a result of poor investment and management of land resources. The negative impacts of overgrazing, seasonal fires; deforestation and expansion of cultivation on marginal lands are further aggravated by the recurrent droughts that have been hitting the region since 1945. Bare soils often with no vegetative cover, devoid of finer particles and blowing sands that accumulate around nearby shrubs are common features, [DECARP, 1976].

Constraints to crop production on sandy soils

- Water Scarcity. Unreliable rainfall.
- Low soil fertility: The sandy soils are easy to cultivate and much of the traditional production activities are on those soils. However, decades of cultivation without soil amendments and crop rotation have depleted the soils.
- Poor crop husbandry.

The alternative was to explore the other soil types such as sandy clay soils, which are thought to have good agricultural potentialities (higher water holding capacity and good fertility status) compared to sandy soils to alleviate the problem of food production. These soils have their constraints also, which include a hard structure and a sealed surface that renders it a low infiltration rate but at the same time conserves soil and water.

Objectives

Improvement of the physical characteristics of sandy clay soils through;

- Reduced tillage.
- Use of water harvesting techniques as means of collecting runoff and enhancing water infiltration rate into the soil.
- To demonstrate the effect of the technique of reduced tillage (chisel) on soil water conservation and the increase of rainwater productivity.
- Increase food security through the increase of sorghum yield in sandy clay soil.

- To demonstrate that this technique is suitable for the sandy clay soil if accompanied with other sound treatment practices.
- To disseminate the results among farmers.
- Reaching full participation of communities in conservation, management and sound utilization of the natural resources and environmental conservation, [El-Obeid Agricultural Research Station. 1984-2002]

Materials and Methods

Sandy clay soils have a finer texture and the clay content varies from about 10 to 30%. They are believed to have a better potential for water and nutrient retention and therefore, a higher productivity potential than that of the sandy soils. Physical conditions are conducive to low water intake and rapid water losses through runoff and evaporation and these soils are very hard when dry and difficult to cultivate and have a very low infiltration rate. As a result, much of the rainwater is lost as runoff. The surface appears to have been eroded. Vegetable growth is sparse due to high mechanical impedance and lack of moisture, [Research programme for Kordofan Region, 1984].

The trials were conducted in three villages of North Kordofan state. Each represents a replicate, with farmers' total participation. Farmers have contributed with an area of one hectare. Each was divided into sub-plots representing the traditional method of cultivation and the improved technical package included:

- Reduced tillage to open the hard pan and alleviate surface sealing, a one-passage chisel plow to the depth of 25 cm. These sandy soils tend to seal off very rapidly.
- Traditionally, farmers till or better scratch the land only superficially with hand tools. With the first rains the soil surface becomes crusty, resulting in run-off and high losses of precious rainwater.
- Tested rainwater harvesting techniques consist of parallel earth bunds, about 40 cm high and built at 20 m distances. The upper half of the strip in between bunds serves as run-off area and the lower half is planted with Sorghum. Sorghum was planted in rows ripped by a chisel or tine. Outlets for excess water were placed to ensure even water distribution. The inner side of the earth bunds were planted with cowpea or groundnuts and Roselle so as to protect the earth bund from being washed out and as a source of additional food and income generation measures, [alfadni-1998-2001].
- Crop husbandry farmers used to observe poor crop husbandry measures. Therefore, it was very essential to demonstrate improved measures; spacing was 50 cm x 50 cm. against 1 m x 1 m as farmers practice. Timely thinning and weeding were also observed.

Data collected

- Establishment %
- Plant Height
- Production: Grain yields
- Rainfall. Averages of 1998,1999,2000 and 2001

Results and Discussions

The 4 rainfall seasons were a good representation of rainfall characteristics of Western Sudan, with 2 seasons below average, one above average and one average. Rainfall was between 150 mm and 600 mm. The last 30 years average was 340 mm.

Plant growth and establishment

Table 1 indicates significant differences in crop growth and establishment, $P < 0.01$, among treatments. One of the main constraints of crop production here is the erratic and unreliable rainfall, which has had an impact on crop establishment at the start and during the cropping season. It also affects plant growth during the season. Traditionally plant height varies significantly due to uneven moisture distribution and periods of dry spells.

Grain production

There was a significant increase in heads production (186%) which was 84% for the earth bunds + reduced tillage treatment while it was only 45% for the traditional treatment (Table 1). Grain yield was 553% higher in the earth bunds + reduced tillage treatment than in the traditional (control) treatment ($P < 0.01$).

Table 1. Effect of water harvesting techniques and reduced tillage on Sorghum.

Treatment	Establishment	Plant height (cm)	Heads(%)	Production (kg ha^{-1})
Reduced tillage+ earth bunds	93.333	102	84.667	1516
Reduced tillage	83.333	95	73.000	1030
Earth bunds	78.000	63	61.667	540
Traditional (control)	62.000	66	45.667	253
Lsd	17.582	30.232	9.788	323.283

Source: Alfadni, 2001

Food security

Food security status was displayed in Table 2. The total need for food is about 100,000 tons while the actual food production was about 18,000 tons produced from an area of 500,000 ha, [North Kordofan Food Security and information system 2000], which were mainly the fragile and poor sandy soils. Water harvesting with only one-fifth of that area could achieve food security and at the same time release the sandy soils and contribute to soil conservation.

Conclusion

The results give a good indication of the merit of using the water harvesting technique to gain high crop production, even though rainfall was lower than the average, which means that the farmer could escape crop failure by adopting the technique.

Table 2. Food Security status in North Kordofan with the traditional cultivation and water harvesting techniques.

Year	Traditional					Water harvesting + reduced till(average 4 years)		
	Area(ha)	Prod.(t) (kg ha^{-1})	Productivity	Need(t)	Deficit(t)	Productivity (kg ha^{-1})	Assumed area(ha)	Production
1998	200	14000	56	49	35	1000	100	100000
1999	250	11000	40	55	44			
2000	210	26000	40	55	29			
2001	300	23000	48	60	37			

Source: Alfadni, 2002

With this simple technique, sorghum yields can be tripled or quadrupled in normal years and the total crop failure can be prevented in dry years (Figure 1).

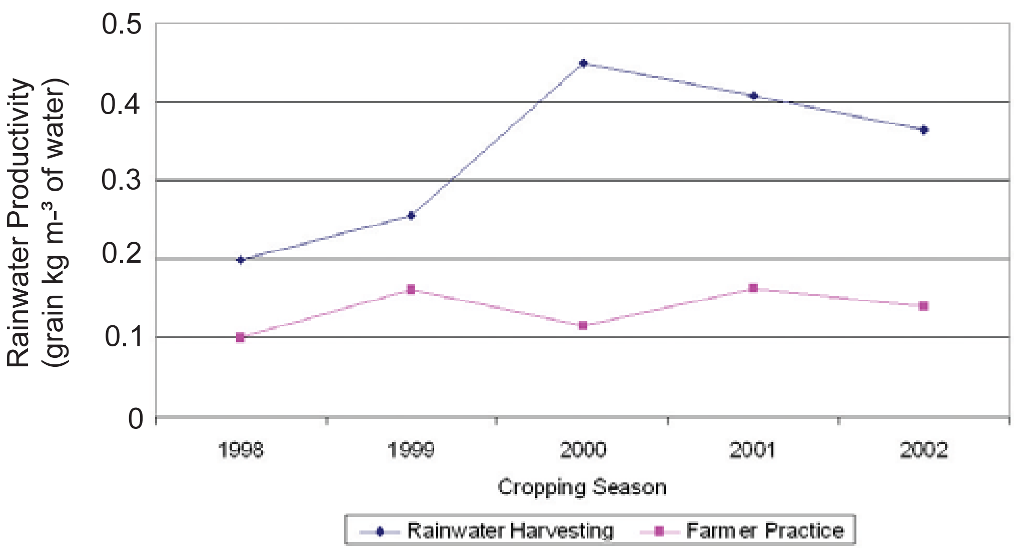

Figure 1. Rainwater productivity, 4 seasons at the farmers' fields (traditional) and the research fields (water harvesting).

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Farming in the drylands of West Africa: Promising soil fertility restoration technologies

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Abstract

Soil fertility is the most limiting factor for crop production in the Sudano-Sahelian zone of West Africa. The region is also the home of the world's poorest people, 90% of who live in villages and gain their livelihood from subsistence agriculture. Per capita food production has declined significantly over the past three decades. Increasing population pressure has, on the other hand, decreased the availability of arable land and it is no longer feasible to use extended fallow periods to restore soil fertility.

Technologies have been tested in several parts in the Sahel with promising results. Organic resources can be used as complimentary inputs to mineral fertilizers and their potential role broadened from a short-term source of N to a wide array of benefits of ecosystem services such as carbon sequestration both in the short and long term. Application of crop residue alone results in both cereal and legume grain and biomass yields compared to that of fertilizer alone in the drier agricultural zone of the Sahel. A very significant additive effect between crop residue and mineral fertilizer can be achieved when the two sources are used in combination. The application of 4 t of crop residue per hectare, for example, maintained soil organic carbon at the same level as that in an adjacent fallow field in the top soil but continuous cultivation without mulching resulted in drastic reduction of organic carbon (Corg). However, annual losses between 1.5 - 7.0% of soil organic carbon can be observed depending on the management systems as compared to 1.2% and 0.5% following 2 and 4 years of fallow respectively.

Another potential is use of locally available phosphate rock, which could be an alternative to use of high cost imported P fertilizers. Since P is the most limiting factor on most Sahelian soils, its correction not only improves yields but also the efficiency of N and water use.

Methods of application of organic and inorganic fertilizer sources enhance use efficiency. Hill placement of inorganic fertilizers and manure is superior to broadcasting. The efficiency of P for example can be optimized through micro-dosing technique. Hill placement of small quantities (3-5 kg ha^{-1}*) of P has shown the highest use efficiency as compared to the recommended practices of broadcasting.*

Crop rotation and intercropping systems are especially important in nutrient and yield improvement as compared to continuous practices. In some cases the yields of pearl millet can be doubled following cowpea cultivation as compared to continuous pearl millet cultivation. In the Sudanian zone nitrogen derived from the soil increased from 39 kg N ha^{-1} *in continuous pearl millet cultivation to 62 kg N* ha^{-1} *when pearl millet was rotated with groundnut.*

Future research challenges include integration of socioeconomic and policy research with the technical solutions, combining rain water and nutrient management strategies to increase crop production and prevent land degradation, increasing the legume component for a better integration of crop-livestock production systems and exploiting the genetic variation for nutrient use efficiency. Another very important issue for research is how to increase crop biomass availability at farm level to alleviate the constraint of non-availability of organic amendments. Use of decision support systems, modeling, and GIS is important in order to extrapolate research findings to other areas in which the successful technologies can be expanded/ scaled out to reach several farmers.

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Introduction

The Sudano-Sahelian zone of West Africa is the home of the world's poorest people, 90% of who live in villages and gain their livelihood from subsistence agriculture. Per capita food production has declined significantly over the past three decades. According to FAO, total food production in Sahelian countries grew by an impressive 70% since 1961 to 1996, but it lagged behind in population control, which doubled causing food production per capita to decline approximately by 30% in the same period. Sahelian countries produce 80% of their total cereal production under very difficult conditions. The ability to obtain the remaining 20% is constrained by inadequate financial resources and underdeveloped marketing channels.

Increasing population pressure has decreased the availability of arable land and it is no longer feasible to use extended fallow periods to restore soil fertility. High population densities have necessitated the cultivation of marginal lands that are prone to erosion. Removal of crop residues from the fields has contributed to negative nutrient balances (Stoorvogel and Smaling 1990). Additionally, low and erratic rainfall, high ambient temperatures, inherent poor soil fertility, structurally degraded soils cause recurrent droughts that lead to low crop productivity in this environment. Consequently, the present farming systems are not sustainable (Bationo et al. 2003). This paper discusses the dryland food production environment, effect of different soil fertility restoration technologies and their profitability, and also presents future research priority area.

Crop production climate

The rainfall in West Africa shows a steep north-south gradient and increases approximately 1 mm km^{-1}. Rainfall is generally low, variable and undependable (Toupet 1965). Sivakumar (1986) used potential evapotranspiration to classify climatic zones in West Africa. According to his scheme, a growing period of 60–100 days was used for defining theSahelian zone. The geographical extent of the Sudanian zone has an average growing period of 100–150 days. The semi-arid zone of the Sudano-Sahelian zone of West Africa (SSZWA) is shown in Figure 1.The average annual rainfall of the cultivated zones varies from300 to 900 mm and the ratio of annual rainfall to annual potential evapotranspiration from 0.20 to 0.65.

The rains occur in short and intense storms and pose special problems in soil conservation (Kowal and Kassam 1978). Charreau (1974) reported rainfall intensities between 27 to 62 mm h^{-1}. In Northern Nigeria, Kowal (1970) reported rainfall intensities over 250 mm h^{-1} for a short period. As a result of the high rainfall intensities and low infiltration rates, runoff and soil loss are common in the region. Runoff and soil loss depend on soil type, erodibility index, landform and management practices (Lal 1980). For example, in Senegal, a total runoff of 39.5% was recorded on a bare soil with a slope of 1.2% resulting in a soil loss of 21 t ha^{-1} yr^{-1}, whereas, in Burkina Faso, soil loss was 6.4 t ha^{-1} yr^{-1} on a pearl millet field with same slope.

Soil lost through erosion is about 10 times greater than the rate of natural soil formation while deforestation is 30 times greater than that of planned reforestation. Buerkert et al. (1996a) measured absolute soil loss of 190 t ha^{-1} in one year on bare plots, as opposed to soil deposition of 270 t ha^{-1} on plot with 2 t ha^{-1} millet stover mulch. Sterk et al. (1996) reported a total loss of 45.9 t ha^{-1} of soil during four consecutive storms. Buerkert et al. (1996b) reported that in an unprotected plot upto 7 kg of available P and 180 kg ha^{-1} of organic carbon are lost

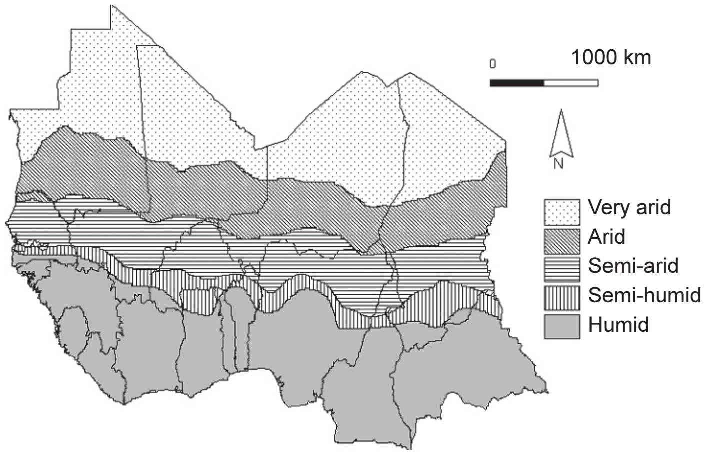

Figure 1. Agroecological zones of West Africa.

from the soil profile within one year. Wind erosion will also decrease the exchangeable bases and increase soil acidification. Wind erosion constitutes one of the major causes of land degradation. The loss of the topsoil, which can contain ten times more nutrients than the sub-soil, is particularly worrying since it potentially affects crop productivity in the long-term by removing the soil that is inherently rich in organic matter.

The physical and chemical properties of the predominantly sandy soils in the SSZWA are also constraining crop production. One striking feature of these soils is their inherent low fertility expressed in low levels of organic carbon (generally less than 0.3%), low total and available phosphorus and nitrogen, and low effective cation exchange capacity (ECEC). The ECEC is attributed to low clay content and the kaolinitic mineralogy of the soils. Bationo and Mokwunye (1991) found that the ECEC is more related to the organic matter than to the clay content, indicating that a decrease in organic matter will decrease the ECEC and thus decrease the nutrient holding capacities of those soils. De Ridder and Van Keulen (1990) reported that a difference of 0.1% in organic carbon content results in a difference of 4.3 C mol kg^{-1} in ECEC.

There is much evidence for rapid decline of Corg levels due to continuous cultivation of crops in Africa (Bationo et al.1995). Annual losses of between 1.5–7.0% of soil organic carbon can be observed depending on management systems as compared to 1.2% for 2 years of fallow and 0.5% for 4 years of fallow (Table 1). For the sandy soils, average annual losses in Corg often expressed by the K value (calculated as the percentage of organic carbon loss per year) may be as high as 4.7% whereas, for the sandy loam soils, reported losses seem much lower, with an average of 2%. The data in Table 1 also clearly indicates that soil erosion can increase Corg losses from 2% to 6.3% and management practices such as crop rotation, following soil tillage, application of mineral fertilizers, and mulching will have a significant effect on annual losses of Corg.

Materials and Methods

The following paper discusses soil fertility management technologies in West Africa. Experience is drawn from literature and other sources. Recommendations for future research and development activities are suggested.

Table 1. Annual loss rates of soil organic carbon measured at selected research stations in the SSZWA.

			Clay + Silt (%)	Annual loss rates of soil organic carbon (K)	
Place and Source	Dominant cultural succession	Observations	(0-0.2 m)	Number of years of measurement	K (%)
Burkina Faso		With tillage			
Saria, INERA-IRAT	Sorghum monoculture	Without fertilizer	12	10	1.5
	Sorghum monoculture	Low fertilizer	12	10	1.9
	Sorghum monoculture	High fertilizer	12	10	2.6
	Sorghum monoculture	Crop residues	12	10	2.2
CFJA, INERA-IRCT	Cotton-cereals	Eroded watershed	19	15	6.3
Senegal		With tillage			
Bambey, ISRA-IRAT	Millet-groundnut	Without fertilizer	3	5	7.0
	Millet-groundnut	With fertilizer	3	5	4.3
	Millet-groundnut	Fertilizer + straw	3	5	6.0
Bambey, ISRA-IRAT	Millet monoculture	with PK fertilizer + tillage	4	3	4.6
Nioro-du-Rip,	Cereal-leguminous	F0T0	11	17	3.8
IRAT-ISRA	Cereal-leguminous	F0T2	11	17	5.2
	Cereal-leguminous	F2T0	11	17	3.2
	Cereal-leguminous	F2T2	11	17	3.9
	Cereal-leguminous	F1T1	11	17	4.7
Chad					
		With tillage, high fertility soil			
Bebedjia, IRCT-IRA	Cotton monoculture		11	20	2.8
	Cotton - cereals			20	2.4
	+ 2 years fallow			20	1.2
	+ 4 years fallow			20	0.5

F0 = no fertilizer
F1 = 200 kg ha^{-1} of NPK fertilizer
F2 = 400 kg ha^{-1} of NPK fertilizer + Taiba phosphate rock
T0 = manual tillage
T1 = light tillage
T2 = heavy tillage

There is also high macronutrient loss as compared to application with many cropping systems reporting negative nutrient balances. For example, annual losses of K of up to 7% at farm level have been noted in semi-arid tropics of Africa. Table 2 shows percentage decreases in soil fertility after 50 years in farmers' fields in the savanna zone of Nigeria following continuous cultivation. Other problems relate to nutrient losses through high soil losses from agricultural systems due to water and wind erosions. Soil loss through erosion is estimated to be 10 times greater than the rate of natural formation.

Soil nutrient depletion is a major bottleneck to increased land productivity in the region and has largely contributed to poverty and food insecurity. Soil nutrient depletion occurs when

Table 2. Percentage decreases in soil fertility after 50 years in farmers' fields under continuous cultivation in the savanna zone of Nigeria.

Zones	Ca	Mg	K	PH
Sudan	21	32	25	4
Northern Guinea	19	27	33	4
Southern Guinea	46	51	50	10

nutrient inflows are less than outflows. Nutrient balances are negative for many cropping systems indicating that farmers are mining their soils. Table 3 shows the aggregated nutrient budgets for some West African countries.

Table 3. Nutrient losses for some West African countries.

		Nutrient losses (1000 tons)		
Country	Area (1000 ha)	N	P_2O_5	K_2O
Benin	2972	41.4	10.4	32.5
Burkina Faso	6691	95.4	27.8	78.8
Ghana	4505	137.1	32.3	90.5
Mali	8015	61.7	17.9	66.7
Niger	10985	176.1	55.3	146.6
Nigeria	32813	110.7	316.7	946.2

Source: Stoorvogel and Smaling 1990

Results and Discussions

Role of organic amendments

Availability

Crop productivity is limited by non-availability of both crop biomass and manure at the farm level. Farmers require at least 2 t ha^{-1} of crop residue (CR) for mulch. However, only 250 kg ha^{-1} of CR is presently available on soil at planting time. This is also limited by the fact that there are many competitive uses for biomass such as fodder and fuel for cooking.

On the other hand, 10 to 40 ha of dry season grazing land and 3 to 10 of rangeland of wet season grazing are required to maintain yields on one hectare of cropland. Potential livestock transfer of nutrients in West Africa is 2.5 kg N and 0.6 kg P per hectare of cropland. The potential of manure to maintain organic carbon levels and sustain crop production is limited by the number of animals available and the size and quality of the rangeland. The quality of the manure also determines its effectiveness. Table 4 presents quality of manure from different sources in selected countries of West Africa.

Organic resources are seen as complimentary inputs to mineral fertilizers and their potential role has consequently been broadened from a short term source of N to a wide array of benefits both in the short and long term (Vanlauwe et al. 2002).

Table 4. Nutrient composition of manure at selected sites in semi-arid West Africa.

	Nutrient composition (%)			
Location and type of manure	N	P	K	Reference
Saria, Burkina Faso				
Farm yard manure	1.5 - 2.6	0.09 - 0.12	1.3 - 3.8	1
Northern Burkina Faso				
Cattle manure	1.28	0.11	0.46	2
Small ruminant manure	2,20	0.12	0.73	2
Senegal				
Fresh cattle dung	1.44	0.35	0.58	3
Dry cattle dung	0.89	0.13	0.25	3
Niger				
Cattle manure	1.2 - 1.7	0.15 - 0.21	-	4
Sheep manure	1.0 - 2.2	0.13 - 0.27	-	4

Role of crop residues

Crop residues have a significant role in increasing productivity. Crop residue alone resulted to the same quantity of total dry matter (TDM) as that with fertilizer alone (Figure 2). However, TDM yield was greatly improved when application of fertilizer was combined with crop residue.

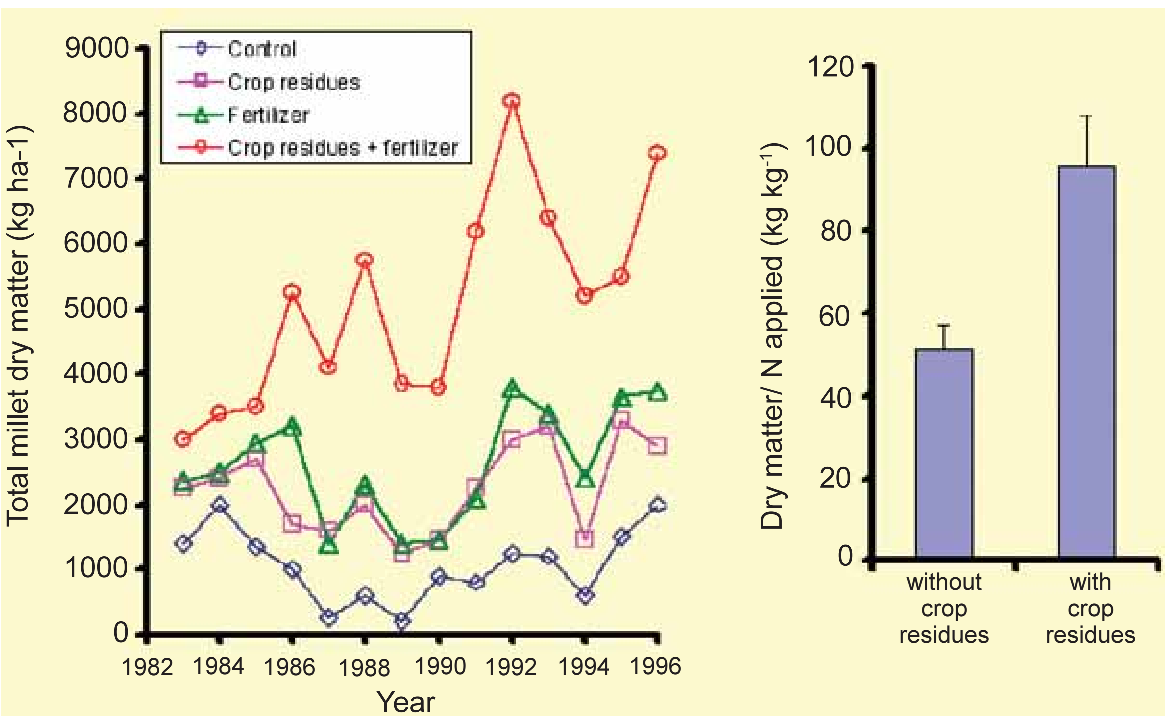

Figure 2. Total millet dry matter yield as affected by long-term application of crop residues and fertilizer, Sadoré, Niger.

In long-term crop residue and management trials in the Sahelian zone a very significant effect between crop residue and mineral fertilizer was reported (Bakayoko et al. 2000). From these experiments started since 1984 the grain yield declined to 160 kg ha^{-1} in unmulched and unfertilized plots (Bationo et al. 1993). However, grain yield could be increased to 770 kg ha^{-1} with a mulch of 2 t crop residue per hectare and 1030 kg ha^{-1} with 13 kg P plus 30 kg N ha^{-1}. The combination of crop residue and mineral fertilizers resulted in grain yield of 1940 kg ha^{-1}. The application of 4 t of crop residue per hectare maintained soil organic carbon at the same level as that in an adjacent fallow field in the top soil but continuous cultivation without mulching resulted in drastic reduction of Corg (Figure 3). In the Sudanian zone, all available reports show a much smaller or even negative effect of crop residue use as soil amendment (Bationo et al. 1995). In the Sahelian zone the application of crop residue increased soil pH and exchangeable bases, and decreased the capacity of the soil to fix phosphorus.

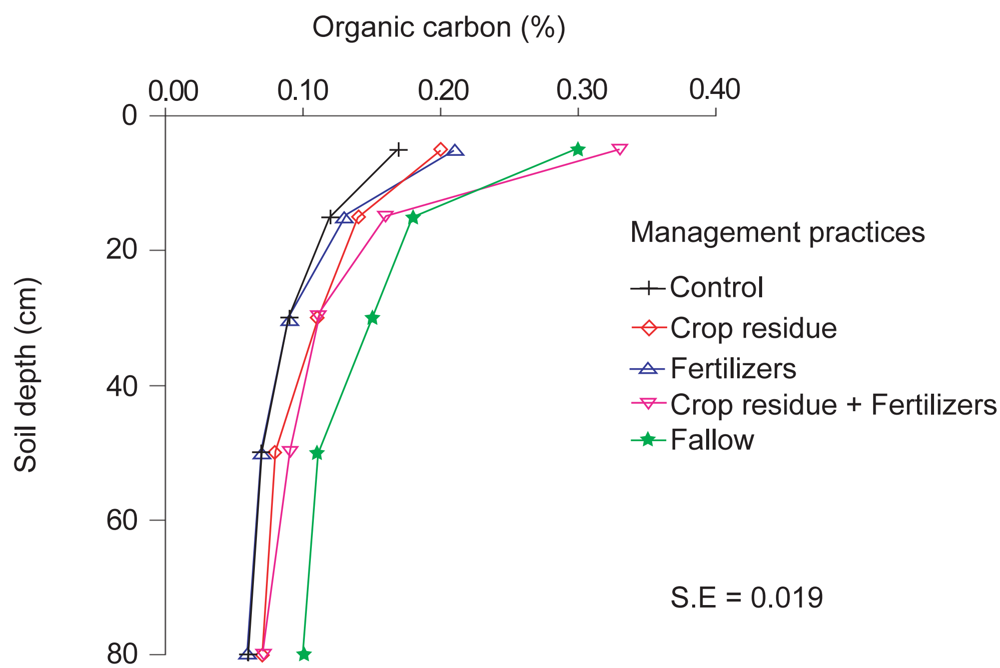

Figure 3. Effect of different management practices on soil organic carbon content after 14 years of cultivation, Sadoré, Rainy season 1997.

Role of animal manure and urine

On the nutrient poor West African soil, manure, the second farm-available soil amendment can substantially enhance crop yields. For Niger, McIntire et al. (1992) reported grain yield increase between 15 and 86 kg for millet and between 14 and 27 kg for groundnut per ton of applied manure. Similar manure effects have been reported from other Sahelian countries.

The contribution of manure in crop productivity from a long-term experiment is shown in Figure 4. Continued application of manure led to annual increase in yield as opposed to lone application of fertilizer and the control both of which recorded annual yield reductions.

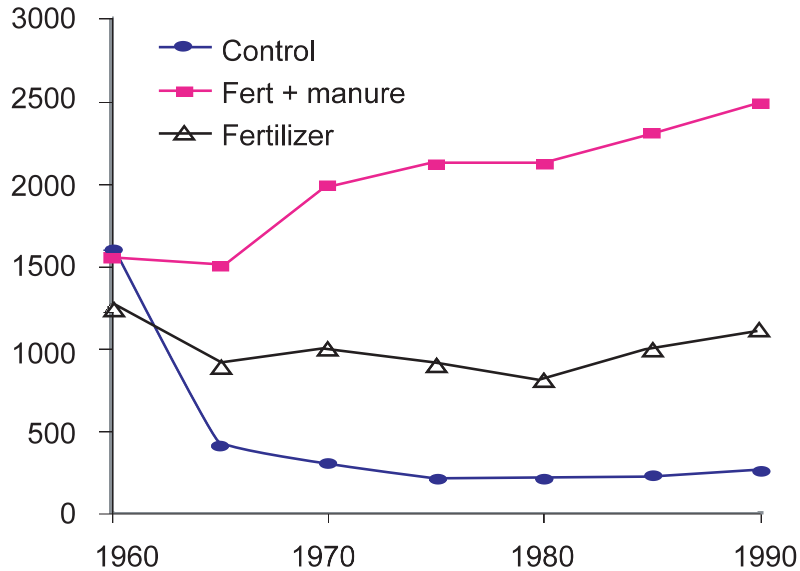

Figure 4. Sorghum grain yield as affected by fertilizer and manure over time.

The potential of both manure and urine has also been evaluated. Powell et al. (1998) found a very significant effect of manure and urine application on pearl millet in the Sahelian zone. In another experiment in Niger, both dung and urine increased yields by between 80 and 200% above those of cattle dung only at various application rates (Table 5).

Table 5. Effect of cattle dung and urine on millet grain and total above ground biomass, Sadoré, Niger.

Cattle Dung	+ Urine		- Urine	
Application	Grain	Biomass	Grain	Biomass
0	-	-	80	940
2990	580	4170	320	2170
6080	1150	7030	470	3850
7360	1710	9290	560	3770
S.E.M	175	812	109	496

Application of low quality manures in Nigeria showed their potential to contribute significantly to overcome P deficiency to maize crop as shown in Figure 5.

However, given the large variation in the nutrient concentration of the manure types applied, comparisons between results from different experiments should be made with precaution.

Role of inorganic fertilizers in crop yields

Availability of fertilizers and rock phosphate

Africa has several deposits of rock phosphate mostly in the western, eastern and southern parts and some can be used for direct application (Figure 6). Bationo et al. (1987) have shown that

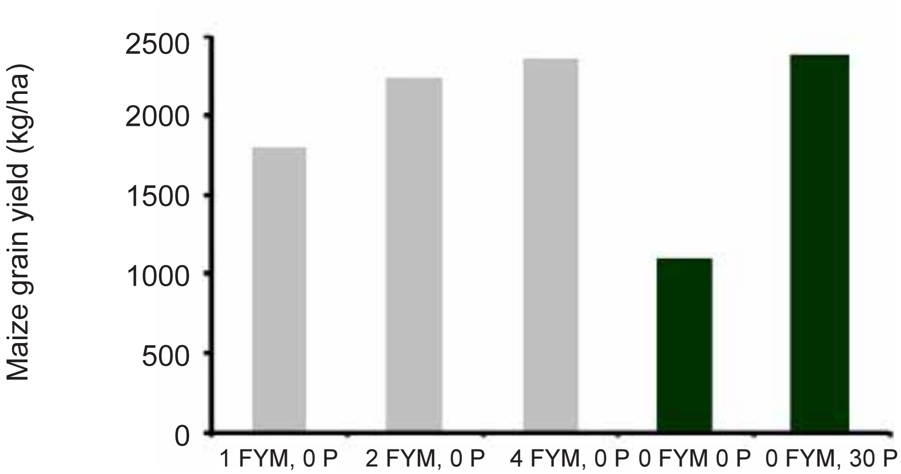

Figure 5. Use of low quality manure (<1% N) to alleviate P deficiency in maize crops in Zaria, Nigeria, 2001.

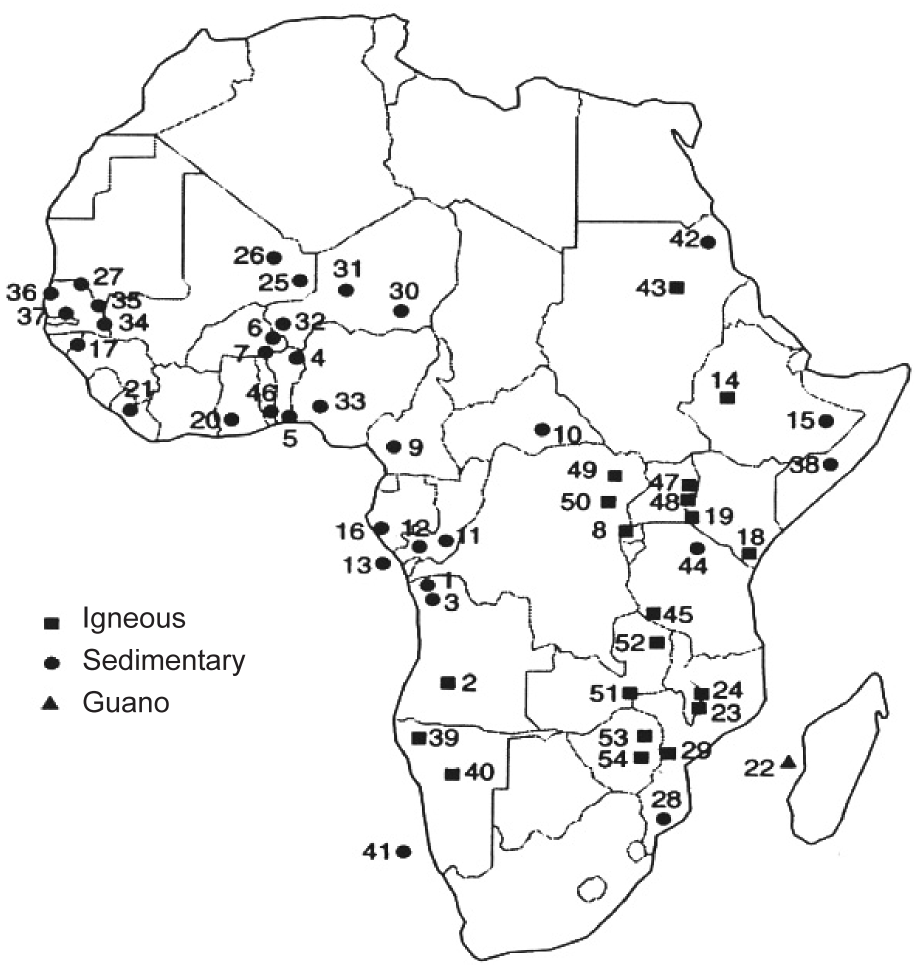

Figure 6. Phosphate rock deposits in Sudano-Sahelian Africa.

Source: McClellan and Notholt 1986; P van Straeten 1997.

direct application of phosphate rock (PR) indigenous to the region may be an economical alternative to the use of more expensive imported water-soluble P fertilizers for certain crops and soils. Evaluation of Parc-W and Tahoua PR indigenous to Niger showed that PR is only 48% as effective as single superphosphate (SSP), whereas the effectiveness of the more reactive Tahoua rock was as high as 76% of SSP (Bationo et al. 1987). Further studies (Bationo et al. 1990) showed that Tahoua PR is suitable for direct application but Parc-W PR has less potential for direct application. The data from a long-term benchmark experiment show that SSP outperformed the other sources and its superiority to sulphur-free Triple Superphosphate (TSP) indicates that with continuous cultivation, sulphur deficiency develops. For both pearl millet grain and total dry matter yields, the relative agronomic effectiveness was almost similar for TSP as compared to the partially acidulated phosphate rock (PAPR) of Parc-W with 50% acidulation (PAPR50) indicating that partial acidification of Parc-W PR can significantly increase its effectiveness (Bationo et al. 1986).

Despite the fact that deficiency of P is acute on the soils of West Africa, local farmers use very little P fertilizer, partially because of the high cost of the imported fertilizers. The use of locally available phosphate rock indigenous in the region could be an alternative to use of high cost imported P fertilizers.

Effect of N and application rates

Urea and calcium ammonium nitrate (CAN) are the most common sources of nitrogen in the region. Trials were undertaken to evaluate these two sources of nitrogen with basal application, broadcast or applied point placed. From the data in Table 6 the following conclusion can be made: (1) fertilizer N recovery by plant was low, (2) there is a higher loss of N with the point placement of urea (> 50%) and the mechanism of N loss is believed to have been ammonia volatilization, (3) losses of N from CAN were less than from urea because one-half of the N in CAN is in the non-volatile nitrate form, and (4) although CAN is a lower N analysis fertilizer than urea, it is attractive as a N source because of its low potential for N loss via volatilization and its low soil acidifying properties (Bationo et al. 2003). The data in Figure 7 clearly indicate that CAN point placed outperformed urea point placed or broadcast and 15 N data from similar trials indicate that uptake by plants was almost three times higher than that of urea applied in the same manner.

Table 6. Recovery 15 N fertilizer by millet applied at Sadoré, Niger, 1985.

		15 N Recovery			
N source	Application method	Grain(%)	Stover	Soil	Total
CAN	Point incorporated	21.3	16.8	30.0	68.1
CAN	Broadcast	10.9	10.9	42.9	64.7
Urea	incorporated	5.0	6.5	22.0	33.5
Urea	Point incorporated	8.9	6.8	33.2	48.9
Urea	Broadcast	5.3	8.6	18.0	31.9
SE	incorporated	1.2	2.0	1.9	2.4
	Point surface				

Source: Christianson and Vlek 1991.

Christianson and Vlek (1991) found that the optimum N rate for sorghum is 50 kg ha^{-1} and 30 kg ha^{-1} for pearl millet. Results from 15 N research concluded that apparent uptake of fertilizer N exceeds measured uptake using 15 N and that uptake of 15 N labeled fertilizer and apparent recovery of unlabelled N decreases with increasing rates of application. Similarly, loss of 15 N labeled fertilizer to the atmosphere and recovery of 15 N in the soil increases with increasing rates of fertilizer application and the estimated losses of N are high regardless of N sources (Mughogho et al. 1986).

N use efficiency can be increased through rotation of cereals with legumes and through optimization of planting density. Bationo and Vlek (1998) reported a nitrogen-use efficiency of 20% in the continuous cultivation of pearl millet but its value increases to 28% when pearl millet is rotated with cowpea, while Bationo et al. (1989) found a strong and positive correlation between planting density and response to N fertilizer.

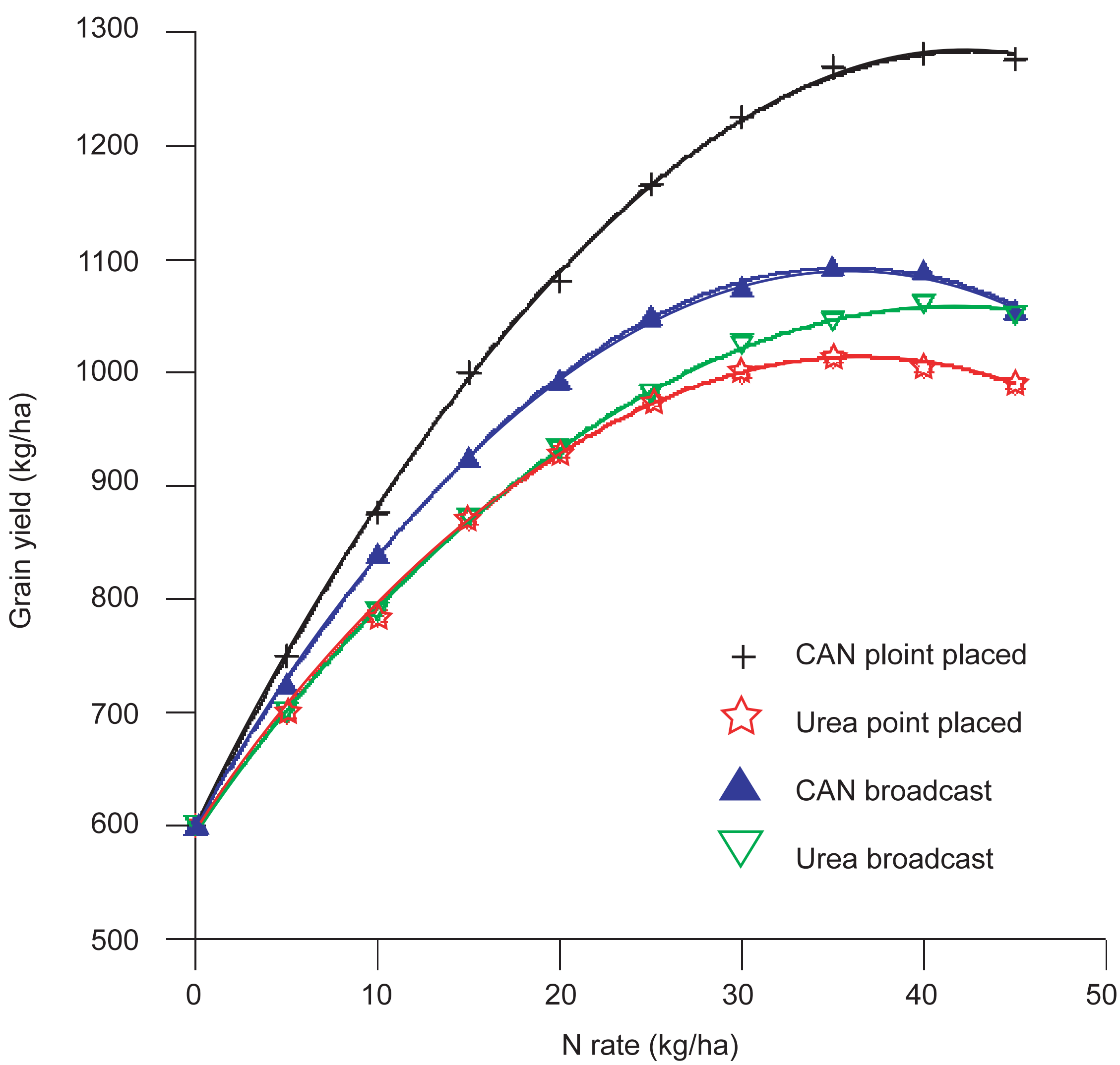

Figure 7. Effect of broadcast and point application methods for Urea and CAN on grain yield.

Effect of P and application rates

Phosphorus deficiency is a major constraint to crop production and response to nitrogen is substantial only when both moisture and phosphorus are not limiting. Field trials were established to determine the relative importance of N, P and K fertilizers. The data in Table 7 indicate that from 1982 to 1986 the average control plot was 190 kg grain ha^{-1}. The sole addition of 30 kg P_2O_5 ha^{-1} without N fertilizers increased the average yield to 714 kg ha^{-1}. The addition of only 60 kg N ha^{-1} did not increase the yield significantly over the control and the average grain yield obtained was 283 kg ha^{-1}. These data clearly indicate that P is the most limiting factor in those sandy Sahelian soils and there is no significant response to N without first correcting the P deficiency. When P is applied the response to N can be substantial and with the application of 120 kg N ha-1 a pearl millet grain yield of 1173 kg ha^{-1} was obtained as compared to 714 kg ha^{-1} when only P fertilizers were applied. For all the years the addition of potassium did not increase significantly the yield of both grain and total dry matter of pearl millet.

Table 7. Effect of N, P, and K on pearl millet grain and total dry matter (kg ha^{-1}) at Sadoré and Gobery (Niger).

	1982		1983		1984		1985	1986	
	Sadoré		Sadoré		Gobery		Sadoré	Sadoré	Sadoré
Treatments	Grain	TDM	Grain	Grain	Grain	TDM	Grain	Grain	TDM
N0P0K0	217	1595	146	264	173	1280	180	180	1300
N0P30K30	849	2865	608	964	713	2299	440	710	2300
N30P30K30	1119	3597	906	1211	892	3071	720	930	3000
N60P30K30	1155	3278	758	1224	838	3159	900	880	3200
N90P30K30	1244	3731	980	1323	859	3423	1320	900	3400
N120P30K30	1147	4184	1069	1364	1059	3293	1400	1000	3300
N60P0K30	274	2372	262	366	279	1434	290	230	1500
N60P15K30	816	2639	614	1100	918	3089	710	920	3100
N60P45K30	1135	3719	1073	1568	991	3481	1200	980	3500
N60P30K0	1010	3213	908	1281	923	3377	920	910	3400
S.E.C.V(%).	10724	34922	12026	23230	14024	32022	16228	25032	40025

N.B. Nutrients applied are N, P_205 and K_20 kg ha^{-1}; TDM= Total dry matter

Availability and total P levels of soil are very low in the SSZWA as compared to the other soils in West Africa (Juo and Fox 1977; Bache and Rogers 1970; Mokwunye 1974; Jones and Wild 1975). For the sandy Sahelian soils total P values can be as low as 40 mg P kg^{-1} and the value of available P less than 2 mg P kg^{-1}. A study of the fertility status of selected pearl millet producing soils of West Africa (Manu et al. 1991), shows that the amount of total P in these soils ranged from 25 to 340% mg kg^{-1} with a mean of 109% mg kg^{-1}. The low content of both total and available P parameters may be related to several factors including, (1) Parent materials, which are mainly composed of eolian sands, contain low mineral reserves and lack primary minerals necessary for nutrient recharge, (2) A high proportion of total P in these soils is often in occluded form and is not available to crop (De Ridder and van Keulen 1990), and (3) Low level of organic matter and the removal of crop residue from fields. Organic matter has a favorable effect on P dynamics of the soil; in addition to P release by mineralization, the competition of organic ligands for Fe and Al oxides surface can result in a decrease of P fixation of applied and native P.

Micro-dosing

Hill placement of small quantities (3-5 kg ha^{-1}) of P has shown the highest use efficiency with the efficiency decreasing with increasing quantity of P (Table 8, Figure 8).

Table 8. Effects of P sources and methods of application on millet grain yield (kg ha^{-1}) and PUE (kg grain/ kg P applied).

	1995		1996	
P applied (kg P ha^{-1})	Yield	PUE	Yield	PUE
0	532	-	641	-
13 (BC)	1138	47	1240	46
3 (HP)	864	111	846	68
5 (HP)	937	81	996	71
7 (HP)	1018	69	1074	62
13 (BC)+ 3 (HP)	1382	53	1279	40
13 (BC)+5 (HP)	1425	50	1295	36
Standard error	92		89	

BC= broadcasting

HP= Hill placement

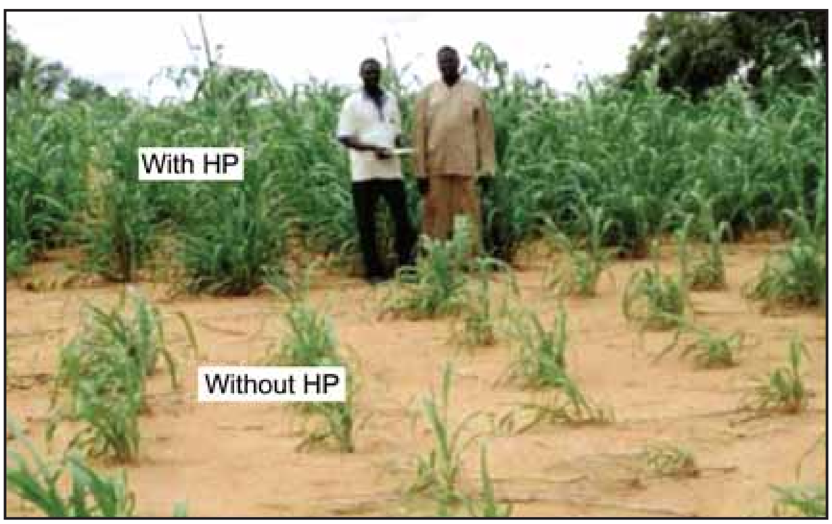

Figure 8. Effect of hill placement of small amounts of P fertilizer (4 kg P ha^{-1}) increases millet growth in the Sahel.

Combining organic and inorganic plant nutrients in production

Combined application of organic resources and mineral inputs forms the technical backbone of the Integrated Soil Fertility Management approach. The data in Table 9 clearly indicate the comparative advantage to combine organic and inorganic plant nutrients for the low suffering soils in the Sahel. Combination of both organic and inorganic P and N sources achieved more yield as compared to inorganic sources alone. Successive levels of manure from 2-8 tons ha^{-1}, with reduction in inorganic P applied resulted to increased yield upto 5718 kg ha^{-1}.

Table 9. Optimum combination of plant nutrients for cowpea fodder in the Sahel (kg ha^{-1}).

Treatments	Yield2001	Yield2002
Absolute Control	1875	2406
30 kg N ha^{-1}	2531	2625
12 kg P ha^{-1}	3781	3281
8 t manure + 30 kg N ha^{-1}	5718	3531
6 t manure + 3kg P + 30 kg N	4843	4625
4 t manure + 6 kg P + 30 kg N	4656	3625
2 t manure + 8 kg P + 30 kg N	4281	3375
12 kg P + 30 kg N	5000	3156
Standard error	204	200
Coefficient of variation (%)	14	12

Role of management systems in crop yields

Crop rotation

The effect of crop rotation on yield from an on-going experiment in the Sahel region involving a combination of rotations, inorganic and organic nutrient sources is shown in Table 10 and has clearly indicated the high potential to increase the staple pearl millet yields in the very poor Sahelian soils.

Table 10. Effect of fertilizers, soil tillage, crop residue, cropping system on pearl millet grain yield; Sadoré 2001-02 cropping season.

Treatments	Pure millet grain yield (kg ha^{-1}) in 2001								Pure millet grain yield (kg ha^{-1}) in 2002							
	- Rotation				+ Rotation				- Rotation				+ Rotation			
	- CR		+ CR		- CR		+ CR		- CR		+ CR		- CR		+ CR	
	-N	+N	-N	+N	-N	+N	-N	+N	-N	+N	-N	+N	-N	+N	-N	+N
Traditional	146	181	331	473					104	104	156	183				
Phosphorus + HC	873	1145	1247	1649	703	1067	1649	1866	244	337	438	594	583	667	724	807
Phosphorus + AT	708	816	935	1114	904	1225	1381	1529	280	355	456	574	586	788	781	903

HC= Hand cultivation, planting on flat

AT= Animal traction, planting on ridges

CR= Crop residue

Crop rotation not only increases yield but also shows a significant effect on organic carbon (Figure 9). The rotation system was also found to increase levels of soil organic carbon (at least 0.27) as compared to that in continuous millet system (0.21%). In the same way, continuous millet TDM is lower by at least 2500 kg ha^{-1} as compared to rotation with cowpea at all levels of P application.

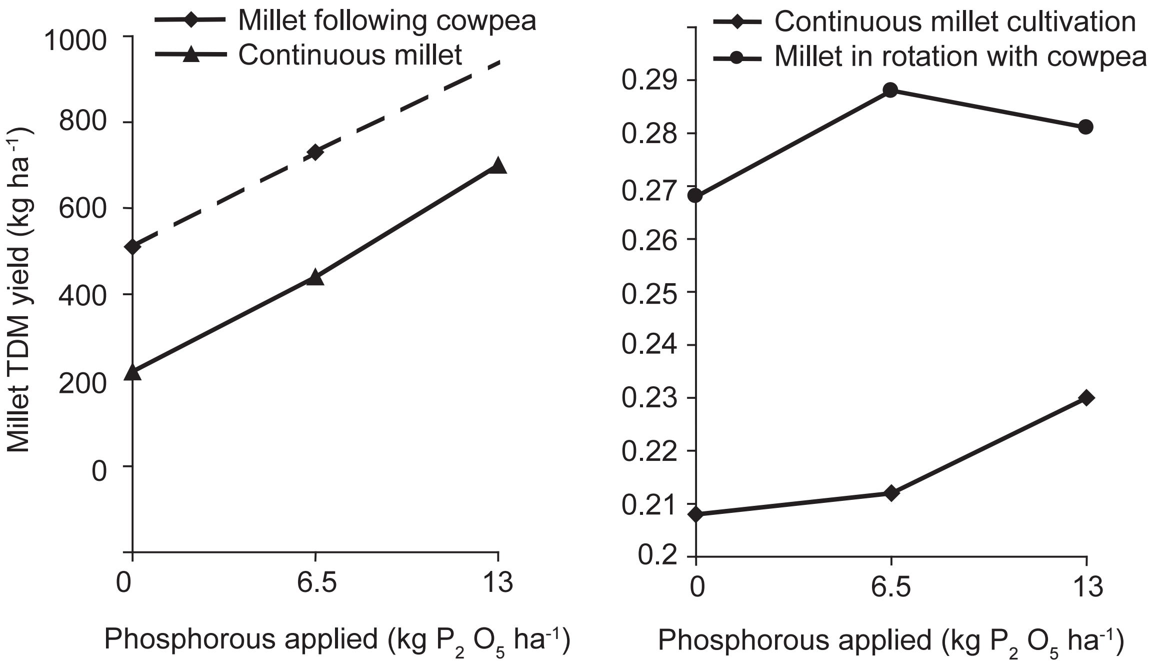

Figure 9. Effect of rotation on millet yield (left) and on soil organic carbon (right).

Using ^{15}N to quantify the amounts of nitrogen fixed by cowpea and groundnut under different soil fertility levels in the Sahel, it was found that nitrogen derived from the air (NDFA) varied from 65 to 88% for cowpea and 20 to 75% for groundnut. In the complete treatment where all nutrients were applied cowpea stover fixed up to 89 kg N ha^{-1} while for same treatment groundnut fixed 40 kg N ha^{-1}. Other legumes such as Mucuna have also demonstrated a high potential to contribute to yield improvement through high amounts of fixed N.

The potential of rotation systems has also been shown by an experiment to determine ^{15}N recovery from different cropping systems of pearl millet grown continuously, in rotation with cowpea, in rotation with groundnut, intercropped with cowpea, and intercropped with groundnut which indicated that nitrogen use efficiency increased from 20% in continuous pearl millet cultivation to 28% when pearl millet was rotated with cowpea (Bationo and Vlek 1998). The same authors reported that in the Sudanian zone nitrogen derived from the soil increased from 39 kg N ha^{-1} in continuous pearl millet cultivation to 62 kg N ha^{-1} when pearl millet is rotated with groundnut. These data clearly indicate that although all the above ground biomass of the legume will be used to feed livestock and not returned to the soil, rotation will increase not only the yields of succeeding cereal crop but also its nitrogen use efficiency.

Intercropping

Several studies have reported nutrient and yield improvement following intercropping systems. Ntare (1989) reported yield advantages of 20–70% depending on the different combinations of pearl millet and cowpea cultivars. Fussell and Serafini (1985) reported yield advantages from 10–100% in millet-cowpea systems. Yield stability is a major advantage of intercropping since farmers want to rely on management practices that increase yields, while improving stability (Baker 1980; Finlay and Wilkinson 1963) of the production in both good and poor rainfall years. For example, the number of days before planting the second crop will depend on the importance of the next rains after the first cereal crops have been planted. With a basal application of P fertilizers cereal growth is rapid and can suppress completely the second crop if its planting occurs three or more weeks after the cereal crops have been sown. In contrast if the legume crops are planted early it will compete more with the cereal crop for light, water, and nutrients and can significantly reduce the yield of the cereal crop. Although traditional intercropping covers over 75% of the cultivated area in the SSZWA, there is a scarcity of information on the efficiency of fertilizers under these systems.

Relay and sequential cropping

In the Sudanian zone with longer growing season and higher rainfall there is greater opportunity, than in the Sahelian zone, to manipulate the systems with appropriate genotypes and management systems. Field trials have been conducted to examine the performance of the cultivars under relay and sequential systems and revealed the potential of these alternative systems over traditional sole or mixed cropping (ICRISAT 1985, 1984-88).

In Mali, by introducing short season sorghum cultivars in relay cropping with other short duration cowpea and groundnut cultivars, substantial yields of legumes and sorghum were obtained as compared to traditional systems (Sedogo 1993).

In the Sahelian zone data of the onset and ending of the rains and the length of the growing period analyzed found that an early onset of the rains offers the probability of a longer growing period while delayed onset results in a considerable short term growing season. The above analysis suggests that even for the Sahelian zone, cropping management factors using relay cropping can increase soil productivity with an early onset of the rains.

Methods of Fertilizer Application

Methods of application of organic and inorganic fertilizer sources affect yields and fertilizer use efficiency.

Phosphorus (P) placement

P placement can drastically increase P use efficiency as shown with pearl millet and cowpea in an experiment involving broadcast (BC) and/or hill placement (HP) of Single Superphosphate (SSP) and Tahoua Phosphate Rock (TPR). For pearl millet grain, phosphorus use efficiency (PUE) for broadcasting SSP at 13 kg P ha^{-1} was 18 kg kg^{-1} P but hill placement of SSP at 4 kg P ha^{-1} gave a PUE of 83 kg kg^{-1} P. Whereas the PUE of TPR broadcast was 16 kg grain kg^{-1} P, the value increased to 34 kg kg^{-1} P when additional SSP was applied as hill placement at 4 kg P ha^{-1}. A further addition of crop residue to TPR broadcast and SSP hill placed showed potential to increase yields by between 100-200 kg ha^{-1} (Bationo et al. Unpublished). For cowpea fodder PUE for SSP broadcast was 96 kg kg^{-1} P but the hill placement of 4 kg P ha^{-1} gave a PUE of 461 kg kg^{-1} P.

Table 11 shows that hill placement of small quantities (3-5 kg ha^{-1}) of P attained the highest use efficiency with the efficiency decreasing with increasing quantity of P. As discussed later in this paper, higher yields per unit of P fertilizer invested saves the farmers pocket and presents higher adoption probabilities.

Table 11. Effects of P sources and methods of application on millet grain yield (kg ha^{-1}) and PUE (kg grain/ kg P applied).

	1995		1996	
P applied (kg P ha^{-1})	Yield	PUE	Yield	PUE
0	532	-	641	-
13 (BC)	1138	47	1240	46
3 (HP)	864	111	846	68
5 (HP)	937	81	996	71
7 (HP)	1018	69	1074	62
13 (BC)+ 3 (HP)	1382	53	1279	40
13 (BC)+5 (HP)	1425	50	1295	36
SE	92		89	

BC- broadcasting HP= Hill placement

Regardless of the method of application, N and P use efficiency is further dependant on the site. Higher use efficiency is observed on non-degraded as compared to degraded sites (Table 12).

Table 12. Use efficiency of N and P in degraded and non-degraded sites at Karabedji, Niger. 1998-2002.

Fertilizer	Site condition	Efficiency (%)
Nitrogen N at 60	Degraded	8.6
	Non-degraded	15.3
Phosphorus P at 30	Degraded	50
	Non-degraded	58

Placement of manure

In a complete factorial experiment carried out in Niger, West Africa, with three levels of manure (0, 3, 6 t ha^{-1}) and three levels of P (0, 6.5 and 13 kg P ha^{-1}) using pearl millet, hill placement of manure performed better than broadcasting and with no application of P fertilizer. Broadcasting 3 t ha^{-1} of manure resulted on pearl millet grain yield of 700 kg ha^{-1} whereas the point placement of the same quantity of manure gave about 1000 kg ha^{-1} (Figure 10). A similar effect was observed with cowpea.

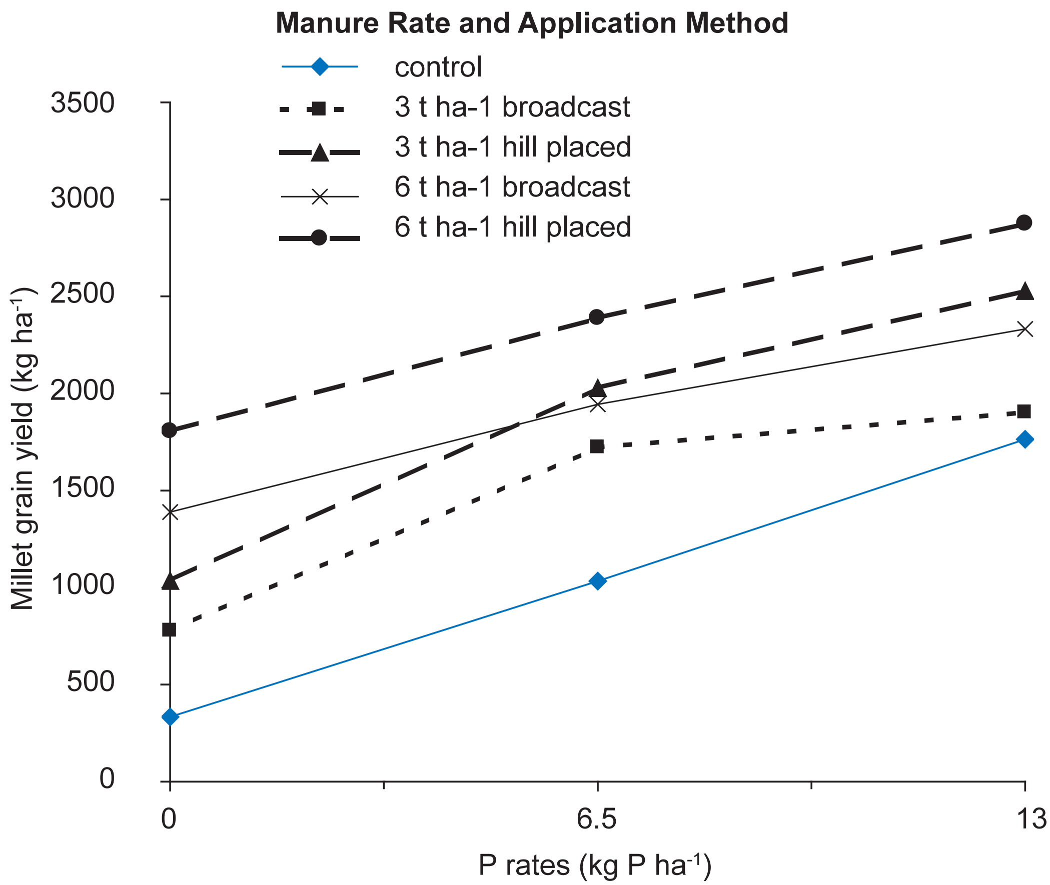

Figure 10. Millet grain yield response to P and manure applied at different rates and methods, Karabedji, Niger, 2002 rainy season.

Water-harvesting technologies

Planting crops directly in pits (Zai technology) increased yields by 300 kg ha^{-1} compared to planting on flat land. When small quantities of manure or compost (3 t ha^{-1}) added in small pits dug in the degraded soil, yields rose to 960 kg ha^{-1}, more than double that of Zai without manure (Table 13).

Table 13. Effect of the zai and manure application on pearl millet grain yield in Western Niger.

Treatment	Grain yield (kg ha^{-1})
Planting in flat	150
Planting in "zai" without manure	450
Planting in "zai" with 3 t ha^{-1} of manure	960

Source: Fatondji (personal communication, 2003)

Other important water-harvesting technologies include use of micro-catchments (v, half-moon, etc), stones bunds and ridging.

Optimizing Production Benefits

Different technologies were tested for many years in areas with annual rainfall between 400-800 mm and with various soil types. The recommended practice was to apply 13 kg P ha^{-1} as single super phosphate (SSP) and 30 kg N ha^{-1} as urea. Both were to be broadcast and incorporated. With the recent evaluation of the currency in Niger, West Africa, FCFA, the cost of fertilizer almost tripled. This was not always followed by the grain yield. Therefore, new strategies were developed to reduce application by hill placing small quantities of P fertilizer at planting time to increase P use efficiency and achieve profitable production for small-scale farmers. The hill placement consisted of placing 4 kg P ha^{-1} and the sources of P tested were compound 15-15-15 fertilizer, SSP and di-ammonium phosphate (DAP).

In all agroecological zones, the hill placement of small quantities of fertilizer resulted in significant increase in yield (Figure 11). A very important result also was that there was no yield difference in hill placement of low analyses of NPK fertilizer with only 15% P_2O_5 and higher analyses of P fertilizer of DAP containing 46% P_2O_5. Given the fact that the cost of the two types of fertilizer was the same in the market for the farmers, it was evident that using the higher analyses P content such as DAP will be more profitable to the farmers for hill placement.

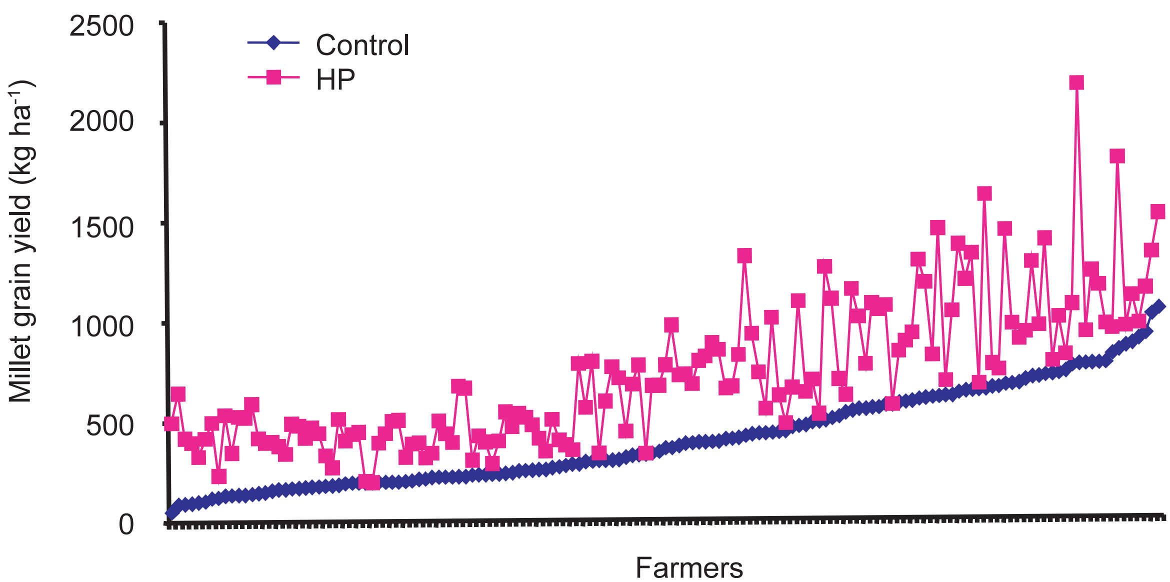

Figure 11. Millet grain yield response to HP application in 150 farmers fields in Sadoré, Karabedji and Gaya in Niger.

Average grain yield of the farmers practice was 400 kg ha^{-1} as compared to 720 kg ha^{-1} with HP application. These average yields from the sites were used for the economic analyses to determine which technologies are viable and more likely to be of interest to the farmers. The study has shown that use of DAP as the P source is superior to 15 15-15 and is a viable option with all the practices at all fertilizer and crop prices. The inferior results of 15-15-15 as P fertilizer source were investigated through a further analyses involving plotting the benefit/cost ratio against the fertilizer/crop price ratio (Figure 12). Viability of most HP 15-15-15 technologies is limited to fertilizer/crop price ratio of <2.0. Their practice when the fertilizer/ crop price ratio is >2.0 return a benefit cost ratio of less than 2. On the other hand, their benefit/cost ratios are limited to <7.0 (Figure 12). However, both rotation and intercropping show superior performance and viability even at higher fertilizer/crop price ratio with rotation as the best practice. Though the technology involving only an application of 4 kg P ha^{-1} as 15-15-15 resulted to the highest benefit/cost ratio, its viability is limited to a fertilizer/crop price ratio of no more than 2.

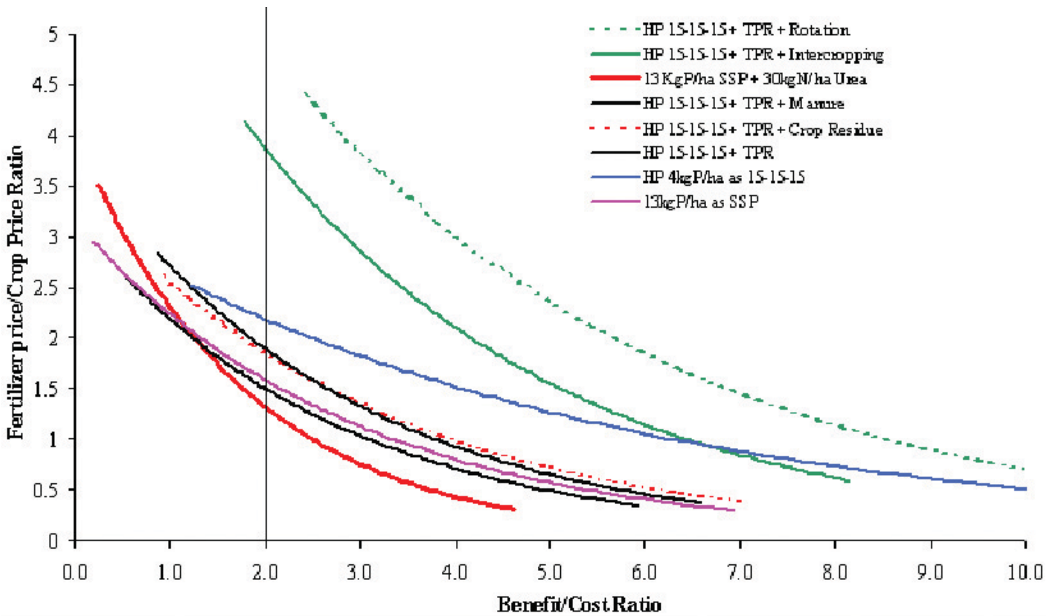

Figure 12. Benefit/ cost ratio of technologies with HP 15-15-15 at various price ratios.

Notes: HP 15-15-15 is hill placement of 4 kg P ha^{-1} of 15-15-15 fertilizers; TPR is broadcast of 13 kg ha^{-1} of Tahoua Phosphate rock; Manure is applied at 2 t ha^{-1}; crop residue is applied at 2 t ha^{-1}; Control grain yield and stover yield were 400 kg ha^{-1} and 1700 kg ha^{-1} respectively.

The source of P can also optimize farmer returns. There was no difference between hill placement of DAP and 15-15-15 indicating that due to its low cost per unit of P associated with DAP, this source of fertilizer should be recommended to farmers. DAP contains 46% P_2O_5 and a compound NPK fertilizer (15-15-15) contains only 15% P_2O_5. Basal application of Tahoua Phosphate rock (PRT) gave additional 300 kg ha^{-1} of pearl millet grain. The combination of hill placement of water-soluble P fertilizer with phosphate rock seems a very attractive option for the resource poor farmers in this region (Bationo et al. 1997 and 1998).

The Way Forward

New strategies for integrated nutrient management

In the past, integrated nutrient management concentrated mainly on the utilization of available organic and inorganic sources of plant nutrients in a judicious and efficient way. Integrated nutrient management is recently perceived much more broadly as the judicious manipulation of all soil nutrient inputs and outputs and internal flows.

Future research needs to adopt this new holistic approach to integrated nutrient management. For a given cropping system or watershed, this will require the establishment of the nutrient balances. Interventions to limit nutrient losses through erosion can be in some cases as important as research on increasing the efficiency of organic and inorganic plant nutrients for sustainable land use. This new approach will enhance more carbon sequestration and increase biomass production on the farms for domestic use and there will be more biomass available for livestock feeds and for soil mulching.

Integration of socio-economic and policy research with the technical solution

In the past several technical solutions to the problem of land degradation in the SSZWA have been researched and tested, and may have shown the potential for addressing the problem in some places. Unfortunately a review of the state of the art indicated that very few of these technologies have been adopted by the resource poor farmers. Therefore, future research should focus more on problems driven by socio-economic factors and enabling policy environment in order to enhance farmers' capacity to invest in soil fertility restoration. The adoption of the participatory approach with farmers carrying out problem diagnosis, planning and implementing soil fertility restoration technologies and evaluating the technologies themselves will be essential. In this way, the technologies generated have a better chance of adoption by land users.

Combining rain water and nutrient management strategies to increase crop production and prevent land degradation

In the SSZWA high inter-annual variability and erratic rainfall distribution in space and time result in water-limiting conditions during the cropping season. In areas with inadequate rainfall or in runoff-susceptible land, water conservation techniques and water harvesting techniques offer the potential to secure agricultural production and reduce the financial risks associated with the use of purchased fertilizers. Under the conditions of adequate water supply, the addition of organic and inorganic amendments is the single most effective means of increasing water use efficiency. Future research needs to focus on enhancing rainwater and nutrient use efficiencies and on capitalizing on their synergies for increasing crop production and preventing soil degradation.

Increasing the legume component for a better integration of crop-livestock production systems

The rotations of cereals with legumes have led to increased cereals yield at many locations in the SSZWA. Factors such as mineral nitrogen increase, enhancement of Vesicular-Arbuscular Mycorrhizal (VAM) for better P nutrition and a decrease in parasitic nematodes have been identified as mechanisms accelerating the enhanced yield of cereals in rotation with legumes. Most of the research has focused on the quantification of the aboveground N fixed by different legumes cultivars, but very little is known on the below-ground N fixed.

There is need to increase the legume component in the mixed cropping systems for a better integration of crop-livestock. The increase of legume component in the present cropping system will not only improve the soil conditions for the succeeding cereal crop, but will provide good quality livestock feed, and the manure produced will be of better quality for soil amendment.

Exploiting genetic variation for nutrient use efficiency

Phosphorus is the most limiting plant nutrient for crop production in the SSZWA and there is ample evidence that indicates marked differences between crop genotypes for P uptake. A better understanding of the factors affecting P uptake such as the ability of plants to (a) solubilize soil P through acidification of the rhizosphere and the release of chelating agents and phosphate enzymes, (b) explore a large volume of soil, and (c) absorb P from low P solution would help screening for the genotypes best appropriate for nutrient use efficiency.

Another important future research opportunity is the selection of genotypes that can efficiently associate with VAM for better utilization of P applied as indigenous phosphate rock.

Use of decision support systems, modeling, and GIS for the extrapolation of research findings

Farmers' production systems vary with respect to rainfall, soil types, and socio-economic circumstances and therefore they are complex. Dealing with such complexity only by empirical research will be expensive and inefficient. Use of models and GIS will facilitate the transfer of workable technologies to similar agroecological zones. The use of DSSAT (Decision Support System of Agrotechnology Transfer), APSIM (Agricultural Production Systems Simulator), and GIS (Geographic Information System) will facilitate extrapolation of findings to other agroecozones similar of the benchmark sites chosen for testing technologies and will be cost effective.

Conclusions

There is potential for yield improvement in the African continent through soil fertility restoration technologies cleverly invented together with the users. Adoption is one of the main obstacles facing soil fertility and yield improvement hence widening food gap in the presence of working on-station developed technologies. Farmer socioeconomic and cultural setting should be an integral part of technology developed and tested. Both intercropping and rotation systems that have proved superior in many research works, for example, need to be tested together with farmers on farm if they are to be adopted. Farmer trials are indispensable in this era of research and are a good pillar in strengthening the Integrated Soil Fertility Management (ISFM) approach (Figure 13).

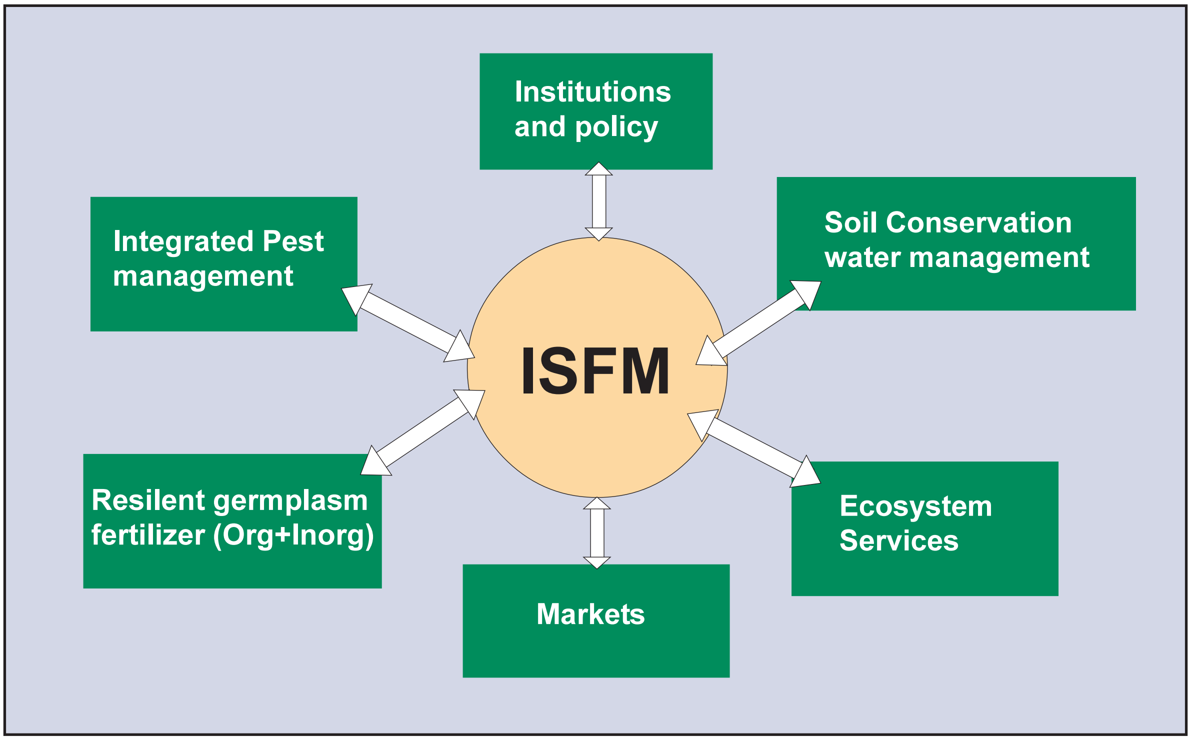

Figure 13. Integrated soil fertility management entry points.

African researchers and farmers need to take advantage of the available resources such as phosphate rock deposits, manure and crop residue to increase nutrients and yields. Efficiency optimization strategies will increase benefits from these resources and increase their appeal to the farmers.

Few technologies have been economically tested. Consideration of the economic benefits of the technologies may be an important prerequisite for the success of technologies. Besides, markets are increasingly becoming part of the research process since farmers have to trade off cash crops and the excess of their food crop produce. Participatory farmer research involving produce prices, post harvest processing and storage, farmer cooperatives should be conducted and may become an important incentive for technology adoption.

Use of decision support systems such as modeling and GIS applications will also help to extend the already concluded research findings to other areas. Such systems should find more use in the current and future research activities as pointers to new research and dissemination areas based on socio-economic and biophysical farmer constraints.

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Chapter 3

Crop and Tree Improvement and Productivity

Moderators: D Pasternak and M Gandah

Rapporteurs: R Matsunaga and K Traoré

Integrated *Acacia senegal*-based agroforestry for sustainable agriculture and rehabilitation of degraded systems

Mohamed Ahmed Elfadl[1] and Olavi Luukkanen[1]

Abstract

The general aim of the project is to develop models and techniques for sustainable agricultural and rehabilitation of forest production on lands that are already degraded or under the threat of degradation in the central gum belt region of the Sudan. The experiments were conducted in two contrasting sites: the sandy soils of western Sudan and the clay plains of central Sudan. The necessary equipment for taking the measurements were either provided by the local institutions or procured by the project. These include, Licor portable photosynthesis systems (Li-6400 & Li-6250), pressure chamber, neutron probe and theta probe. Soil analyses were done at the Agricultural Research Corporation (ARC) central laboratory, whereas other sophisticated measurements such as plant tissue nutrient analyses and determination of $\delta^{13}C$ *were done in Helsinki, Finland. Experiments on the sandy soils showed the following results:*

- *Seeds collected from trees grown on the sandy soils have shown better growth performance than those collected from trees on clay soil.*
- *Agricultural crops have no significant effect on seedling survival and growth, however, seedlings grown with sesame performed better.*
- *Soil working has no significant effect on seedling survival and growth.*
- *The gum yield of farm stands, whether planted or natural, was 47 to 60% lower than that of research stands.*
- *Late tapping reduced the gum yield by 40% and 50% at the two different locations.*
- *The yield was highly determined by the rainfall: the yield positively correlated with the rainfall in six out of eight years. Results can be used for improving the gum arabic yield by management interventions and for predicting the yield in relation to stand type, management regime and rainfall.*
- *Gum yield was positively correlated with tapping intensity, rainfall and the minimum and maximum temperatures at tapping time, and negatively correlated with tapping time and the minimum and maximum temperatures at gum collection.*
- *The time of tapping, tapping intensity, rainfall and the maximum temperature at gum collection were found to explain 73% ($r^2 = 0.73$) of the total variability in gum yield per unit area.*
- *The gum yield (g) of the first pick was highly correlated ($r = 0.93$) with total yield (g/tree). These models could help in understanding the causes of yield variability in gum arabic.*
- *The results indicated that as the tree size increases, the amount of water depleted from the soil profile increases.*
- *Strong correlation was found between the amount of water in the profile and photosynthesis rate. ($r=0.82$).*
- *Small trees deplete water from the topsoil layer (75cm), while larger trees extract water from deeper soil layers.*
- *Gum yield increased when sorghum was sown within the tree stands and the yield was higher when the density of trees was higher.*

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- *δ^{13}C indicates that Acacia senegal provenances from the sandy soil are more drought tolerant and with greater use efficiency than those from the clay soil.*
- *The gum arabic produced by A. senegal varied according to the geographical location of the source and the data showed significant differences in the values of gum optical rotation, solubility in water and viscosity.*

Introduction

The dryland of the Sudan constitutes about two thirds of the country's total area of 2.5 million sq km. The Sudan shows great variation in environmental conditions because of its geographical location in the southern fringes of the largest desert in the world, where rainfall is as low as 0-200 mm, and increases steadily toward the south to more than 1,200 mm, with frequent drought cycles. Afforestation/reforestation have been repeatedly attempted mainly for the purpose of combating desertification, particularly on marginal lands with wind-erodible soils, but quite often with ineffective results. This trend coupled with political/economic instability makes sustainability of agriculture in arid regions especially challenging. To promote sustainable agriculture, economic and social development, the Viikki Tropical Resources Institute of the University of Helsinki (Vitri) has suggested the integration of forestry into agricultural practices as the only strategy for poverty reduction and alleviation of many developmental problems in the drylands.

In many parts of the drylands of the Sudan, the progressive shortening of the fallow period, annual burning to maintain grass fodder, overgrazing, tree cutting for fuel, and inappropriate agricultural practices to produce agricultural crops have resulted in depletion of vegetation biomass and soil erosion. These changes are often difficult to reverse because of the positive feedback that tends to stabilize the new situation. As population pressure continues to increase, it becomes even more difficult to include a fallow period in the farming system. The bush-fallow system is eventually starting to disappear and is currently being replaced with permanent cropping. Low productivity and increase of human and animal population is coupled with expansion of area under cultivation on both forest area and on marginal lands in order to meet food and income needs.

As a result of prolonged drought in the Sudan, much of the woody vegetation was cleared for various reasons and the rest has dried up and blown by the wind. Hence, there has been no regeneration. Management and protection measures against over-exploitation, fire, and grazing might offer additional opportunities for increased exploitation and mitigation of the effects with help and involvement of local communities. In this aspect, local communities have a great role to play in natural resources management in terms of conservation and food production in an agroforestry setting.

The gum Arabic belt is the zone in which *A. senegal* (*hashab*), the tree that yields gum arabic, occurs naturally. This belt (300 km wide) lies entirely within the Sudano-Sahelian zone characterized by erratic and scanty rainfall, which is irregular and variable in amount, time and distribution. The gum belt comprises two types of soils: the sandy soils (*qoz*) dominate the western part of the country and the dark cracking clay soils extend over the eastern part. The gum arabic belt covers an area of about 52 million ha encompassing 2.8 million inhabitants. Wide areas of the gum belt support zero-input; unmechanized rainfed farming dependent on low and erratic summer rainfall, and comprising variable mixes of field crops, livestock and indigenous tree-crops.

In the Sudano-Sahelian zone in Africa and particularly in the Sudan, the best-known traditional agroforestry system is based on *A. senegal* the indigenous tree producing gum Arabic. Systems based on this species have been practiced for centuries for the production of gum Arabic, wood, fodder, and associated food crops. Recently, this system had been neglected because of transition to commercial agriculture, severe droughts, and indiscriminate clearing of natural *A. senegal* stands in favor of continuous cultivation of single agricultural crops.

The ability of dryland acacias to restore the land productivity is supported by evidence from traditional farming practices and from scientific research. The re-introduction of gum gardens and rehabilitation of degraded lands using *A. senegal* and other dryland acacia species can serve as a model for agricultural land rehabilitation for the entire Sudano-Sahelian zone. In order to carry out meaningful new scientific work it is an absolute necessity to collect and analyze the existing written sources on this topic. Casual surveys show that much of the scientific information on dryland rehabilitation lies hidden in technical reports and in the "grey" scientific literature and that the Sudan is one of the most important sources for existing information on dryland acacias and their role in land rehabilitation.

The Sudan is a country that, perhaps, can be best used as an example of environmental problems and their possible solutions in the entire Sudano-Sahelian zone of Africa. It is the largest country in the African continent and the one in which traditional dryland agroforestry systems based on acacias are most diversified and most important for the local as well as the national economy. The country has a long history of agricultural and forestry research and an earlier attempt to retrieve and disseminate the "hidden" scientific information has given promising results eg, "Sudan-Finland Forestry Programme Reprints" (Elsheikh and Luukkanen 1989).

In the Sudan, to date, efforts to restock the gum Arabic belt have not been met with great success due to poor quality of seedling and the lack of proper management guidelines or understanding of agroecological interactions of the trees. These in addition to the changing economic and social situation, the recent serious droughts and the increased popular awareness about the environment necessitate a deep re-examination of the knowledge to provide advice and management recommendations for silvicultural and agroforestry practices that can then readily be adopted by rural people.

Understanding of the ecophysiological aspects of the natural forests and agroforestry systems practiced will help in setting better management guidelines. In particular this information is needed for proper allocation of the limited water supply among components of the production system.

Trees are seldom distributed randomly in a stand or uniformly as expected, if the competition is the main process creating the spatial pattern of the trees. The small-scale variability of the soil is an appealing explanation to this variation, though soil surface often appears homogenous. The apparent homogeneity of the topsoil is often misleading as the soils of the study area have strongly layered structure. Soil degradation, wind and water erosion have also created new structures of variation.

On sandy soils in the North Kordofan State, field trials are underway for clarifying the adaptation of *A. senegal* populations, with the same set of provenances and parallel isozyme laboratory studies for designing optimal tree-crop systems with sesame, sorghum and *karkadeh* as agricultural crops (with pearl millet to be added in the future). The aim is also to determine the optimal silvicultural interventions for natural *A. senegal* forests converted to permanent agroforestry systems (so as to prevent total tree clearing by monoculture farming). The data available by the end of year 2000 consists of preliminary results on the problem of establishment of the seedlings when associated with agricultural crops and data on how the crops could negatively affect the establishment of seedlings. Results may also point out the effect of seed exchange on seedling survival and may suggest the use of seed zonation for the future. This means that, seeds are to be sown within a zone of similarity to their original environment. Moreover, preliminary results are now underway establishing the relationship between gum yield and tree density. It also indicates the effects of trees of different ages and densities on the soil moisture availability and how that links to tree-crop association. All these results are just indicatives as there is great heterogeneity in soil and climate.

Altogether, the results indicated the complexity of the system and call for more research work and more replications in time and space if sound results are to be obtained.

In the upper Blue Nile region (Ed Damazin), commercial gum Arabic production has been initiated by the private sectors on clay soils (previously not used for gum gardens); the ongoing field experiments will test the genetic variation and adaptation of *A. senegal*, as well as intercropping models with sesame, sorghum and sunflower as the main agricultural crops (with pearl millet to be added in the future). The data input covers wide area of research. It touches on the nutrient cycling starting form the first year of the association of seedlings and crops. It supports the results from the interaction experiment conducted on the sand site and helps to complete the rotation of the bush-fallow system. The initial measurements of soil and plant tissue nutrients have been done. The last season, soil-plant water relation data at year one has been collected. The physiological parameters of the seedlings both in the nursery and the field were measured. To determine the adaptation and genetic variability, the same lots of seeds sown on the sandy site were used in this site. Before sowing, the seeds and fruits were characterized. Records are now kept for the individual seed characteristics, seedlings growth and development in the nursery (both morphological and physiological parameters) and the same seedlings are now being followed in the field to study their performance under both contrasting sites.

Justification of the research

This research will contribute towards providing better understanding of the interaction of *A. senegal* and the associated agricultural crops. It is apparent that all known components have to be considered when management actions are made. This could be accomplished through understanding the ecosystem and the society and recognizing that they are inexorably linked. It has been obvious that the traditional bush-fallow system can no longer accommodate the cultivation cycle. Recently the demand for land has increased because of many factors, of which population increase is the main, and consequently the fallow period became shorter, and in many parts of the region the land is being continuously cropped and the marginal lands are not allowed to rest. This led to loss of soil fertility and deteriorated soil physical properties. This situation leads to decline in crop yields and consequently loss of the natural resource base for agriculture, the *A. senegal* tree.

This decline in yield has been attributed to many factors of which variability in rainfall is always mentioned. Other factors, such as pests and disease, poor genetic stock, and poor soil fertility also play an important role. Nitrogen deficiency is considered a major constraint to agricultural productivity. The present situation where the land has become scarce calls upon introduction of management methods where the land can be cultivated continuously and sustainably.

Theoretical framework

The changes that occur in natural systems in the gum belt are those of limited disturbances. Trees and grasses have interacted and coexisted for centuries without endangering each other. Some idea of the relation, however, can be formed and imitated for creation of a man-made synthetic system with the better understanding of what is available and what the ecosystem can readily offer and the requirement of the ecosystem components. Since we never know those ecosystems in sufficient details to compute their states to every instant of a change, instantaneous measurements of the current state of the ecosystem aided with the information and knowledge that could be obtained by studying the past history or external conditions, such as climatic change or past management practices, allows determination of the potentials for coexistence and to evaluate the trade-offs between the different land use options.

Much competition among plants takes place below ground, where plants root systems influence biogeochemistry, hydrology and primary productivity of terrestrial ecosystems. On the other hand, soil characteristics play a significant role in plant species distribution through their effects on root system development and subsequently on establishment of the growth of plant communities. As shown in our studies, water is the main factor limiting plant growth and competition is severe between the woody plants and agricultural crops for both water and nutrients. *A. senegal* is a deep-rooted tree species capable of using deep soil resources and its presence may enhance ecosystem productivity. In spite of that, many agroforestry experiments argued for the competition between trees and crops at the top 50 to 60 cm. Yet, the presence of such extensive deep roots in many systems and their functional importance is overlooked in current theories of ecosystem functioning and models.

A traditional *A. senegal* agroforestry system, been in practice in the Sudan for centuries, is always seen as complex and dynamic, reacting to a wide variety of long-term external changes and short-term disturbances including, climate, topography, soils, geomorphology, herbivory, fires and human intervention. There is much evidence for strong negative impacts of these changes on the traditional agroforestry system based on natural *A. senegal* forests. Understanding the nature of coexistence between the components of the ecosystem, which under other circumstances are mutually exclusive or unequal partners, yields theoretical insights and has practical implications for sustainable management. However, these modifications can take many forms, some of which have positive effects (facilitative) and others negative (competitive). In this respect, the three models, which have been proposed for the savannahs: Niche separation models, Balanced competition models and Disequilibrium models; seem to be inadequate for the current situation. In order to facilitate management options in *A. senegal*-based agroforestry, the CGIM model of the TSU and HyPAR v.3 model can be used (Huang 1998; Mobbs et al. 1999). Both models are aimed for prediction, simulation and identification of resources on which plants are competing in agroforestry systems for better understanding of the mechanisms involved and the ecological impact of those interactions.

Despite many common problems and interactions between sedentary, transhumant and nomadic production systems, to achieve focus, the project will not attempt to cover all the three. It is proposed to concentrate on the traditional sedentary *A. senegal*-based agroforestry (TSA) system, acknowledging the reality of fuzzy boundaries with the other two systems. If necessary, the inter-system relationships affecting TSA will be studied. From the planning stage, the project has sought the involvement of local farmers for their local knowledge and worked with local researchers for their scientific technical know-how and for utilization of the ARC facilities.

Altogether, the project is conceived as an interdisciplinary suite of interdependent social, economical and biophysical research and development activities. Research has started and is to be continued mainly at three levels: on gum Arabic research and demonstration forest reserve (Domokeya, Elobied Research Station), on privately owned land ascribed only for gum production and on a community land, but with some research-station back-up work where needed. Recognizing the long-term nature of many of the problems to be tackled, this research is designed as far as possible to be “dual-purpose” ie, to deliver:

a. Short-term production knowledge and technologies potentiallytransferable to farmers at an early stage, including those which confer an increase in efficiency in the utilization of the resource base and of immediate impact on improvement of the traditional practice(s).
b. Identification and quantification of the existing trends (positive or negative) affecting production and utilization of the present land condition and resource base and improvement of the management practices based on sound ecological principles and improved technology.
c. Promotion of current trends in research methodologies and institutionalization of a holistic resource-management approach in parallel with human resource development as the project seeks to build capacity among researchers as influential development personnel and to create a greater awareness among farmers as well.

The diverse patterns of plant growth observed in natural *A. senegal* trees are presumably a result of plants adaptation to each environment. Little is known on how site and climatic factors influence the balance between above- and belowground components and how these factors affect gum production. Results from the ongoing experiments conducted in the earlier phase of this project have shown that gum production per tree was higher when the density of trees was higher. Such results are surprising. It suggests that more research needs to be done for better understanding on how the system works. For example, research on the long-term impacts of environment and management on ecosystem properties, structure and function such as carbon sequestration, net primary productivity, nitrogen/carbon supply, nutrients and water balance of the system and their spatial and temporal variation. This might be important in understanding of the complexity of the *A. senegal* based agroforestry system and how carbon gained is divided between the different components of the ecosystem on general level and within a tree at the top of the hierarchy. Moreover, the immediate impact of the management interventions and human disturbance on the physiology of the tree and the associated agricultural crops or grasses.

Research programs

The research program covers the following thematic issues:

1. Early Establishment of *Acacia senegal* (L.) Willd (some provenances and from bulk seeds) in sandy soils.
2. Yield trends of gum Arabic from *A. senegal* as related to some environmental and managerial factors.
3. Improvement of traditional agroforestry: Ecophysiological characteristics as indicators for tree-crop interaction in natural tree stands.
4. Tropical dryland agroforestry on clay soils: Adaptation and yield of the components of *A. senegal* farming system of the Blue Nile region in the Sudan.

Cross-cutting research

1. Integrated approach for degraded rehabilitation in Gedarif area central Sudan.
2. The role of Sudanese women in land degradation and land rehabilitation.

Aim of the project

The overall general objective of this research is to provide a better understanding of agroforestry potentials as a productive, sustainable system through improved efficient use of the fragile resource base of the natural environment and to suggest mechanisms for their establishment and management in the Sudan and corresponding situations elsewhere in the Sudano-Sahelian zone.

Specific objectives

1. To develop methods to locate the most favorable areas, plots and points for tree establishment.
2. To model and evaluate, in terms of agricultural, gum and wood biomass production, *A. senegal* agroforestry systems in plantations and natural forests.
3. To determine the optimal silvicultural intervention especially thinning and pruning regimes needed for converting natural acacia forests to permanent agroforestry systems (and to prevent their total clearing for monocrop agriculture).
4. To investigate the effect of shoot pruning on root distribution, nodulation, soil water content and gum yield.
5. To examine the photosynthetic response and biomass accumulation in trees in relation to nutrients, moisture availability and management interventions.
6. To evaluate the genetic variation and performance in contrasting *A. senegal* populations on clay and on sandy soils, by using gumand wood biomass yield and morphological and physiological characteristics as criteria and by comparing these findings with isozyme analysis of their same population.
7. To study and improve gum production, especially by identifying high-yielding genotypes, which are adapted to the sites.

8. To study soil properties as affected by tree plantation and intercropping systems, so as to produce recommendations for practical rehabilitation procedures for smallholder farmers and other potential users.
9. To determine the profitability of the land use practices in a changing environment and society.

Hypotheses

- Spatial variation of the soil properties determines the spatial pattern of seedling establishment and tree growth.
- *A. senegal* compete for water and nutrients with agricultural crops.
- Nutrient cycling in *A. senegal* agroforestry is more efficient compared to the monocropping.
- Water-use efficiency and nutrient-use efficiency are higher under agroforestry system.
- Variability in gum arabic yield is influenced by climatic factors, management and silvicultural practices and has a genetic component.
- Gum arabic variability between trees can be explained by understanding the physiology of *A. senegal* tree.
- Gum yield is affected by stand density and the associated crop component.
- Trees with different age and size differ in their water-use efficiency.
- Well- adapted genotypes can be screened by their physiological traits.
- Well- prescribed pruning and thinning has positive effect on tree growth and crop yield but decline gum yield.

Technical field research and experiments

Experiments

1. Characterization of provenances collected from various parts of gum belt in the Sudan, monitoring their growth in the nursery and the field.
2. Determination of some physicochemical characteristics of the gum collected from the provenances.
3. Characterization of the growth of seedlings from bulk seeds of *hashab* when grown with agricultural crops in the field.
4. Effects of climatic factors, tapping dates and tapping intensity on gum Arabic yield.
5. Nutrient cycling dynamics and soil fertility management practices.
6. Water balance in trees of different age or size and their contribution to the depletion of soil moisture.
7. Water relations balance in an agroforestry system.
8. Investigation on the presence of ecotypic variation in *A. senegal*.
9. Effect of thinning and shoot pruning of *A. senegal* in an agroforestry system on: tree growth, crop growth and yield, gum yield and soil water content.
10. Modeling of integrated farming systems with *A. senegal* in drylands.

Some expected deliverables

1. Establishment of database of gum Arabic yields and yield trends for prediction of future production to match international demands and hence improving the gum industry.
2. Development of new method(s) for characterization of soils spatial variability that will help in locating favorable site for seedling establishment.
3. Production of superior planting stock of *A. senegal* for agroforestry and reforestation programs that would give high survival and better tree crop will have direct impacts on the rural poor and indirectly to the national economy in the Sudan, since gum Arabic is the leading export commodity. The results are of benefit to reforestation programs in the whole Sahelian region.
4. The project will provide information on the effect of socio-economic factors on current management systems and produce scenarios for the possible changes.
5. Provide decision-makers and land use planners with information on the characteristics that need to be maintained or created to ensure a productive and sustainable ecosystem.
6. In maximizing the quality and quantity of *A. senegal* tree products and its growth rate, the main benefits lie in generating additional income and earnings for the rural poor from the sale of gum and other related products of the tree, and also create off-season employment. This implies far-reaching implications on strengthening the economic role of poor rural women and improvement of their status.
7. New alternatives to the existing traditional system(s) will be formed through focusing on local basic problems, such as maintaining the quality of the environment and sustainably managing the existing resources (ie, agroforestry).
8. The results will lead to better understanding of the extent and pattern of natural variation in *A. senegal* and the adaptability of its provenance to potential planting sites. Such knowledge will also help in the selection of the right materials for future breeding work.
9. The result will provide a strong scientific backup to the local fundamental problems of land management and soil conservation, agro-ecological characterization, sustainable crop production and management, soil fertility, gum productivity etc.
10. Development of effective methods for helping projects and all agencies working in this and related fields.
11. Establishment of a coherent team of local researchers aware of ecosystems management and familiar with research methodologies, assessment and analyses.
12. This project will work in close collaboration with Forests National Corporation (FNC), the host of more than 10- years support from the then Finnish International Development Agency (FinnIDA) and it will improve further the capabilities of this institution. Results of this project will be of direct applicability to FNC and will also benefit FinnIDA-supported forestry projects of this kind in other countries and contribute significantly to the new scientific knowledge.
13. This project will provide training to young researchers from the Sudan and Finland on integrated farming systems with emphasis on multi-disciplinary and a holistic approach.
14. The project will produce three doctorate degrees in dry land ecosystem management, farming system and/or management of *A. senegal*-based agroforestry systems. Several articles in reviewed international journals will be produced in collaboration with local researchers.

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Sélection de nouvelles variétés synthétiques de mil tolérantes au mildiou à travers la participation paysanne

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Résumé

Le mil [Pennisetum glaucum (L) R. Br] est l'une des principales cultures céréalières du monde. Sa culture est confrontée à différentes contraintes dont le mildiou. Pour résoudre cette contrainte, 10 nouvelles variétés tolérantes au mildiou ont été créées à la Station de Recherche Agronomique de Cinzana (SRA-Cinzana). Elles ont été comparées à leurs parents, à 3 témoins de différents niveaux de sensibilité au mildiou et au témoin local. L'évaluation a porté sur l'adaptabilité, le potentiel productif, l'incidence du mildiou en condition naturelle d'infestation. Elles ont été soumises à l'appréciations de 20 paysans pour identifier les variétés qui répondent à leurs préoccupations. Les critères d'appréciation des paysans ont été définis. Les appréciations ont porté sur le cycle, les composantes de rendement et l'incidence du mildiou. Les paysans ont caractérisé chaque variété, identifié leurs points forts et points faibles et effectué des choix.

Les résultats de l'évaluation ont montré qu'il n'y a pas de différences fondamentales entre les critères de sélection des paysans et ceux des chercheurs excepté l'appréciation du cycle. Les nouvelles obtentions ont enregistré des gains génétiques significatifs par rapport à leurs parents pour le potentiel productif, la tolérance au mildiou. Les synthétiques CzSyn 03-09, CzSyn 03-10 et CzSyn 03-03 ont un rendement supérieur de l'ordre de 40 à 26% respectivement par rapport à celui de leurs meilleurs parents. Elles demeurent cependant moins productives que la locale. Les synthétiques CzSyn 03-01, CzSyn 03-03 et CzSyn 03-05 sont indemnes de mildiou contrairement à leurs parents. Le caractère de non sénescence (stay green) assimilé par les paysans comme signe de tolérance à la sécheresse post florale a été constaté et apprécié chez les synthétiques CzSyn 03-01 et CzSyn 03-10. En dépit de tous ces acquis, la locale a été préférée par les paysans aux nouvelles obtentions en raison de son adaptabilité, de sa vigueur et de l'aspect de sa chandelle.

Abstract

Pearl Millet, Pennisetum glaucum *(L.) R. Br., is one of the main cereal crops in the world. Its cultivation is facing many constraints, one of which is the downy mildew. Towards resolution of this problem, 10 new mildew-resistant varieties have been created at SRA-Cinzana (Station de Recherche Agronomique de Cinzana). They were compared to theirs parents; to 3 control varieties of different susceptibility to downy mildew and to the local variety. We evaluated adaptability, potential production and mildew incidence under natural infestation condition.*

They have been offered to 20 farmers for appraisal and for identifying ones which serve their needs better. The appraisal criteria were cycles, yield components and mildew incidence. Farmers made characterization of each variety, identified their weak and strong points and proposed their choice.

The results of appraisals showed that there were no fundamental differences between farmer's and researcher's selections. Significant genetic gains from new varieties compared to their parents have been recorded for productivity and mildew susceptibility. Synthetic varieties, CzSyn 03-09, CzSyn 03-10 and CzSyn 03-03 have 26 to 40% superior yield compared to their best parents. However they

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stay less productive than the local one. Synthetic varieties CzSyn 03-01, CzSyn 03-03 and CzSyn 03-05, contrary to their parents, are unaffected by mildew. Non-senescence characteristics taken as a sign of a post floral drought tolerance by farmers, has been noted for the synthetic varieties CzSyn 03-01 and CzSyn 03-10. In spite of these outputs, the farmers preferred the local variety to the new ones because of its adaptability, its vigor and the appearance of its head.

Introduction

Le mil [*Pennisetum glaucum* (L) R. Br] est l'une des principales cultures céréalières du monde. Il constitue la principale culture pour des millions d'individus de la zone sahélienne de l'Afrique de l'ouest et du nord de l'Inde. Il est cultivé dans cette partie sur environ 36.000.000 ha dont 15.000.000 en Afrique et 13.000.000 en Inde (Hanna 1998). En Afrique de l'ouest, le mil représente une part importante de la production céréalière. Pendant la campagne 1999-2000 dans 9 pays de l'Afrique de l'ouest, il représentait 47% de la production, contre 27% pour le sorgho, 14% pour le riz et 10% pour le maïs (Anonymous 2000).

Cultivé pour plusieurs raisons, le mil est essentiellement utilisé dans l'alimentation humaine et animale, comme bois de chauffe et pour la construction des hangars. Sa culture est confrontée à différentes contraintes dont le mildiou causé par *sclerospora graminicola*. Il peut affecter les plants à chaque stade de son développement par infestation primaire et secondaire. Il peut rendre les feuilles sclérotiques et jaunâtres, transformer totalement ou partiellement la chandelle en organe foliacé, provoquer un rabougrissement de la plante et entraîner sa mort. Généralement, les pertes de rendement grain occasionnées par le mildiou n'excèdent pas 20%. Cependant dans des zones endémiques, l'importance des dégâts peut atteindre 30–40% (Andrews 1987). Au Mali ces pertes de rendement sont de 40% (Scheuring 1980).

Il existe différentes méthodes de lutte contre le mildiou. Parmi ces méthodes**,** l'alternative la plus efficace et la moins onéreuse pour les paysans est de disposer des variétés résistantes ou tolérantes. La création de variétés synthétiques tolérantes s'inscrit dans ce cadre. Cependant, malgré les efforts considérables de la recherche et de la vulgarisation, peu de variétés améliorées ont été adoptées par les paysans (Matlon 1985). Les nouvelles obtentions ne se comportent pas mieux que les variétés locales dès qu'elles sont cultivées sous la gestion paysanne (Galt 1989 ; Simmonds 1991, Kouressy et al. 1998).

Des expériences de l'Equipe Système de Production et de Gestion des Ressources Naturelles de Sikasso (Mali), ainsi que celles d'autres pays d'Afrique de l'Est ont montré clairement la nécessité d'impliquer les paysans dans le processus de recherche. Une analyse critique de l'expérimentation en milieu paysan par Kamara (1993) a montré les limites de la faible implication des paysans dans le processus de recherche. Dans le soucis de prendre en compte les appréciations paysannes sur le choix des variétés, des paysans ont été associés à l'évaluation du matériel au stade de l'essai préliminaire de rendement. Dans cet article, nous aborderons les critères d'appréciation paysanne, les choix des paysans ainsi que la réaction des paysans sur les performances des nouvelles obtentions.

Matériels et Méthode

Des croisements ont été effectués entre deux écotypes locaux Sanioba 12 et Boboniba 13) et deux parents mâles qui sont des lignées expérimentales (CInzana VARiété EXpérimentale-CIVAREX). Les parents femelles sont photosensibles, adaptés à la zone sahélienne mais sont sensibles au mildiou et de grande taille. Tandis que les géniteurs sont résistants au mildiou, de courte taille et possèdent un bon tallage fertile. L'étude des descendances de croisement a été effectuée dans la pépinière sous forte infestation artificielle afin d'obtenir des lignées indemnes de mildiou.

L'objectif des croisements était d'obtenir dans un délai relativement court des variétés synthétiques tolérantes/résistantes au mildiou, photosensibles, légèrement précoces par rapport à la locale, de taille courte à moyenne et possédant un bon tallage fertile.

Le matériel végétal était composé de 10 nouvelles variétés synthétiques de mil tolérantes au mildiou. Les noms et pedigree des synthétiques sont consignés dans le Tableau 1.

Tableau 1. Nom et pedigree des descendances de croisement impliqués dans l'étude.

Nom	Pedigree	Nom	Pedigree
CzSyn 03-01	Sanioba 12 x Civarex 9106	CzSyn 03-06	Sanioba 12 x Civarex 9105
CzSyn 03-02	Sanioba 12 x Civarex 9106	CzSyn 03-07	Boboniba 13 x Civarex 9105
CzSyn 03-03	Sanioba 12 x Civarex 9106	CzSyn 03-08	Boboniba 13 x Civarex 9105
CzSyn 03-04	Sanioba 12 x Civarex 9105	CzSyn 03-09	Boboniba 13 x Civarex 9105
CzSyn 03-05	Sanioba 12 x Civarex 9105	CzSyn 03-10	Boboniba 13 x Civarex 9105

Les 10 nouvelles variétés synthétiques étaient comparées à leurs parents Sanioba 12, Boboniba 13, Civarex 9105 et Civarex 9106, aux témoins de résistance au mildiou (ICMV 92326), de sensibilité (7042), et de tolérance (SoSat) ainsi qu'au témoin local (Boboni de Sanogola)

L'essai a été semé le 5 juillet à la SRA de Cinzana en 2 répétitions aux écartements de 0,75 m x 0,50 m sur des parcelles élémentaires de 5 mètres de long et 2,25 mètres de large. La parcelle a été pulvérisée et billonnée. Les entretiens culturaux ont porté sur l'apport de 100 kg/ha de phosphate d'ammoniaque au semis et 50 kg/ha d'urée à la montaison, deux désherbages, le buttage et le démariage à 2 plants par poquet. Les semences n'ont reçu aucun traitement fongicide en raison de la nature de l'étude.

Le matériel a été soumis à l'appréciation de 20 paysans ayant une bonne connaissance dans la gestion des variétés au niveau local. Ces paysans viennent des 4 antennes de la Station de Recherche Agronomique de Cinzana. Ils ont été repartis en 4 groupes. L'évaluation a été faite à la maturité physiologique et s'est déroulée selon la méthodologie suivante:

1 Définition par les paysans des critères d'appréciation de la bonne variété. Pour éviter que les réponses des uns n'influencent celles des autres, cette partie de l'entretien a été individuelle.
2 Présentation de l'objectif de l'essai et des différentes variétés à l'ensemble du groupe.
3 Caractérisation par le groupe du cycle, du tallage, de l'aspect de la chandelle et l'importance des dégâts causés par le mildiou.
4 Identification des points forts et des points faibles de chaque variété par l'ensemble du groupe.

5 Choix des variétés par les paysans. Pendant cette étape, chaque paysan a attaché une banderole sur la chandelle de la variété choisie. Une nouvelle visite des parcelles a été organisée pour permettre aux paysans d'opérer leurs choix. Les raisons du choix ont été précisées.

Résultats et discussions

Critères de sélection des paysans

Pour le choix d'une bonne variété 13 critères ont été définis par les paysans dont 7 pour la phase de culture et 6 pour la phase culinaire. Les résultats obtenus sont consignés dans le Tableau 2.

Les critères liés aux composantes de rendement tels que la vigueur à la levée, le tallage, l 'aspect de la chandelle (la longueur et compacité des chandelles, la grosseur et la couleur des grains) occupent environ 65% des préoccupations des paysans. Les contraintes biotiques comprenant le mildiou, les chenilles mineuses des épis et le striga occupent la deuxième place avec environ 25%. Parmi ces contraintes le mildiou est la contrainte la plus importante (15%). Cependant l'un des faits marquants de l'inventaire des critères de sélection est l'absence de la sécheresse parmi les critères retenus. Cette omission, à priori, surprenante pour des paysans qui sont fréquemment confrontés à des poches de sécheresse pourrait s'expliquer par la bonne pluviométrie de cette année. D'où la nécessité de toujours prendre en compte le contexte environnemental dans lequel l'inventaire a été effectué.

Pour les appréciations culinaires, les critères les plus importants sont l'aspect farineux, le goût et le rendement au décorticage. Une bonne variété doit contenir beaucoup de farine que de brisures, contenir moins de son, avoir un bon goût, une bonne coloration et une bonne consistance du tô qui est l'un des plats traditionnels au Mali.

Dans l'ensemble ces critères sont conformes à ceux des chercheurs. En raison de la très forte probabilité d'arrêt précoce de la pluie, l'accent a été mis sur des variétés photosensibles dont le cycle est légèrement plus précoce que la locale d'environ 5 à 10 jours.

Analyse de la réaction des paysans sur les performances agronomiques.

Les observations faites par les chercheurs et celles faites par les paysans sont synthétisées respectivement dans le Tableau 3 et 4.

Tableau 2. Inventaire de l'appréciation des critères de sélection des paysans.

Appréciations au champ	Score	Pourcentage	Appréciations Culinaires	Score	Pourcentage
1. Tallage	18	25	1. Farineux	9	33,3
2. Vigueur à la levée	13	18	2. Goût	8	29,6
3. Aspect chandelle	16	22,2	3. Rendement décorticage	6	22,2
4. Adaptation du cycle	7	9,7	4. Vitrosité	1	3,7
5. Tolérance au mildiou	11	15,2	5. Couleur du tô	1	3,7
6. Tolérance chenilles mineuses des épis	6	8,3	6. Consistance du tô	1	3,7
7. Striga	1	1,6			

Le critère d'appréciation du cycle des variétés par les paysans a été la faculté de la variété à faire coïncider la fin de son cycle avec la fin de la saison des pluies (photosensibilité). La référence était la locale. En fonction de ce critère 3 groupes de variétés ont été dégagés par les paysans avec des appréciations différentes.

1 Réaction favorable pour CzSyn 03-05 car ayant le même cycle que la locale.
2 Réaction défavorable par rapport à CzSyn 03-10 car ayant un cycle plus long que celle de la locale
3 Réaction mitigée pour les 8 autres synthétiques car ayant un cycle plus court que la locale. Dans ce groupe l'écart de la période de floraison de ces variétés et celle de la locale varie entre 13 et 3 jours. Dans ce groupe 3 variétés ayant un cycle statistiquement égal à celui de la locale ont été appréciées. Parmi les variétés précoces 3 synthétiques ayant un cycle légèrement plus précoce que la locale ont été appréciées car pouvant échapper aux arrêts précoces de la pluie sans être exposées aux attaques des oiseaux. Il s'agit de CzSyn 03-01, CzSyn 03-02 et CzSyn 03-08. Par contre les 5 autres variétés très précoces ont été désapprouvées par les paysans. Cette désapprobation pourrait s'expliquer, soit par les dégâts causés par le charbon sur CzSyn 03-07 et CzSyn 03-03 et soit par les dégâts de dysdercus sur CzSyn 03-06 (Tableau n°3). Les dégâts causés par le charbon et les dysdercus sont cependant mineurs. Il est à noter qu'aucune des nouvelles obtentions n'ont été sujettes aux attaques d'oiseaux contrairement à ICMV 92323.
4 Cette désapprobation de certaines variétés par les paysans à cause de leur précocité doit être située dans le contexte de la durée de la saison de pluie exceptionnelle de cette année. Très probablement leurs appréciations seraient différentes en cas d'arrêt précoce de la pluie. En raison des incertitudes liées à la fin probable de la saison des pluies, au niveau de la recherche, l'accent a été mis sur des variétés qui fleurissent 7 à 10 jours avant la locale.
5 La pression du mildiou a été particulièrement importante cette année. Pour caractériser le comportement des variétés par rapport au mildiou, les paysans ont utilisé les termes absence, trace et importance du mildiou. Ces trois termes pourraient correspondre respectivement à résistance, tolérance et sensibilité. A partir de cette classification on obtient 3 groupes.
6 Absence de mildiou : CzSyn 03-01, CzSyn 03-05 et le témoin de résistance ICMV 92386.
7 Trace de mildiou : 6 nouvelles synthétiques et les 2 parents mâles.
8 Importance: CzSyn 03-08 et CzSyn 03-10, la locale.

Les deux premières variétés sont indemnes de mildiou. (Confère Tableau 3). Le témoin de tolérance SoSat a été particulièrement affecté avec une incidence de 35%. Excepté CzSyn 03-08, CzSyn 03-10, toutes les nouvelles obtentions ont des notes qui sont comprises entre celle du témoin de résistance et celle de SoSat. La CzSyn 03-10 avec une incidence de 79% est la synthétique la plus sensible même si elle est moins affectée que le témoin de sensibilité. Dans l'ensemble, ces observations des chercheurs sont conformes aux appréciations des paysans (Tableau n°4). Les variétés résistantes et tolérantes au mildiou ont été appréciées. Il s'agit des synthétiques : CzSyn 03-01, CzSyn 03-03 et CzSyn 03-05. Cependant, les paysans ont précisé que l'importance du nombre de plants malades n'a pas d'incidence significative sur le rendement. Ainsi, la locale bien que très attaquée par le mildiou a été appréciée par les paysans. La classification paysanne s'est faite en fonction de la sévérité et non en fonction du nombre de plants malades.

Pour le tallage, de l'avis des paysans six synthétiques ont un bon tallage dont 3 ont un bon tallage fertile. Il s'agit des CzSyn 03-01, CzSyn 03-03 et CzSyn 03-10. Les variétés qui ont un tallage fertile moyen ou faible n'ont pas été appréciées par les paysans.

Concernant l'aspect des chandelles, les appréciations ont porté sur la longueur, la grosseur des grains, la compacité et le remplissage des chandelles par les grains. Les synthétiques sont issues des croisements entre variétés qui ont des chandelles courtes ce qui expliquerait la courte taille de leur chandelle (Tableau 3). Cependant la CzSyn 03-03 avec 35 cm possède la chandelle la plus longue de la série mais elle n'est pas statistiquement différente de CzSyn 03-07. Les synthétiques CzSyn 03-02, CzSyn 03-03, CzSyn03-08, CzSyn03-09, CzSyn03-10 ont été appréciées par les paysans pour la compacité et le remplissage des chandelles. Les CzSyn 03-03, CzSyn 03-09 et CzSyn 03-10 ont été appréciées pour la grosseur des grains. La CzSyn 03-06 a été appréciée pour la présence de deux grains par involucre. Les paysans n'ont pas apprécié le mauvais remplissage des chandelles des CzSyn 03-01, CzSyn 03-06 et CzSyn 03-07. Pour la CzSyn 03-01, le mauvais remplissage est d'ordre variétal. La couleur violacée des soies de la chandelle pourrait expliquer le mauvais remplissage de ses chandelles. Il concerne les parties basale et apicale des chandelles qui sont complètement dégarnies. Pour les deux autres variétés, le mauvais remplissage des chandelles est dû aux attaques des chenilles mineuses des épis et aux dysdercus.

Les choix des paysans ont porté sur 4 des 18 variétés. Il s'agit de la locale, CzSyn 03-01, CzSyn 03-09 et de CzSyn 03-10 (Tableau 4) avec respectivement des scores de 50 ; 25 ; 20 et

Tableau 3. Synthèse des résultats des performances morpho-agronomiques des variétés suivant la notation des chercheurs.

Variétés	HMP (cm)	50% flo (J)	LoC (cm)	NTF	Mildiou (%)	Rdt(kg/ha)
CzSyn 03-01	102	77	29	194	0	1090
CzSyn 03-02	250	75	28	184	25	1380
CzSyn 03-03	240	67	35	234	2	2245
CzSyn 03-04	230	70	25	218	5	1840
CzSyn 03-05	210	80	22	219	0	1445
CzSyn 03-06	165	71	30	160	12	1090
CzSyn 03-07	160	70	31	137	4	1245
CzSyn 03-08	210	76	27	197	40	1180
CzSyn 03-09	240	71	27	228	9	2110
CzSyn 03-10	255	83	28	217	79	2270
Civarex 9106	170	73	27	85	5	755
Civarex 9105	150	71	27	151	6	980
ICMV 92326	210	56	34	181	2	1045
7042	140	73	16	5	97	25
Boboniba 13	255	78	30	190	19	1670
SoSat	205	58	24	185	35	1045
Sanioba 12	220	71	33	155	29	1355
Boboni de Sanogola	305	80	32	199	43	2910
CV%						
Signification	7	3,25	8,36	16,3	47,7	19,99
traitement	HS	HS	HS	HS	HS	HS
PPDS	25	4	4	49	19	285

HMP : Hauteur moyenne des plants

50% flo (J): délais semis-50% floraison

LoC : longueur des chandelles

NTF: nombre de talles fertiles

Mildiou: Incidence mildiou

Rdt: rendement grain

Tableau 4. Récapitulatif des avis des paysans.

Varietes	Points forts	Points faibles	Nombre de paysans ayant choisis les variétés
CzSyn 03-01	Absence de mildiou, résiste à la sécheresse, bon tallage fertile, légèrement précoce, Chandelle compacte.	Chandelles courtes avec parties apicale et basale dégarnies de grain, traces de charbon.	5
CzSyn 03-02	Présence de mildiou, bon tallage, chandelle compacte et bien remplie, légèrement précoce.	Tallage fertile moyen, attaque importante de chenilles foreuses des tiges, précoce, sensible à la sécheresse.	0
CzSyn 03-03	Présence de mildiou, bon tallage fertile, chandelle bien remplie et gros grain.	Beaucoup de tiges cassent, sensibleà la verse, sensible à la sécheresse, traces de charbon.	0
CzSyn 03-04	Présence de mildiou, bon tallage, chandelle bien remplie, tolère la sécheresse.	Chandelle courte, tallage fertile moyen.	0
CzSyn 03-05	Présence de mildiou, cycle adapté.	Chandelle courte, tallage fertile moyen, mauvaise vigueur.	0
CzSyn 03-06	Tolérant au mildiou, 2 grains par involucre.	Faible tallage fertile chandelle pas bien remplie suite aux attaques de dysdercus, grain petit, chandelles semi-compactes.	0
CzSyn 03-07	Présence de mildiou.	Tallage fertile moyen, beaucoup de charbon, grain petit, beaucoup d'attaques de chenilles mineuses des épis. Précoce. Chandelle vide par endroits.	0
CzSyn 03-08	Chandelle bien remplie et compacte, grain de couleur blanche, légèrement précoce.	Sensible au mildiou et à la sécheresse, tallage moyen.	0
CzSyn 03-09	Présence de mildiou, bon tallage, cycle adapté, tolère sécheresse, chandelle bien remplie, gros grain.	Tallage moyen.	4
CzSyn 03-10	Chandelle bien remplie et compacte, bon tallage fertile, résiste à la sécheresse, chandelle bien remplie, gros grain.	Beaucoup d'attaque de mildiou.	1
Civ 9106	Tolérant mildiou et charbon, gros grain.	Chandelle courte semi–compacte, vide par endroits, tallage moyen, précoce.	0
Civ 9105	Tolérant mildiou, chandelle bien remplie, bon tallage, grain moyen.	Faible tallage fertile, chandelle pas bien remplie.	0
ICMV 92326	Absence de mildiou, chandelle longue, bon tallage.	Très précoce, sensible aux attaques d'oiseaux.	0

continué

Tableau 4. *continué*

Varietes	Points forts	Points faibles	Nombre de paysans ayant choisis les variétés
7042		Tous les plants sont décimés par le mildiou, très précoce.	0
Boboniba 13	Bon tallage, tolère mildiou et la sécheresse, cycle adapté, chandelle longue.	Chandelle moins garnie. Semi-compacte.	0
SoSat	Chandelle bien remplie et compacte, bon tallage, gros grain.	Très précoce, beaucoup d'attaque de mildiou et aux chenilles foreuses des tiges, chandelles courtes.	0
Sanioba 12	Chandelle bien remplie, chandelle longue.	Faible tallage, grain moyen, beaucoup d'attaque de mildiou.	0
Boboni de Sanogola	Chandelle longue et compacte, cycle adapté, bon développement végétatif, tige robuste, bon tallage.	Beaucoup de mildiou, tallage fertile moyen, petit grain.	10

5%. Concernant le choix de la locale, les atouts majeurs sont la photosensibilité (adaptation de son cycle par rapport à la pluviométrie), le bon développement végétatif, la longueur et la compacité des chandelles et le tallage fertile moyen. Le principal défaut est le nombre de plants attaqués par le mildiou qui est important. En effet, elle occupe la 16ème place concernant la notation de l'incidence du mildiou (Tableau n° 3). Cependant, cette forte présence du mildiou n'a pas eu d'incidence notable sur son développement végétatif et son potentiel de rendement. Ce choix est encore conforté par la première place que la locale occupe pour le rendement grain (donnée non disponible au moment de l'évaluation paysanne). De l'avis des paysans, la forte présence de plants attaqués dans la parcelle de la locale n'était pas de nature à affecter de façon significative son potentiel productif.

Lorsque l'on se réfère à l'appréciation paysanne, la place occupée par la CzSyn 03-10 devient surprenante. En effet en comparant les appréciations paysannes (tableau n°4) et les données de caractérisation morpho-agronomique de la locale à celle de la CzSyn 03-10 (Tableau n°3), on est surpris par la ressemblance de ces deux variétés. La CzSyn 03-10 est plus tolérante à la sécheresse que la locale. Cette variété aurait du occuper la première ou la deuxième place, cependant sur les 20 paysans, uniquement 1 seul l'a préféré. Néanmoins, la locale et la CzSyn 03-10 sont de bonnes variétés et la présence de mildiou n'a pas eu d'incidence majeure sur leur comportement.

La deuxième place occupée par la CzSyn03-01 pourrait s'expliquer par 3 facteurs importants qui sont: la résistance au mildiou, la tolérance à la sécheresse post-florale (Stay green) et le bon tallage fertile. Il faudrait signaler cependant qu'il n'y a pas eu d'étude physiologique pour connaître la sensibilité de cette variété à la sécheresse. La résistance à la sécheresse post florale n'est qu'une observation subjective visuelle au champ. Cette observation est également valable pour la CzSyn 03-10. Le principal défaut de la CzSyn 03-01 est l'aspect de la chandelle qui est de courte taille et pas bien remplie. Ce qui explique son faible potentiel productif. Les informations sur le rendement grain n'étaient pas disponibles au moment de l'évaluation paysanne.

Conclusion

Ce programme de création variétale a permis de mettre au point des variétés qui ont apporté des améliorations sur 3 aspects par rapport aux parents.

1 Concernant le potentiel productif, les variétés CzSyn 03-10 et CzSyn 03-03 ont un rendement plus important que ceux de leurs parents avec un gain génétique de 40 à 26% respectivement par rapport aux parents femelles et respectivement 66% et 57% par rapport aux parents mâles.

2 Pour la tolérance au mildiou, les variétés CzSyn 03-01 et CzSyn 03-05 sont indemnes de mildiou contrairement à leurs parents.

3 Les variétés CzSyn 03-01 et CzSyn 03-10 contrairement à leurs parents conservent leur feuillage vert jusqu'à la maturité. Ce qui peut être assimilé à la tolérance à la sécheresse post-florale.

Des efforts importants restent à fournir pour obtenir des variétés répondant aux aspirations des paysans dans le domaine de la lutte variétale contre le mildiou.

Compte tenu de la variabilité pathogénique, les nouvelles obtentions seront évaluées dans des hot spots afin de les soumettre à différentes souches de *sclerospora graminicola*.

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Quantification of village level agroforestry biodiversity according to management units and its livelihood functions in three villages of the Ségou region, Mali

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Abstract

Recent decades have not been kind to the Sahelian landscape or the people who inhabit this band of semi-arid land that stretches from Senegal in the west to Chad in the east. Its northern edge is being pushed southwards as the sands of the Sahara Desert swallow up vast tracts of formerly arable land. And as repeated droughts hit this fragile Sahelian buffer separating desert from savannah lands further south, the flora and fauna of the Sahel suffer. Inevitably, so do the people.

That is not to say that the people of the Sahel have not learned, over time, how to manage the scanty natural resources around them. During the clearing of forest for agricultural production, farmers conserved specific trees that grew on their cropland. These offered invaluable fruit for food security, leafy vegetables for sauces, oils, medicines, fodder, fibre, and wood for construction and fuel, and also shade, which is a precious commodity for humans and livestock in the hot Sahel. These traditional agroforestry systems are known as parklands and they evolved over centuries from shifting cultivation. Sahelian populations attached great importance to many of these 'parklands' trees that they retained in the farm landscape in their indigenous agroforestry system.

But the parklands system is in trouble. It faces pressure from biophysical, socioeconomic and policy issues. For these reasons, we are undertaking a key study of biodiversity in the parklands system in and around the important historical town of Ségou in Mali and how best to conserve and promote it in the Sahel.

From the preliminary results we are able to determine actual levels of biodiversity and how they are related to villages and management units. It is clear that biodiversity varies between individual villages and different land management units. "Village fields", close to the homesteads, have the least biodiversity and lowest tree density. "Bush fields" where varying periods of natural fallows are practiced have more biodiversity. The greatest biodiversity and tree density is found in pastureland, which is unsuited to crop production and is left for grazing and utilization of forest products. The species are also ranked using farmers criteria in terms of preference. The most important products for which farmers value trees in the study area are food, medicine, fuel, and fodder. This research provides strong basis for the orientation of future research and dissemination activities for the rehabilitation of the Sahelian traditional parklands.

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Introduction

The parkland system is the most widespread indigenous agroforestry system in the arid and semiarid lowlands of the Sahel. The system originated from the old practice of shifting cultivation. During clearance of forest for agricultural production, farmers conserve trees that grow on crop fields for the protection of crops and workers from the sun, and for the supply of fuelwood, fodder, fruits, and medicinal products (Kater et al. 1992; Kessler 1992; Jaiyeoba 1996). In the Sahelian zone, woody species producing useful products and providing shade are preferred; other trees are cut at knee height and burnt with their branches. Some of the burnt trees die, but many resprout every year (Breman and Kessler 1995). Though natural regeneration of such species is favored and even assisted during the cropping phase, planting them is rather exceptional.

The trees that are maintained assiduously include a large number of species. The most common ones are *Parkia biglobosa*, *Vitellaria paradoxa*, *Faidherbia albida*, *Adansonia digitata*, *Borasus aethiopium*, *Bombax costatum*, *Pterocarpus erinaceus*, *Prosopis* spp. and *Acacia* spp.. The species diversity in the parkland system is very much related to ecological conditions: as the rainfall in a region increases, the species diversity and system complexity increase (Nair 1993). This is illustrated in the semi-arid Sub-Saharan Africa (SSA) where parklands are of higher density and diversity in the Sudanian zones (900 to 1200 mm rainfall per year) than in the Sahelian ones (150 to 600 mm rainfall per year). Breman and Kessler (1995) report that the average densities range from 5 to 20 trees per ha. The highest densities recorded are 300 *Borassus aethiopium* per ha and 50 *Faidherbia albida* per ha.

Although parklands occur in other areas of the world, such as southern Africa and the Mediterranean, it is here in the semi-arid West Africa that the parkland systems are most widespread, for example in Mali, occupying 90% of the agricultural land.

The ecological and socioeconomic importance of these parkland systems is widely recognized in terms of the multiplicity of products and services that they provide. Parkland trees are important sources of food and nutritional security; producing fruits, oils, leaves, nuts and spices that are the main components of diet. Trees also supply wood for multiple uses, medicine for human and animal health and feed for livestock. They are an important source of additional income particularly during the hunger period and for the less endowed section of the population. Studies undertaken in the region have shown that shea nuts were sold at US$150 per ton in Burkina Faso in 1994-1995, contributing as much as US$35 per annum to households and estimated to be the third most important export earner for the country in the mid 1980s. A US$270 increase of household income is estimated every year through the sale of néré fruits and a return of US$55 per hectare per year was reported from a farmland having eight *V. paradoxa* and *P. biglobosa* trees per hectare. Baobab leaves (high in vitamin A) are eaten fresh or dried and ground into powder for use in sauces. *Parkia biglobosa* produces pods from which the seeds are processed into a spicy paste, 'soumbala', and the yellow powder—made out of the pulp—is used as a porridge.

In addition, parkland systems provide very important environmental services. They have beneficial effects on the microclimate, reducing temperatures by 5–10 ºC at 2 cm soil depth (subsequently improving moisture retention and lowering other detrimental effects of high temperatures).

Bonkoungou (1992) highlights that Sudano-Sahelian Africa has not developed a planting tradition; thus, today the combined effects of land pressure and drought are degrading many tree stands. The absence of planting tradition constitutes, at least in part, a serious constraint to regenerating existing parks or establishing new ones. A general observation is that the parklands are victims of ageing (the trees are decades or even hundreds of years old!). Trees and shrubs are either dying or very unproductive in terms of biomass, soil fertility improvement, and other products and services. The very low tree density (5 to 20 trees ha^{-1}) mentioned by Kessler and Breman (1991) as compared with the 20 to 50 trees ha^{-1} density about thirty years ago is striking evidence. Research and development efforts have been recently focused on (a) "assisted natural regeneration" of native species where farmers protect stump sprouts and root suckers, (b) experiment with different management practices (timing and severity of pruning), and (c) planting young seedlings (including new species) in an effort to increase tree density and/or rejuvenate the system. However, these efforts are limited in scope and not well documented yet.

It is in the light of these many considerations that the present research is initiated in the Ségou region, Mali using simultaneously, socioeconomic and biophysical research approaches to ensure greater benefits of the system through conservation of agroforestry biodiversity in the parkland system.

Hypotheses

The main hypothesis the present study aims to test is that 'agroforestry biodiversity of the parkland system is different with respect to villages and management units within the village territory'.

Objectives

The main objective of the study is to characterize and quantify species biodiversity within and between villages and land management units in the Ségou region.

Materials and Methods

Description of the study area

The study has been undertaken in seven villages belonging to different ethnic groups in the Ségou region, Mali. The Ségou region is located between 12°30' and 15°30' N and 4° and 7° W. The region, 55,000 km^2 in area, hosts 1,675,357 inhabitants (DNSI 2001) mainly comprising *bobo*, *bamanan*, *peuhl*, *senoufo* and *bozo/somono* ethnic groups practicing agriculture, animal husbandry, and fishing in complex agrosilvopastoral farming systems. Administratively, the region has 7 circles made of 118 rural communes, which constitute the smallest decentralized units managed by locally elected representatives. The average rainfall received in the region between 1994 and 1998 is 586.2 mm in 44 days (MDRE 1999). Soils in the region are fragile and nutrient depleted. The vegetative cover has seriously declined since the early 1970s because of the combined effects of drought and overexploitation both for agriculture and animal production.

Methods

A step-by-step approach is being practiced in the region for this study.

Step 1: Stratification

The region enjoys wide diversity in terms of climate, farming systems and other social aspects. Thus, it is important to capture this diversity in order to target specific areas of interest for testing the hypothesis. The region is stratified according to the following pertinent biophysical and socioeconomic criteria.

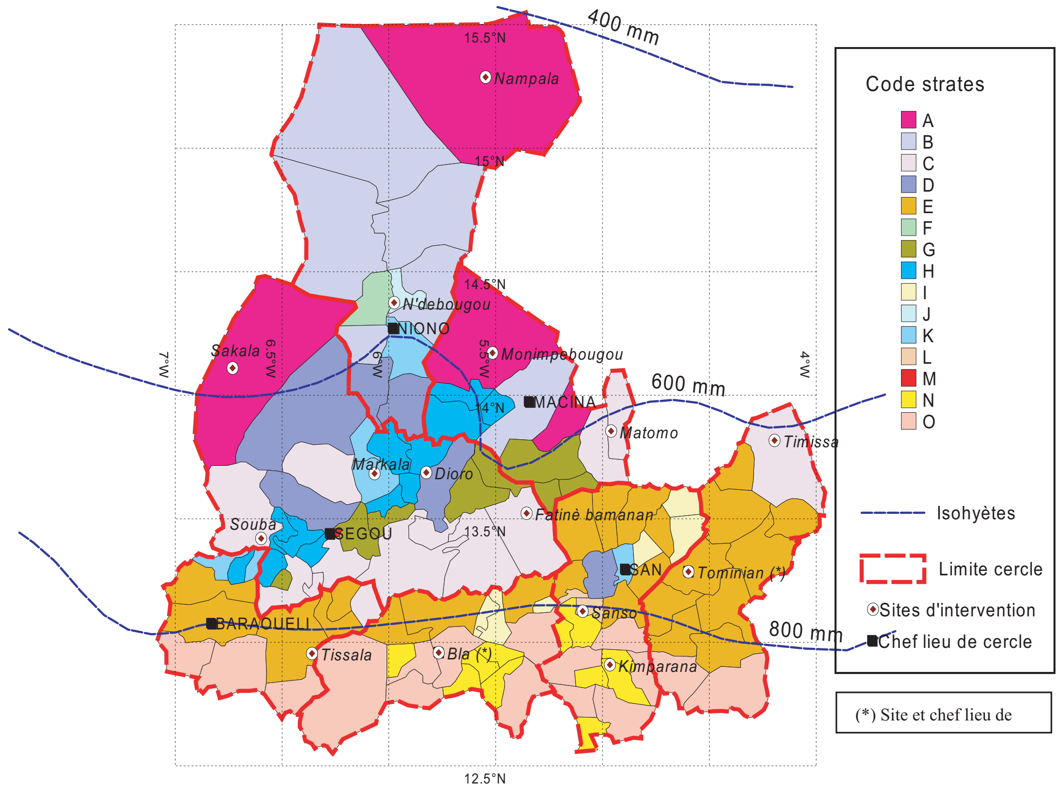
- Rainfall: Being one of the most determinant factors determining farming systems and explaining the vegetation and species distribution in the Sahel, a map was produced indicating the 30-year average of annual rainfall (isohyets). The 400 mm, 600 mm and the 800 mm isohyets were considered. We have thus, defined three main strata: 400 – 600 mm; 600 – 800 mm and greater than 800 mm.
- Farming practices: We have identified and mapped the following three farming practices in the region: (a) cereal based dry farming - where millet and sorghum are the main crops with little or no chemical inputs but manure and other household waste are commonly used though at insufficient quantities; (b) cotton based dry farming - where cotton, as a cash crop receiving important mineral inputs, is the leader of the system. It is followed by cereals such as maize, millet and sorghum; and (c) rice based irrigated system - with full control of the irrigation water (Office du Niger zone) and partial or no control of water (Office Riz Ségou zone).
- Human population density: To a large extent, the human population is one of the most important indicators of the pressure imposed upon natural resources, hence, explaining the level of management and utilization leading to greater or lesser biodiversity. This is particularly true in the Sahel where people's livelihood strategies depend heavily on the use and exploitation of their natural resources. We have identified and mapped three densities: Low: less than 42 people per sq km, Medium: between 42 and 84 people per sq km and High: greater than 84 people per sq km.

These three map layers were superimposed to produce a composite map (Map 1), which when corrected after ground truthing yielded 15 homogeneous and well identifiable strata. Villages were then selected from these strata to test our hypothesis.

Step 2: Diagnosis

Participative diagnosis of the selected villages was conducted using rapid rural appraisal tools (village resources map, transects and identification of village biodiversity). Village resources maps, identifying different land management units, were drawn by different villagers groups and scanned. During the transects, important benchmarks were identified, their coordinates taken with a GPS system and entered in a GIS system. The GPS equipment used is a GPS GARMING© working with WGS84 projection system in absolute mode. These coordinate numbers were transferred to a Microsoft Excel file and then imported to GIS using MapInfo© to finally produce accurate maps showing all the major land management units (Knezovic and Amstalden 2003).

Map 1. Different strata of the Ségou region.



Map 1. Different strata of the Ségou region.

A: Low density, cereal based dry farming, 400 - 600 mm rainfall per annum

B: Low density, rice based irrigated system, 400 - 600 mm rainfall per annum

C: Low density, cereal based dry farming, 600 - 800 mm rainfall per annum

D: Low density, rice based irrigated system, 400 - 600 mm rainfall per annum

E: Low density, cotton based dry farming, 600 - 800 mm rainfall per annum

F: Medium density, rice based irrigated system, 400 - 600 mm rainfall per annum

G: Medium density, cereal based dry farming, 600 - 800 mm rainfall per annum

H: Medium density, rice based irrigated system, 600 - 800 mm rainfall per annum

I: Medium density, cotton based dry farming, 600 - 800 mm rainfall per annum

J: High density, rice based irrigated system, 400 - 600 mm rainfall per annum

K: High density, rice based irrigated system, 600 - 800 mm rainfall per annum

L: High density, cotton based dry farming, 600 - 800 mm rainfall per annum

M: High density, cereal based dry farming, 600 - 800 mm rainfall per annum

N: Medium density, cotton based dry farming, more than 800 mm rainfall per annum

O: Low density, cotton based dry farming, more than 800 mm rainfall per annum

Step 3: Inventory

On the final maps, every management unit was divided into 50 x 25 m grids representing the size of the sampling units (subplots) numbered from 1 to last. Using a 5% sampling rate the corresponding sample numbers were determined for every management unit. Then numbers were selected at random and their coordinates taken giving a list of sample numbers and coordinates. Making use of this list, the map, and the GPS instrument, the team located the center of each sampling unit and then materialized the 50 x 25 m area in which the entire inventory was carried out. The inventory consisted in identifying the species, recording the mode of regeneration, i.e. from seeds or suckers, and measuring the circumference (at the base for small trees and at 1.35 m for big ones) of every tree encountered. In case a tree has more than three sprouts/stems, the circumference was measured for only one of them selected at random.

In addition to the inventory, horizontal and vertical species ranking was carried out. In the horizontal ranking, the populations were identified different usages for each species and ranked the species as per importance to the society. The vertical ranking was used to classify different species having similar usages.

Data management and analysis

A database is setup using Microsoft Access 2000 in which all the collected socioeconomic and biophysical data are stored in a compatible format. The R statistical package (R 1.7.1.; Ihaka and Gentleman 1996; http://cran.r-project.org) was used for all the statistical analyses. Species accumulation curves were calculated by using the vegan library of the R package (vegan 1.5-41; http://cc.oulu.fi/~jarioksa/). The species accumulation curves show the average number of species that are expected for sample units that are randomly pooled together (Kindt 2002).

The relationship between species richness and characteristics of the sample plot were analyzed with generalized linear models (GLM) based on the pseudo-Poisson family. The choice of the GLM followed an earlier analysis of the residuals of linear regression models and the observation of over dispersion of the Poisson family. The same GLM was used for the average number of trees per sampling unit, as this was also an appropriate model for count data as the response variable.

Results and Discussion

The study was carried out in seven villages covering diverse strata. However, the present paper summarizes only the findings from three villages belonging to two similar strata having only the human population density as major difference. The results on the complete data set will be presented elsewhere. The strata are:

- Ngama: 600 – 800 mm annual rainfall, Rice based irrigated system, Medium human population density.
- Tiongoni and Mpebougou: 600 – 800 mm annual rainfall, Rice based irrigated system, High human population density.

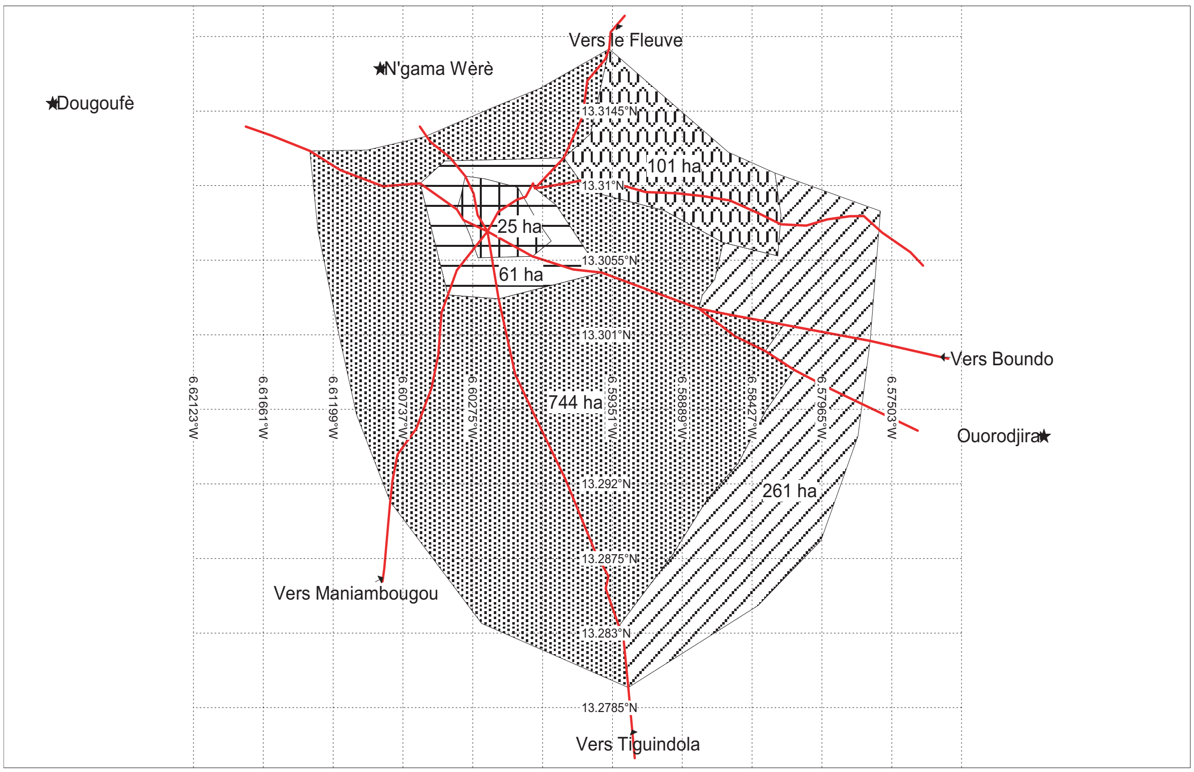
Stratification

In collaboration with other research partners, the region was stratified according to three main criteria, i.e. annual rainfall, human population density and cropping systems. Fifteen homogeneous strata are identified and 2 to 3 villages are selected from each stratum for in depth agroforestry biodiversity characterization (Map1).

Diagnosis

The participative tools used demonstrate their effectiveness in helping the population express themselves in a dialogue environment. Most important and common tree species according to their importance to peoples' lives were identified and categorized according to social preferences. From the maps put together by the villagers, which represent in all aspect the way they perceive their resources, coordinates of important benchmarks were taken in a GPS system and entered in a GIS system to finally produce accurate maps on scale (Map 2).

Map 2. Cadastral map of the Ngama village territory (improved from the population resource map) in the Ségou region, Mali.



It was very satisfying to discover how knowledgeable the rural populations are on the status of their natural resources, especially when 'resource maps' were sketched by different gender groups. The results of this diagnosis confirm the existence of the generally so-called ring cultivation system where land management units are organized in concentric circles around the homestead. The most common land management units found in the study area are described bellow:

- The homestead (*Habitation*) where houses are found and where most people live as a community or settlement. In general the houses are very modest, built in clay with, sometimes, iron-sheet roofing. This management unit is a centerpiece from where most nutrients and inputs go and most products generated by farming and non-farming activities are transported, stored, transformed and consumed. This unit represents a special interest in terms of biodiversity because, thanks to more personal control over resources, most new, introduced and domesticated species can be and are planted and cared for even in the backyards.

- The village fields (C*hamps de case*) form the unit immediately surrounding the settlement or homestead unit where manure and household waste can be applied every year due to the proximity to the village. These lands are continuously under cultivation (cereal and vegetable crops). However, because of land scarcity, the plots are generally limited in size and there is lot of animal interference both in terms of manure input and grazing pressure.
- The bush fields (C*hamps de brousse*) located far away from the village and larger in size. Because of lack of transportation, not all farmers can afford to transport manure and household waste. Soil fertility management is done usually through fallowing though this practice is now being abandoned because of land use pressure.

Both village and bush fields are located in the parkland system where annual crops are grown under well-protected large trees.

- The pasturelands (*Zone silvopastorale*) usually unsuited for crop production and left for grazing, fuelwood, small timber, and exploitation of non-wood forest products.

Other units, which can be found in some villages, are:

- Though not very common anymore, special animal trails (*Bourtol*) units do exist in some villages. They are designed to ensure animal passage through village and bush fields to pasturelands without causing damage to annual crops, thus, limiting conflicts between and among communities.
- Orchards (*Vergers*): Few of them are found in some villages generally, next or close to the homestead along depressions or river channels/beds.

Traditionally, local people in Mali are reluctant in showing physical village territory limits usually to prevent from having new or reviving old land disputes between villages and communities. However, it was very satisfying to discover how enthusiastic and comfortable the populations were in the selection of important reference marks and the indication of the limits of their village territory and land management units. Table 1 presents the village territory land area for each management unit in the three villages presented in this paper. The coordinates of these points, entered in an existing digital map of the region in a GIS package (MapInfo) yielded more exploitable maps -similar to the ones sketched by the populations- giving all the quantitative information the former do not provide. This is again a confirmation that the necessary qualitative information given by the local people can be valued with new science based tools and knowledge.

Table 1. Village territory land area per management unit.

		Management units			
Villages	Village fields	Bushfields	Silvopastoralzone	Homestead	Village territory
	%				ha
Mpebougou	11.25	62.5	14.58	11.67	600
Ngama	5.59	68.19	23.92	2.29	1091
Tiongoni	23.26	71.85	3.25	1.63	503.79

Biodiversity

Biodiversity is a complex subject area as different aspects could be studied, such as richness, evenness or differences in species' composition. Only the concepts of species richness and tree abundance and how they are related to villages and management units along with the species ranking by the population are presented in this paper.

a. Species richness and tree abundance

Species richness is calculated by simply counting all species encountered. Though this value is relatively easy to compute, its calculation has several pitfalls (Gotelli and Colwell 2001; Kindt 2002). The most important difficulty in analyzing species richness is that the number of species encountered depends on the size of the area that is sampled. Especially when species richness is compared from areas of different sizes, results can be misleading. The results of species richness are presented for the total area sampled of each land use in Table 2. Table 2 also shows the average number of species per sample and the average number of trees (tree abundance) for each village and land use category.

Table 2. Number of species and trees per management unit and per village.

Statistic	Village	Bush field	Village field	Homestead	Orchard	Silvo-pastoral zone	Total
N							
	Mpebougou	124	15	0	0	55	194
	Ngama	259	23	0	0	124	406
	Tiongoni	141	45	0	2	4	192
	(total)	524	83	0	2	183	792
Stot							
	Mpebougou	31	16	0	0	25	40
	Ngama	73	10	0	0	75	91
	Tiongoni	37	25	0	4	10	46
	(total)	95	59	25	4	112	135
Ntot							
	Mpebougou	2852	59	0	0	4621	7532
	Ngama	7369	97	0	0	13840	21306
	Tiongoni	3261	664	0	108	165	4198
	(total)	13482	820	0	108	18626	13036
Savg							
	Mpebougou	4.9	2.3	0.0	0.0	6.1	5.0
	Ngama	6.4	2.0	0.0	0.0	14.0	8.5
	Tiongoni	4.8	4.5	0.0	2.5	4.8	4.7
	(total)	7.2	4.2	4.6	2.5	10.2	6.8
Navg							
	Mpebougou	23.0	3.9	0.0	0.0	84.0	38.8
	Ngama	28.5	4.2	0.0	0.0	111.6	52.5
	Tiongoni	23.1	14.8	0.0	54.0	41.3	21.9
	(total)	36.5	25.0	40.4	54.0	106.3	58.2

N-number of samples
Savg-average species richness
Navg-average abundance
Stot-total species richness
Ntot-total abundance

The difficulties in comparing total species richness for areas of different sample sizes can be seen from Table 2. For example, Ngama with 91 species has more species than Mpebougou where 40 and Tiongoni where 46 species were encountered. However, in Ngama more than twice as many samples were taken than in the other villages. Thus, the higher species richness in Ngama may well be caused by a sampling effect rather than by an actual difference in species richness between the three villages. An opposite pattern can be observed between the bush fields and the silvopastoral zone. More samples were taken in the bush field than in the silvopastoral zone (524 versus 183), but more species were encountered in the silvopastoral zone (112 versus 95).

The proper method of analyzing differences in total species richness between areas of different sample sizes is to construct species accumulation curves as this allows comparing areas based on the same sample size.

Figure 1 shows the species accumulation curves for the various categories of land management. From the species accumulation curves, the observation can be made that the curves do not intersect. This means that sample scale does not change the order of the richest to the least rich management unit. The silvopastoral zone is the richest landuse type field that contains a larger number of plots and fewer species would even contain a smaller number as the species accumulation curve is above the other curves for its entire range. The bush amount of species if the comparison with the silvopastoral zone would be done on the same basis of 183 sample plots.

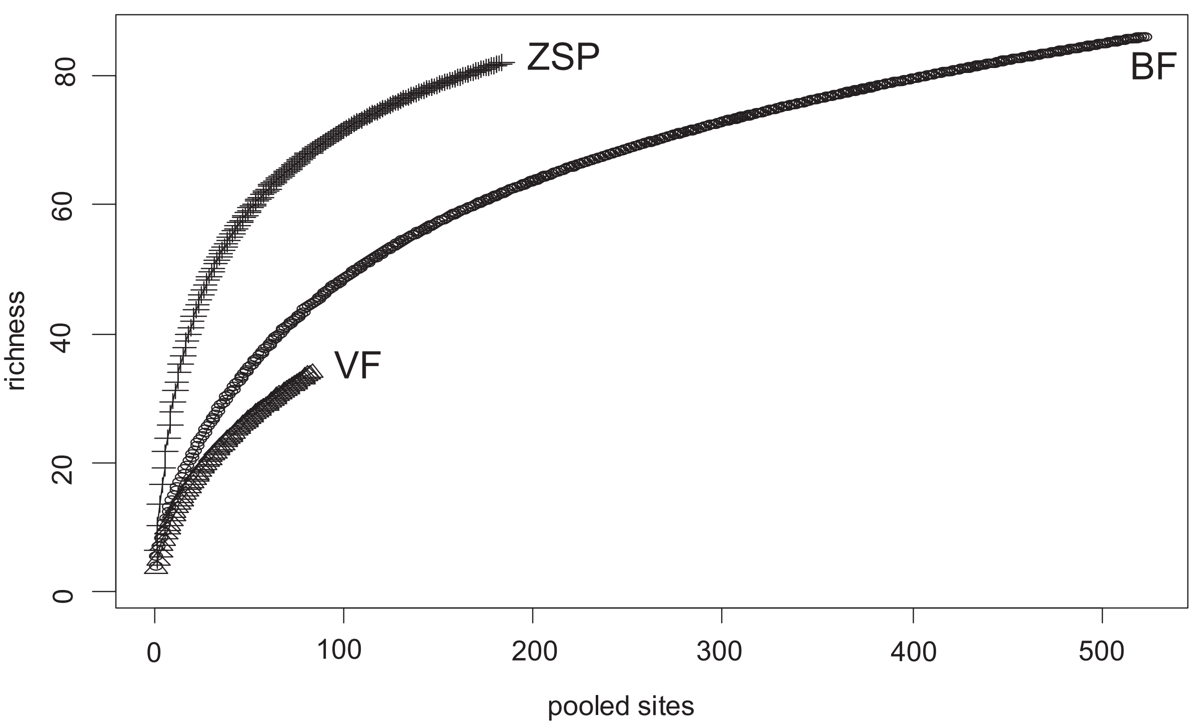


Figure 1. Species accumulation curves for the various land management units (ZSP: silvopastoral zone, VF: village fields, BF: bush fields).

This analysis, based on the sample size, which is always the same (1250 m^2), does not suffer the pitfalls highlighted above. Thus, from Table 2 we can now conclude that the species richness is the highest in the silvopastoral zone (10), and the lowest in the orchards (2.5) followed by the village (4.2) homestead fields (4.6) and bush fields (7.2). Analyzing average abundance per sample reveals that the greatest number of trees is encountered in plots in the silvopastoral zone (106), and the lowest number of trees in the village fields (25). On the same basis, the Ngama village territory is richer (8.5 species) than either the Mpebougou (5) or the Tiongoni (4.7) territories. This could well be the explanation of the impact of the higher human population densities found in these two villages.

b. Species abundance

The abundance gives the occurrence of each species in percentage of the total. This analysis reveals that the most common big parkland species (*Parkia biglobosa*, *Vitrellaria paradoxa*, *Adansonia digitata*, etc) represent only 11.35% of the total while others such as *Guierra senegalensis*, *Combretum micranthum* and *Bauhinia reticulata* form more than one half (50.64%) of the species (Table 3). This may well be a clear indication that these common species are under threat due to excessive pressure. This is also reflected by the general decline of production, especially for karité, néré, tamarind and baobab reported to the research team by the population.

Table 3. Species abundance in the study area.

Species	Proportion (%)
Common parkland species	
Vitellaria paradoxa	6.56
Ziziphus mauritiana	2.26
Faidherbia albida	2.09
Adansonia digitata	0.15
Tamarindus indica	0.12
Pterocarpus erinaceus	0.09
Parkia biglobosa	0.08
Total	**11.35**
Abundant species	
Guierra senegalensis	27.05
Combretum micranthum	9.07
Bauhinia rufescens	7.62
Piliostigma reticulata	6.90
Total	**50.64**
All the others (n=100)	**38.01**
Total	100.00

A species preference/priority setting exercise was conducted to determine top species according to their usages by the population. Though there exist tens of usages, the results indicate that the population value trees species mostly for food, traditional medicine, fuel, and fodder. The top ten species at the scale of the study area, all usages and genders considered, is as follows: *Vitellaria paradoxa*, *Guierra senegalensis*, *Adansonia digitata*, *Faidherbia albida*, *Anogeissus leiocarpus*, *Combretum micranthum*, *Tamarindus indica*, *Piliostigma reticulatum*, *Pterocarpus lucens* and *Pterocarpus erinaceus*. However, when it comes to the four main usages listed above, there are huge gender differences. For example, while men rank *V. paradoxa* as 1 and *A. digitata* as 2 for food, women rank them the other way round. The same happens with traditional medicines for which women have a wider range of species.

In 1995, a similar exercise was undertaken in Senegal, Mali, Burkina Faso and Niger by ICRAF (World Agroforestry Centre) and collaborating NARS (National Agricultural Research Systems). The most important species from farmers view point, because of their impact on farmers livelihood, were in the following order, *Vitellaria paradoxa*, *Adansonia digitata*, *Parkia biglobosa*, *Tamarindus indica*, *Lannea microcarpa*, *Faidherbia albida*, *Sclerocarya birrea*, *Khaya senegalensis*, *Cordyla pinnata* and *Borassus aethiopum* (ICRAF 1996). It is worthwhile to notice the differences between the two priority setting exercises, the one in this study being of a smaller scale. These differences may well be the expression of growing human needs for natural resources. One important aspect is the evolution/shifting of peoples' preferences as a function of what is available in the village territory. Thus, even the functions of the species are subject to a certain evolution. For example, decades ago, it was not imaginable that *G. senegalensis* would be classified as preferred or important fuel wood species in the study area.

Conclusion

Participative regeneration of parklands is a long process. This study (a) confirms the necessary complementarities between indigenous local knowledge and modern science, (b) clearly documents biodiversity variations as a function of management units and village territories, and lastly (c) men and women of the study area do not have the same expertise and preferences especially when it comes to medicinal and food products from the native species.

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Systèmes de production du *Moringa oleifera* le long du fleuve Niger: Quelles perspectives pour leur amélioration?

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Résumé

Moringa oleifera est une plante pérenne introduite au Niger il y a de cela plus de 50 ans. Cette espèce est de nos jours rentrée dans l'habitude alimentaire des populations nigériennes. Elle est aussi insérée dans les systèmes de cultures à cause de ses potentialités alimentaires et les revenus qu'elle procure aux producteurs. Une étude sur les systèmes de production de cette espèce a été conduite dans trois villages le long du fleuve Niger.

Les résultats ont montré que parmi les activités secondaires des chefs de ménage, le jardinage avec Moringa oleifera occupe 83,10%. Les semences de cette espèce sont obtenues sous forme de don (57,14%), achetées au village (22,86%) et au marché (14,29%). Le semis est direct (100%) et est fait pendant l'hivernage (65,71%). Le nombre de graines semées par poquet varie de 2 à 3 suivant les villages. Les écartements utilisés varient de 1 m X 1 m (58,57%) et 1 m X 1,5 m (12,86%). Les superficies de moringa occupées par ménage varie de 0,89 ha ±0.28 à Sarando avec 266 plants /ha ±103, 0,65 ha ±0,77 à Tagabati avec 40 plants/ha ±30,92, 0,70 ha ± 0,29 à Toulwaré avec 270 plants/ha ±118,76. Le régime d'arrosage est de 1 fois /jour (80%), 2 fois / jour (10%). Pour la fertilisation, le fumier simple est majoritairement utilisé (65,71%) et le fumier avec de l'urée (12,86%). Les modes d'exploitation sont l'arrachage des feuilles (60%) suivi de la coupe (38,57%). Les types d'acquéreurs sont en général les grossistes (68,75%) et les détaillants (14,06%). La durée du cycle avant l'exploitation varie de 3 à 5 mois et le nombre de récolte est fonction du mode d'entretien apporté. Le revenu moyen par producteur est variable suivant les ménages ; il est de 150.000 FCFA à 350.000 FCFA/an. Les contraintes majeures évoquées sont l'irrigation, les attaques parasitaires et l'acquisition des fertilisants. La vulgarisation des techniques et méthodes disponibles de production du moringa, l'identification et la valorisation d'autres systèmes de production d'espèces ligneuses, l'appui aux producteurs en système d'irrigation plus performant, la lutte contre les parasites, l'identification et la disponibilité du (des) meilleur (s) fertilisants pourront constituer la voie de sortie pour l'amélioration des systèmes de production du moringa dans cette zone ; une base solide et durable du système pourrait ainsi être mis en place pour le bien être des populations nigériennes et sahéliennes en général.

Abstract

Moringa oleifera is a perennial plant introduced in Niger for more than 50 years. In recent times, this species has become a regular component in the diet habits of the local populations of Niger. Due to its food potentialities and the income it promises to the producers, it has been introduced in the farming systems. A study on the systems of production of this species was conducted in three villages along the Niger River.

The results showed that among the secondary activities of the household heads, gardening with Moringa oleifera occupies 83.10%. The seeds of this species are obtained in the form of gift (57.14%), bought at the village (22.86%) or at the market (14.29%). Sowing is direct (100%) and is done during

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2. ICRAF/Sahel, BP 320, Bamako, Mali.
3. IPDR de Kollo, Kollo, Niger.

the rainy season (65.71%). The number of seeds sown per seed hole varies from 2 to 3 according to villages. The spacings used vary from 1 m x 1 m (58.57%) and 1 m x 1.5 m (12.86%). The land area occupied by moringa in a household varies from 0.89 ha ±0.28 in Sarando with 266 seedlings ha^{-1} *±103; 0.65 ha ±0.77 in Tagabati with 40 plants ha*$^{-1}$ *±30,92; 0.70 ha ± 0.29 in Toulwaré with 270 plants ha*$^{-1}$ *±118,76. The mode of watering is 1 time / day (80%) or 2 times / day (10%). For fertilization, simple manure is mainly used (65.71%) and in some cases, manure with urea is used (12.86%). The modes of exploitation are the pulling up of leaves (60%) followed by cutting (38.57%). The types of purchasers are in general the wholesalers (68.75%) and the retailers (14.06%). The duration of the cycle before the exploitation varies from 3 to 5 months and the number of harvests is a function of the maintenance procedures carried out. The average income by producer is variable according to the households; it is 150.000 FCFA to 350.000 FCFA/year. The evoked major constraints are irrigation, parasitic attacks and fertilizers. The popularization of the available techniques and methods of production of moringa, the identification and the valorization of other systems of production of woody species, support to the producers in more useful irrigation systems, fight against parasites, identification and availability of better fertilizer will constitute the exit point for the improvement of the systems of production of moringa in this zone. A solid and sustainable basis of the system could thus be set up for the well being of the populations of Niger and in the Sahel in general.*

Introduction

Au Niger, les problèmes de sécurité alimentaire et de la lutte pour l'autosuffisance alimentaire constituent une préoccupation importante pour les populations. Cette situation s'est accentuée depuis les sécheresses des années 1970 et 1980. Pour les populations rurales, une des solutions envisagées était la diversification des cultures tout en développant des systèmes de production capables de minimiser les risques liés aux caprices des saisons hivernales.

Les systèmes de production développés depuis lors étaient relatifs aux cultures annuelles considérées comme principales spéculations. Ces différentes spéculations agricoles produites dans des champs en majorité pauvres du point de vue fertilité des sols sont le mil, le sorgho et le niébé. Compte tenu de la baisse drastique des rendements et l'accroissement important de la population, une diversification des spéculations s'est imposée pour augmenter la disponibilité alimentaire. Dans le cadre de cette diversification, de nouvelles cultures sont introduites.

Cette situation a évolué avec le temps et depuis deux décennies déjà, les producteurs nigériens, notamment ceux de la région du fleuve et le long du Goulbi Maradi, ont incorporé dans leurs systèmes de production une autre espèce ligneuse pérenne dans la liste d'espèces végétales cultivées. Il s'agit du *Moringa oleifera*. Cette espèce a suscité l'engouement des producteurs car elle est consommée par les populations toute l'année et procure des revenus substantiels aux ménages. Elle est rentrée dans le mode alimentaire des populations. Sa culture se pratique en général dans les jardins soit en monoculture ou en association avec d'autres cultures notamment maraîchères (Squalli 2001).

La culture du moringa qui était au tout début de son introduction au Niger, il y a de cela plus de 50 ans, pratiquée sur des petits lopins de terres et autour des points d'eau (Arnelle 1997 ; Abou 1997), est aujourd'hui une activité principale pour certains producteurs. Cet état de fait a permis le développement des systèmes de production propres à cette espèce.

Selon Touré (cité par Potchier G 1992), "le système de production est un ensemble de production (végétale et animale) et de facteurs de production (terre, travail, capital) que le producteur gère pour satisfaire ses objectifs socio-économiques et culturels au niveau de l'exploitation ».

Ces systèmes de production sont mis en place et rendus actifs par les producteurs eux-mêmes pour atteindre des objectifs donnés. En zone sahélienne d'une manière générale, Prudencio (1996) a identifié un certain nombre de contraintes qui influent sur la productivité des systèmes de production ; il s'agit entre autres: i) du déficit hydrique dans l'alimentation des plantes ; ii) de la faible fertilité des sols et la dégradation de la qualité des terres ; iii) de la faible productivité des outils agricoles utilisés et la main d'œuvre ; iv) des attaques parasitaires ; v) de la divagation des animaux et vi) du régime foncier.

Toutes ces contraintes sont prises en compte par les producteurs dans le développement des systèmes de production du *Moringa oleifera* au Niger même si par ailleurs, elles constituent toujours un goulot d'étranglement pour l'épanouissement de cette culture.

L'objectif recherché à travers le présent travail est de comprendre les bases de fonctionnement des systèmes de production du *Moringa oleifera* par les producteurs le long du fleuve Niger afin de prospecter les voies d'amélioration pour une meilleure production de cette culture.

Des enquêtes ont été conduites dans trois terroirs villageois le long de la vallée du fleuve Niger pour mieux appréhender les systèmes.

Matériel et Méthodes

Les sites d'étude

L'étude a été conduite dans trois terroirs villageois : Tagabati, Sarando et Toulwaré situés le long du fleuve Niger (Figure1).

Figure 1. Localisation des sites.

L'échantillonnage

Un échantillon de 50% du nombre de ménages par village a été pris afin d'avoir une certaine variabilité en se basant sur les résultats du recensement général de la population de 1988. La taille des échantillons dans les villages est:

- Tagabati: 26 ménages
- Sarondo: 25 ménages
- Toulwaré: 25 ménages

L'enquête

L'objectif est de comprendre comment les agriculteurs mobilisent les ressources disponibles et les moyens de production nécessaires à l'exploitation agricole et à la mise en valeur du milieu, et comment ils choisissent et conduisent les productions végétales et animales qui assurent cette mise en valeur (P Jouve 1992).

Au niveau de chaque ménage, un questionnaire est administré au chef de ménage dans les villages.

Les chefs de ménages sont pris individuellement pour l'administration du questionnaire. Au besoin des visites sont effectuées sur le terrain afin de compléter certaines informations.

L'analyse des données

Les données ont été dépouillées, saisies et analysées. Les analyses descriptives ont été faites avec les logiciels EXCEL et SPSS.

Resultats

Informations générales sur les ménages des villages enquêtés

Tous les chefs de ménages enquêtés sont des hommes à 100% et ils appartiennent aux groupes ethniques suivants:

La majorité des chefs de ménages sont des Zarma (56,34%). Ils sont suivis des Peulhs (33,80%). Les Sonraï et les Haoussa sont minoritaires (Tableau 1).

L'âge moyen des chefs de ménages varie entre 40 et 49 ans et le nombre de personnes par ménage varie entre 8 et 12 personnes.

Tableau 1. Groupes ethniques des chefs de ménages dans les 3 villages.

	Groupe ethnique			
Sites	Haoussa	Peulh	Sonraï	Zarma
Sarondo			12,00	88,00
Tagabati			14,29	85,71
Toulwaré	4,00	96,00		
Total (%)	1,41	33,80	8,45	56,34

Caractéristiques structurales des exploitations

L'agriculture est l'activité principale des chefs de ménages dans tous les villages (100% des personnes enquêtées).

Parmi les activités secondaires, le jardinage occupe à lui seul 83.10% des chefs de ménages. Il est suivi du petit commerce (5.83%).

La moyenne par chef de ménage en terme du nombre de champs tourne autour de 4 champs par personne. Les superficies quand elles sont variables suivant les champs et les villages.

Pour le mode de tenure de terres, l'héritage est le plus important. Il occupe à lui seul entre 75 et 89%. Il est suivi du prêt et de l'achat des terres.

Les différentes cultures pratiquées dans les champs sont par ordre d'importance : mil, sorgho et niébé. Ces cultures pratiquées sont soit en pure ou en association. Il existe aussi d'autres cultures secondaires telles que le Moringa, le manguier et le goyavier qui sont en général dans les jardins.

Les types de sols les plus importants sont : sableux, sablonneux, sablo-argileux, argileux et latéritiques.

Le matériel agricole est local. Dans tous les villages enquêtés, seulement 7,1% des ménages possèdent une unité de culture attelée (UCA) dont la source de financement provient à 70% du jardinage. D'autres matériels aratoires tels que la houe, la daba, le coupe-coupe existent et sont acquis localement à travers le jardinage.

Le nombre du type de matériel agricole est variable suivant les ménages et les villages.

L' élevage est aussi une des activités importantes de la population des villages enquêtés. Cette activité se caractérise par la prédominance des petits ruminants et des bovins. Les différentes catégories de volaille sont élevées.

Le nombre de types d'animaux est variable suivant les ménages et les villages.

Les principales sources de financement pour l'acquisition d'un cheptel au niveau d'un ménage est variable. Cependant, le jardinage contribue à lui seul à plus de 60% dans tous les ménages des villages enquêtés.

Ces animaux sont soit au piquet ou conduits par quelqu'un en saison pluvieuse, de récolte et saison sèche froide. Ils ne sont qu'en constante divagation que pendant la saison sèche chaude.

Systèmes de production du *Moringa oleifera*

Types de semis et mode d'obtention des graines

Moringa oleifera est semé dans tous les ménages par semis direct. La production en pot pour une transplantation n'a jamais été faite par les producteurs des villages enquêtés. Les semences sont obtenues sous forme de don (57,14%), achetées au village (22,86%) ou au marché (14,29%) (Tableau 2).

Périodes de semis

D'une manière générale, les semis sont effectués pendant la saison des pluies (65,71%) et en saison chaude (7,14%). Certains producteurs y en pratiquent pendant d'autres périodes de l'année (Tableau 3).

Tableau 2. Type de semis et mode d'obtention des graines du Moringa.

SITES	Espèce: Moringa (%)	Type de semis: Semis direct (%)	Achat au village (%)	Mode d'obtention de graines: Achat et don (%)	Don(%)	Marché (%)	Marché et don (%)	Marché local (%)
Sarando	100,00	100	12,50	8,33	37,50	37,50	4,17	-
Tagabati	100,00	100	61,90	-	33,33	4,76	-	-
Toulwaré	100,00	100	-	-	96,00	-	-	4,00
Total	100,00	100	22,86	2,86	57,14	14,29	1,43	1,43

Tableau 3. Périodes de semis pour la production du Moringa dans les sites enquêtés.

Période de semis (%) SITES	Avant la pluie	Avant saison de pluie	Saison chaude	Saison chaude et saison des pluies	Saison chaude et saison froide	Saison des pluies	Saison des pluies et froide	Saison des pluies et saison sèche	Saison froide	Saison sèche
Sarando	-	-	12,50	-	-	58,33	4,17	4.17	20,83	4,17
Tagabati	-	-	-	-	-	76,19	-	-	23,81	-
Toulwaré	4,00	4,00	8,00	4,00	8,00	64,00	-	-	4,00	-
Total	1,43	1,43	7,14	1,43	2,86	65,71	1,43	1.43	15,71	1,43

Superficie occupée par le moringa, nombre de plants et de graines semées et coût d'implantation

La superficie moyenne occupée par les exploitations de moringa sont variables suivant les villages et les chefs de ménages ainsi que le nombre de plants par unité de surface. Le nombre moyen de graines semées par poquet est aussi variable suivant les villages (2 à 3). Le coût d'implantation est aussi variable suivant les villages ; il est important à Toulwaré (750 FCFA/h/j) et moins cher à Tagabati (350 FCFA/h/j) (Tableau 4).

Type d'écartement utilisé

Les écartements utilisés dans la production de moringa est très variable d'un village à un autre et même au sein des ménages. Les écartements les plus utilisés sont de 1 m x 1 m (58,57%) et 1 m x 1,5 m (12,86%).

Régime d'arrosage

Le régime d'arrosage le plus important est une fois par jour dépendemment de la disponibilité du producteur. Il est effectué deux fois par jour. Certains producteurs arrosent 3 fois par jour et d'autres chaque deux jours (Tableau 5).

Type de fumure utilisée

Le type de fumure utilisée dans la production de moringa est le fumier simple (65,71%) ; il est suivi du fumier mélangé avec de l'urée (12,86%). D'autres types d'apports minéraux sont faits par les producteurs.

Tableau 4. Superficies moyenne et coût moyen d'homme/jour.

Sites		Superficie occupée (ha)	Nombre de plants	Nombre de graines (/poquet)	Coût d'implantation/h/j (FCFA)
Sarando	Moyenne	0,89	265,83	3,08	625,00
	Ecart type	0,28	102,78	0,72	607,59
	Minimum	0,50	100,00	1,00	100,00
	Maximum	1,50	500,00	4,00	1500,00
Tagabati	Moyenne	0,65	40,00	2,95	350,00
	Ecart type	0,77	30,92	0,67	-
	Minimum	0,25	4,00	2,00	350,00
	Maximum	4,00	100,00	4,00	350,00
Toulwaré	Moyenne	0,70	270,12	2,24	750,00
	Ecart type	0,29	118,76	0,78	-
	Minimum	0,25	100,00	1,00	750,00
	Maximum	1,00	600,00	4,00	750,00
Total	Moyenne	0,75	199,61	2,74	600,00
	Ecart type	0,49	140,66	0,81	488,88
	Minimum	0,25	4,00	1,00	100,00
	Maximum	4,00	600,00	4,00	1500,00

Tableau 5. Régime d'arrosage des exploitations du Moringa.

Sites	Régime d'arrosage (%)			
	1 fois	2 fois	3 fois	chaque 2 jours
Sarando	95,83	4,17	-	-
Tagabati	42,86	28,57	4,76	23,81
Toulwaré	96,00	-	4,00	-
Total	80,00	10,00	2,86	7,14

Mode d'exploitation et types d'acquéreurs

Le mode d'exploitation pratiqué est la cueillette (60%), suivi de cueillette et coupe (38,57%). La coupe est rarement utilisée comme mode d'exploitation par les producteurs enquêtés.
Les types d'acquéreurs sont en général les grossistes (68,75%) suivis de détaillants (14,06%). Les consommateurs sont en général les gens du village qui n'ont pas d'exploitation du Moringa.

Quelques éléments indicatifs de la production du Moringa

La durée du cycle avant l'exploitation

la durée du cycle avant l'exploitation varie de 3 à 5 mois suivant les villages. Cette durée dépend du type d'entretien apporté aux plants au niveau de l'exploitation (fumure, régime d'arrosage, etc).

Nombre moyen de coupes ou de cueillettes par an

Les coupes ou les cueillettes comme mode d'exploitation de moringa sont fréquentielles. La fréquence de coupe ou de cueillette est variable suivant les villages, les ménages. L'élément fondamental qui occasionne la périodicité de l'exploitation est aussi le mode d'entretien de l'exploitation (fumure, régime d'arrosage, entretien des plants, etc.). La fréquence varie de 6 à 23 fois par an suivant les villages.

La hauteur de coupe

Pour les producteurs qui font la coupe comme mode d'exploitation, les hauteurs de coupe varient entre 0.5 et 1 m.

Nombre moyen de personnes utilisées pour une exploitation et coût de la main d'œuvre extérieure

Lors de la coupe ou de la cueillette, le nombre de personnes utilisées pour ce travail varie d'un ménage à un autre et d'un village à un autre (3 à 11 personnes). Le coût de la main d'œuvre extérieure est aussi variable ; il est plus élevé à Tagabati (3200 FCFA/h/j) et moins cher à Sarando (1051 FCFA/h/j).

Nombre moyen d'unités de mesures vendues par coupe et le prix moyen de l'unité de mesure

Le nombre moyen d'unités de mesures vendues par coupe ou cueillette est très variable suivant le site et ménage. Il varie entre 13 et 100 unités de mesure qui est le sac. Quant au prix de l'unité de mesure, il n'est pas significativement variable. Il oscille autour de 2500 FCFA/sac.

Revenus générés par la production du Moringa

La production de moringa est une activité qui procure des revenus substantiels aux producteurs. Les revenus générés sont variables suivant les villages et les ménages. Ils varient de 150 000 FCFA à 350 000 FCFA par producteur et par an (Tableau 6). Cette somme générée par la production de moringa n'est pas négligeable.

Tableau 6. Revenus moyens par producteur.

Sites		Revenu annuel (FCFA)	Revenu par activité principale (FCFA)
Sarando	Moyenne	152291,67	-
	Ecart type	160555,96	-
	Minimum	45000,00	-
	Maximum	750000,00	-
Tagabati	Moyenne	105727,27	362954,55
	Ecart type	59931,78	268897,79
	Minimum	50000,00	92500,00
	Maximum	248000,00	900000,00
Toulwaré	Moyenne	325750,00	
	Ecart type	215010,86	-
	Minimum	75000,00	-
	Maximum	1000000,00	-
Total	Moyenne	206054,55	362954,55
	Ecart type	191186,01	268897,79
	Minimum	45000,00	92500,00
	Maximum	1000000,00	900000,00

Ces revenus générés par la commercialisation de moringa permettent aux producteurs d'acheter des vivres en cas de déficit alimentaire. Ils sont aussi utilisés pour l'habillement, la reconstitution du cheptel et certains producteurs les utilisent pour faire du petit commerce. En somme, ces revenus permettent aux producteurs de subvenir à leur besoin quotidien.

Les contraintes liées à la production de *Moringa oleifera*

Trois principales contraintes ont été relevées lors de l'enquête. Ces contraintes sont relatives aux systèmes de production.

1. l'eau : la majorité des producteurs enquêtés soulignent que l'eau est le principal facteur limitant la production de moringa. Le système d'arrosage couramment utilisé est l'exhaure avec des puits traditionnels. Un travail tracassant et non efficace. Un régime d'arrosage pour non seulement réduire le temps du travail mais aussi maximiser la production de moringa doit être recherché.
2. les attaques parasitaires : Plusieurs parasites, notamment les chenilles, attaquent les tiges et les feuilles de moringa, ce qui réduit considérablement la production. Il n'existe pas de remède disponible pour les producteurs. Le seul produit utilisé est le DDT, un produit prohibé et interdit.
3. la fertilisation : Le seul type de fertilisant utilisé est la fumure organique. La fumure minérale est connue pour son efficacité mais les moyens financiers font défaut pour en procurer. Aussi, la dose optimale n'est pas connu afin de leur permettre d'avoir une production maximale.

Propositions d'amélioration des systèmes de production de *Moringa oleifera*

Les résultats obtenus ci-dessus montrent que la population locale des villages enquêtés produisent le moringa avec des systèmes plus ou moins différents et s'en sortent à leur manière du point de vue rentabilité. Cependant, il existe des problèmes sur plusieurs aspects de cette production. Ainsi, pour améliorer la production de cette espèce ligneuse alimentaire très prisée, les propositions suivantes sont formulées. Il s'agit entre autre de :

- procéder d'une manière générale à une campagne de sensibilisation sur l'importance de cette espèce sur tous les aspects: nutritionnel, socio-économique, etc.;
- inciter les producteurs à produire davantage, en leur accordant la chance d'avoir un encadrement technique qui pourra compléter leurs efforts;
- informer et former les producteurs (paysan – pilote) aux techniques améliorées de production de moringa en prenant en compte leur avis et leur expérience;
- sensibiliser les femmes des différents sites, pour les amener à s'intéresser et à produire d'elles-mêmes sur leur propre terre;
- appuyer les paysans en petits matériels (arrosoirs, coupe-coupe, houe, etc.) et en moto - pompe sous forme de crédit rural;
- entreprendre les installations des haies vives défensives comme moyen de protection des différents sites, afin de réduire la dégradation du couvert végétal;
- favoriser l'approvisionnement des zones défavorables du pays en introduisant le système de production de moringa;
- valoriser les produits issus de moringa "Kopto" en introduisant d'autres recettes nouvelles.

En terme de recherches :

Pour améliorer les systèmes de production du moringa, les axes de recherche suivants doivent être prospectés :

1. la fertilisation et le régime d'arrosage afin de déterminer non seulement le meilleur niveau de fertilisation (organique et/ou minéral) et le meilleur régime d'arrosage et la quantité d'eau pour accroître la production et en même temps économiser l'eau ;
2. la lutte contre les chenilles et autres insectes qui attaquent les feuilles de moringa et compromettent la production ;
3. la recherche d'une meilleure association avec les autres cultures annuelles afin de mieux exploiter l'espace ;
4. la détermination d'une meilleure densité de semis ;
5. la détermination de la meilleure hauteur de coupe pour assurer une regénération de la plante ;
6. la détermination de la meilleure technique de conservation des feuilles en toute saison ;
7. l'introduction d'autres variétés améliorées de moringa sera un atout ;

Conclusion

L'étude conduite dans les différents terroirs villageois de Tagabati, Sorondo, Toulwaré montre que le système de production de moringa est une activité qui se développe et qui génère des revenus. Cette activité entre dans la droite ligne de la sécurité alimentaire et de la réduction de la pauvreté pour les populations visitées.

La production de moringa même si elle est conçue comme une activité secondaire, occupe une place de choix dans l'amélioration des vies des populations des villages enquêtés. Les revenus générés par la production de moringa dépassent en coût d'opportunité ceux obtenus par l'activité principale c'est à dire les cultures vivrières (mil, sorgho, niébé, etc.).

Les différents systèmes de production pratiqués par les populations, bien que basés sur des pratiques locales et ne bénéficiant d'aucun encadrement technique, méritent d'être supportés à travers des appuis techniques et en matériels pour accroître la production afin de satisfaire les demandes qui sont de loin supérieures à l'offre.

Recommandations

D'une manière générale, à la suite de cette étude, des recommandations sont formulées pour l'amélioration des systèmes et la satisfaction des populations nigériennes en produits alimentaires de base : il s'agira pour ce faire de :

- vulgariser les meilleures techniques et méthodes de production et d'exploitation de moringa afin de développer l'usage de ce système;
- identifier et valoriser d'autres systèmes de production (espèces ligneuses alimentaires) pouvant améliorer les conditions de vie des populations en leur permettant de rester chez eux (réduire l'exode rural) et d'avoir aussi des retombées économiques;
- appuyer les producteurs à mettre en place un circuit d'écoulement efficace de production;
- créer des associations de producteurs;

- introduire d'autres systèmes de production de moringa et valoriser certains sous-produits issus de cette espèce;

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Seed spices crops – Status and production potential in low rain areas

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Abstract

The seed spices are a group that denotes all those annuals whose dried fruits or seeds are used as spices. Worldwide, about 20 seed spices are grown of which the most prominent ones are coriander (Coriandrum sativum L.), fennel (Foeniculum vulgare Miller), fenugreek (Trigonella foenum-graecum L, Trigonella corniculata L), cumin (Cuminum cyminum L.), ajowan (syn. Bishop Weed, Trachyspermum ammi), dill (Anethum graveolens L, A. sowa Kurz), celery (Apium graveolens L.), anise (Pimpinella anisum L.), nigella (Nigella sativa L), caraway (Carum carvi L) and parsley (Petroselinum crispum). Seed spices are grown in the Mediterranean region, South Europe and Asia; the former two regions being the centers of origin for seed spices. Almost all of the seed spices crops are grown in India and presently 52% of the global demand is met by this country. The seed spices producing countries other than India are Morocco, Russia (for Fennel), Bulgaria (for Coriander, Fenugreek), Turkey, Iran, Egypt (for Cumin, Ajowan, Nigella), China (for Celery), Romania, Iran, Germany, Hungary (for Dill), Southern France, Cyprus, Germany, Russia (for Aniseed), Pakistan and Sri Lanka.

Among seed spices, coriander, fennel, fenugreek, cumin, ajowan and dill are popular as arid land spices as they are grown successfully under low rain areas or with limited available water conditions.

The arid and semi-arid regions in the world are disadvantaged and inhospitable due to host of environmental factors. Climatically, these lands experience low and erratic rainfall, frequent droughts, high evaporation and erosive winds in summer. The seed spices crops are known to grow well under the regions having Mediterranean type of climate, which is characterized by mild and rainy winters (250–500 mm) and hot and dry summers, found along the Line of Cancer covering Morocco, Algeria, Libya, Egypt, Iran, Pakistan and India, and along the southern and northern coasts of Africa. In India, a similar semi-arid to arid belt exists in the western states of Rajasthan and Gujarat. Both these Indian states are known for their production of quality seed spices and contribute to 80% of the total production. The seed spices crops such as coriander, fennel, ajowan and dill are successfully grown under rainfed areas having rainfall ranging from 501–700 mm and in the areas with least rains, less than 500mm. Likewise, cumin, coriander, ajowan, dill also grow well in farming lands possessing limited water availability and requiring about 3–5 light irrigations depending upon soil conditions and prevailing climate. In India, the seed spices are mostly grown during winter season in October and harvested during summer, March to May. These crops require a mild cool weather during growing period and dry warm weather for reaching seed maturity.

The rain-fed agriculture under hot arid agro-ecological regions is rarely practiced as a single crop or single livestock system. Mixed farming and diversity are its main features. The seed spices crops eg, coriander, cumin, ajowan (bishop weed), dill are grown successfully as intercrops with fruit crops eg, ber, pomegranate, aonla and with vegetable crops particularly cluster bean for green pods, summer squash, chillies, onion and with other crops like mustard. The seed spices crops fit well in the cropping system as they are winter season crops and are grown when the season is preferably cool, resulting in comparatively low evaporation and thus reducing the irrigation frequency. From the semi arid lands with rainfall distribution ranging from 550–650 mm and having heavy soils, the average seed yield of

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4 q ha^{-1} coriander, 6.5 q ha^{-1} dill, 4.5 q ha^{-1} ajowan and 5.0 q ha^{-1} fennel can be obtained in addition to the yield from main crop particularly from ber, pomegranate, aonla, chillies, mustard and cluster bean. The seed spices crops known as arid land spices have fairly good production potential for their growth under the naturally deprived arid to semi-arid ecosystem by growing them in between the rows of main crops, which shall ultimately contribute towards improving the economy of farmers by giving additional income particularly under rainfed farming system.

Introduction

The seed spices is a group that denotes all those annuals whose dried fruits or seeds are used as spices. The seed spices are aromatic vegetable products of tropical origin and are mostly used in pulverized state, primarily for seasoning or garnishing food and beverages. They are characterized by pungency, strong odor, sweet or bitter taste. They are well known appetizers and often contain essential oils, which yield the aroma and add flavor to food relieving a monotony of staleness of the food materials and increasing the pleasure of eating. Spices possess several other properties such as medicinal as anti oxidants or antibiotics and as preservatives in pickles and chutneys. The important seed spices crops are cumin, coriander, fennel, fenugreek, ajowan, dill, celery, anise, caraway and *kalongi*. These seed spices crops are successfully grown in low rain areas or under limited available water conditions and thus are called arid land spices. This paper focuses on the status and production potential of seed spices under low rain areas.

Status and production potential of seed spices

Seed spices crops offer the best choice for diversification for a number of reasons in order that more land use efficiency can be achieved while maintaining the basic agriculture production system. The true potential of seed spices crops indicating the best choice for crop diversification under low rain areas is described here under various facets.

Origin and distribution

The seed spices are cultivated in arid to semi-arid regions and mostly grow well under Mediterranean climatic conditions. There are about 20 seed spices grown world over but the most prominent seed spices are coriander (*Coriandrum sativum* L.), fennel (*Foeniculum vulgare* Miller), fenugreek (*Trigonella foenum-graecum* L., *Trigonella corniculata* L.), cumin (*Cuminum cyminum* L.), ajowan (syn. bishop weed, *Trachyspermum ammi*), dill (*Anethum graveolens* L., *Anethum sowa* Kurz), celery (*Apium graveolens* L.), anise (*Pimpinella anisum* L.), nigella (*Nigella sativa* L), caraway (*Carum carvi* L) and parsley (*Petroselinum crispum*). Most of these seed spices belong to family Apiaceae except fenugreek, which belongs to the family Fabaceae and nigella, which belongs to the family Ranunculaceae. Such spices are grown in different parts of the world covering mainly Mediterranean region, South Europe and Asia.

Almost all of the seed spices crops are cultivated in India. India has got the privilege to be called the largest seed spices producing country in the world. The prominent states where seed spices are produced are Rajasthan and Gujarat and relatively in small areas in other states like Madhya Pradesh, Haryana, Punjab, Uttar Pradesh, Bihar, West Bengal, Orissa, Tamil Nadu and

Karnataka. Almost all the states in India grow one or more seed spices but the major growing belt spreads from arid to semi-arid regions covering large areas in Rajasthan and Gujarat. India produces about 600,000 t of seed spices from an area of 900,000 ha, annually.

The seed spices producing countries other than India are Morocco, Russia (aniseed, fennel), Bulgaria (coriander, fenugreek), Turkey, Iran, Egypt (cumin, ajowan, nigella), China (celery), Romania, Germany, Hungary (dill), Southern France, Cyprus, Pakistan and Sri Lanka. Many other countries of South America, Europe, South African and Asian continent are also likely to enter in the production of seed spices (Vijay and Malhotra 2002).

Production potential in relation to semi-arid and arid agro-climate

Among seed spices, coriander, fennel, fenugreek, cumin, ajowan and dill are popular as arid land spices as they are grown successfully under the low rain areas or with limited available water conditions in the arid to semi-arid regions. The seed spices crops are known to grow well under the regions having Mediterranean type climate that is characterized by mild and rainy winter (250-500 mm) and warm and dry summers. More or less similar climate exists in India covering large parts in the states of Rajasthan and Gujarat, known as semi-arid to arid belt and famous for the production of quality seed spices. Similar type of climate is found along the Line of Cancer covering Morocco, Algeria, Libya, Egypt, Iran and India. The mean annual rainfall is less than 500 mm in arid climate zone and it ranges between 501-700 mm in semi-arid climate zone. The seed spices crops such as coriander, fennel, ajowan and dill are successfully grown under rainfed areas having rainfall ranging from 501-700 mm. Likewise, cumin, coriander, ajowan and dill also grow well in the farming lands possessing limited water availability and requiring about 3-5 light irrigations depending upon soil conditions and prevailing climate. In India, the seed spices are mostly grown during winter season in October and harvested during March to May. These crops require preferably mild cool weather during growing period and dry warm weather for reaching seed maturity. (Malhotra and Vijay 2004).

Export potentiality

The usage of spices by consumers is increasing worldwide as they are completely natural and are preferred to artificial additives for seasoning and flavoring of foods. Thus an increasing trend in export of seed spices has been observed in the last decade particularly to developing countries of Asia, Latin America and Middle East. The global demand estimated for seed spices worldwide is 90,000 t of which at present, India is able of supplying about 48,000 t annually valuing to about Rs 206 crores, which is 52 percent of the total demand. The arid and semi-arid regions offer a lot of scope for cultivation of exotic seed spices such as celery, dill, anise, parsley, lovage, caraway and few others. Being herbal there is ever increasing demand of such exotic seed spices in the world market.

The spices produced for export purpose should conform to both intrinsic and extrinsic quality measures. The extrinsic qualities are mainly seed size, shape and luster, cleanliness from dead insects, animal excreta, hair and other foreign material. The intrinsic qualities are high essential oil content, free from pesticide residue, low aflatoxin level and microbial load. India is exporting a good amount of seed spices and there is scope for increasing export to two times if quality aspect is considered at paramount.

Now with the changing market trends, consumer's preferences, health awareness, and the emergence of super markets, the focal point of export has shifted towards value added spice products. The global market is increasingly shifting away from commodity to value added products. There are excellent facilities in India for making spice oils, oleoresins, curry powder, ground spices and organic spices for export market. More value added products from seed spices need to be developed and marketed globally. Existing value added products need to be strengthen to gain additional market advantage (Malhotra 2000).

Developed regions like USA, Japan, Canada, Australia and Europe are the major markets for Indian seed spices. Smaller but interesting markets are developing in many other countries including a few developing countries. There is a demand for organic raw spices of fenugreek, cumin, fennel, celery and anise in the world market. The demand for organic spices is increasing and has gained importance in modern society. India has succeeded in exporting a good amount of organic seed spices in the recent past. The organic seed spices fetch a premium in the international market. The prices are higher by 20–50% and in some cases even 100%.

Diversification in seed spices production- cropping/farming systems

Monocropping is instrumental in degradation of the natural resource base. Besides, it fails to ensure stable income of growers and causes crop loss due to biotic and abiotic stresses in such fragile eco-system of semi-arid and arid regions. Most of the seed spices crops eg cumin, coriander, ajowan and dill require comparatively less water than other crops. With dwindling arable land and increasing demand of seed spices, it seems that more land area will not be available exclusively for cultivation of such crops. Therefore a strategy has to be worked out to incorporate these crops into regular agricultural systems in order that more land use efficiency can be achieved while maintaining the basic agriculture production system.

Diversification is not a new concept for farmers. There is plenty of evidence to show that they are quite skilled in adjusting the mix of products they produce to select changes in the relative profitability and risk of each activity. The rainfed agriculture under hot arid agro-ecological region is rarely practiced as a single crop or livestock system. Mixed farming and diversity are its main features. The seed spices crops such as coriander, cumin, ajowan (bishop weed), dill are grown successfully as intercrop with fruit crops such as ber, pomegranate, *aonla* and with vegetable crops particularly cluster bean for green pods, summer squash, chillies, onion and with other crops such as mustard. The seed spices crops fit well in the cropping system as they are winter season crops and are grown when the season is preferably cool, resulting in comparatively low evaporation and thus reducing the irrigation frequency. In the semi arid lands with rainfall distribution ranging from 550-650 mm and having heavy soils, the average seed yield of 4 q ha^{-1} coriander, 6.5 q ha^{-1} dill, 4.5 q ha^{-1} ajowan and 5.0 q ha^{-1} fennel can be obtained in addition to the yield from main crop particularly from ber, pomegranate, *aonla*, chillies, mustard and cluster bean. The yield advantage of intercropping combination originates either due to higher yield of individual crop or due to higher plant population densities or both. The suppression in yield of seed spices is only about 10% when intercropped with vegetable crops. The seed spices crops known as arid land spices have fairly good production potential for their growth under the naturally deprived arid to semi-arid ecosystem by growing them in between the rows of main crops. The returns from such diversification programs yield sufficient income and contribute towards improving the economy of farmers particularly under rainfed farming system.

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Dynamique de la régénération ligneuse durant la phase de culture dans un système de culture semi-permanente du Sud du Sénégal

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Résumé

La dynamique de la régénération ligneuse est étudiée dans un système de culture semi-permanente situé en front pionnier au sud du Sénégal. Des défriches relativement récentes s'échelonnant de 1 à 14 ans de cultures sont étudiées en mode synchrone. Dans les parcelles cultivées, les souches constituent l'essentiel du potentiel de régénération ligneuse. Au bout de 6 ans de culture, la densité des souches a diminué de 50% et de 80% au bout de 15 ans de culture. Dans le même temps, le nombre d'espèce sous forme de souche n'a diminué que de 50%. Les pertes des germinations sont presque deux fois plus rapide. Entre 12 et 13 années de mise en culture, les germinations ne concerneraient que trois ou quatre espèces. La composition spécifique est un facteur important dans la dynamique des ligneux sous culture.

Abstract

Woody tree component is important for sustainability of Sahelian agriculture systems. Woody regeneration dynamic is studied in a semi-permanent cropping system in the southern zone of Senegal. New cleared parcels of 1 to 14 years old are studied in synchronous mode. Results show that stumps are the principal regeneration potential during the cropping period. Six years cultivation leads to 50% density loss and up to 80% nine years later. In the same period, stumps species richness falls down to 50%. Fourteen years cultivation causes nearly twice more rapid loss of germination and only about three to four species are concerned with seed sprouting. Floristic diversity is an important factor on vegetation dynamic during cultivation.

Introduction

En Afrique de l'Ouest, les terroirs cultivés sont généralement organisés en deux zones ou auréoles autour des villages: une zone de culture permanente et une zone où est pratiquée l'alternance entre des périodes de culture et de jachère (Pélissier 1966). La structure et l'équilibre des savanes et des forêts sèches sont marqués par les perturbations anthropiques tels que le feu ou l'élevage (Menaut et al.1995; Maass 1995). La rotation culture jachère est une autre perturbation majeure sur ces systèmes écologiques. De nombreuses études ont porté sur la dynamique de la végétation après abandon cultural (Fournier et al. 2000). Le temps de jachère est essentiel dans la reconstitution de la végétation et le maintien de la biodiversité des savanes (Donfack 1998; Mitja 1990). Concernant les ligneux, la succession post-culturale est déterminée par le potentiel de régénération au moment de la mise en jachère. Ce potentiel est

1. ISRA/CNRF BP 2312 Dakar Hann Sénégal.
2. IRD 01 BP 182 Ouagadougou 01 Burkina Faso.

constitué par les différentes formes végétales présentes pendant la phase de culture: les souches et les arbres rémanents. Les régénérations par semis n'interviennent généralement qu'après dix ans d'abandon. Souches et rémanents constituent ainsi les formes végétales permanentes des cycles culture-jachère (Mitja et Puig 1993).

Cette étude a pour objectif d'étudier la dynamique des ligneux (souches et autres régénérations) pendant la phase de culture après abandon cultural. La dynamique du potentiel de régénération pendant une période de culture après défriche a été étudiée dans les systèmes de culture sur brûlis en forêt humide. De Rouw (1993), en Côte d'Ivoire montrent que la phase de culture courte (un an) permet la reconstitution d'une canopée d'arbres pionniers provenant de la banque de graines du sol pré-existante et des rejets de souches. Il montre aussi que la culture prolongée (3 ans) entraîne la destruction de la banque de graines du sol mais affecte moins les plantes qui rejettent. Dans les zones non cultivées, Khan et Tripathi (1989) ont montré que la hauteur de coupe de même que le diamètre avait une influence sur la croissance des rejets de souches. Ils ont montré aussi que la croissance est meilleure en été et plus basse en hiver. Très peu d'études concernent les régions semi-arides et arides. Yossi (1996) insiste, au Mali, sur les pratiques de coupe au moment de la défriche pour assurer le potentiel de régénération.

Au Sénégal, la Haute Casamance constitue une région de terres neuves disponibles où s'installent depuis 20 ans des agriculteurs pratiquant un système de culture basé sur la rotation arachide céréale. Pour garantir la reconstitution de la biodiversité végétale des savanes après abandon cultural, on peut s'interroger sur les pratiques culturales visant à optimiser le potentiel de régénération ligneuse pendant une période de culture.

A partir de relevés en mode synchrone, on répondra aux questions: quelle est la dynamique des régénérations ligneuses en fonction du temps de culture ? la diversité spécifique joue t-elle un rôle dans cette dynamique?

Matériels et Méthodes

L'étude a été menée dans le village de Sobouldé en Haute Casamance au Sénégal (13°10'N et 15°6'W). Cette région est caractérisée par un climat à deux saisons contrastées. La pluviosité annuelle moyenne est de 1000 mm. Ce village, se situant en lisière de la forêt de Pata, présente des blocs de parcelles où le défrichage a débuté depuis une quinzaine d'années. Les sols sont décrits comme des sols ferrugineux sableux. La végétation ligneuse est dominée par *Pterocarpus erinaceus*, *Terminalia macroptera*, *Bombax costatum*, *Vitex doniana*, *Terminalia avicennioides*.

Les pratiques de culture depuis la défriche des parcelles sont identiques : rotation arachide-mil. Le défrichement pratiqué par les paysans consiste à un abattage des arbres coupés à des hauteurs variables suivant leurs tailles, les morceaux de bois d'une certaine taille sont exportés et le reste est mis en tas et brûlé. Certains arbres sont préservés *(Cordyla pinnata*, *Parkia biglobosa*, *Ziziphus mauritiana*, etc.). Au cours des cycles culturaux, les rejets de souches sont coupés avant le semis en fin de saison sèche, mis en tas et brûlés. Pendant le cycle cultural, ces rejets sont coupés en moyenne deux fois pour les cultures de mil et jusqu'à quatre fois pour une culture d'arachide.

En novembre 1999, 23 parcelles ont été choisies dans une zone pionnière du village. Ces parcelles, toutes soumises à des pratiques culturales identiques, diffèrent par leur temps de mise en culture s'échelonnant de 1 à 14 ans. Sur chaque parcelle, sur une surface de 250 m^2, ont été inventorié toutes les régénérations d'espèces ligneuses: les souches (ST), les repousses issues de graines (RE), les drageons (SU). La progression de l'inventaire est organisée par tranche de 50 m^2 pour mieux scruter les différents individus présents dans l'échantillon. Ainsi, la base de chaque individu présent a été dégagée à une profondeur de 5 à 20 cm pour en déterminer l'état morphologique (souches, semis ou drageons) et l'état physiologique (vivant ou mort). Pour chaque individu répertorié, l'espèce est déterminée à partir de la flore de Berhaut (1967) et des travaux de Eynden *et al*. (1993); les diamètres croisés au niveau du sol (deux mesures perpendiculaires) sont mesurés. Les mesures sont effectuées en novembre 1999 en fin de cycle cultural.

La diversité spécifique et la densité des différentes formes de régénération sont analysées.

Résultats

Dynamique de la composition floristique dans les parcelles cultivées

Dans les parcelles cultivées, 39 espèces ont été observées (tableau 1). 95% des espèces sont rencontrées sous forme de souche, 67% sous forme de repousses à partir de graines et 18% sous forme de drageons. Toute régénération confondue, trois espèces ne sont plus présentes au-delà de 3 ans, 9 espèces disparaissent entre 7 et 9 ans, 7 espèces entre 10 et 13 ans. Enfin, 20 espèces sont toujours présentes dans des parcelles cultivées depuis 14 ans (Tableau 1) avec une courte phase d'abandon culturale dans le passé.

Densité et diversité des souches

La densité de souches diminue exponentiellement (Figure 1) en fonction du temps de culture avec un coefficient $k = 0,11$ ($p<0,0001$; limite de confiance à 95% = 0,06). Selon un modèle exponentiel ($k=0,08$ ($p<0,0001$, limite de confiance à 95% = 0,04), un tiers des espèces présentes sous forme de souche ont disparu au bout de sept années de culture et la moitié au bout de dix ans (Figure 1).

L'absence d'une souche dans une parcelle cultivée peut être due, (1) à sa disparition liée à la difficulté de survie à l'état de souche régulièrement coupée, (2) à la rareté de l'espèce considérée et une surface d'échantillonnage non suffisante. L'étude de la dynamique spécifique des souches ne peut donc être réalisée que pour les espèces qui sont relativement abondantes dans les parcelles récemment mises en culture. 40% des souches proviennent des epèces : *Dichrostachys glomerata*, *Combretum glutinosum*, *Bombax costatum* et *Terminalia avicennioides*. *D. glomerata* et *B. costatum* en représentent 21%. Seule l'espèce *Bombax costatum* présente une diminution significative de sa densité en fonction du temps de culture, avec un coefficient k de décroissance exponentielle de 0,41 ($p<0,0001$; limite de confiance à 95% = 0,18) (Figure 2). La densité en fonction du temps de culture des autres espèces ne s'ajuste pas significativement à une courbe exponentielle. Toutefois, les souches de *Pterocarpus erinaceus* ont tendance à disparaître après deux années de culture. Pour les autres espèces, *Combretum glutinosum*, *C. geitonophyllum*, *Terminalia avicennioides* et *Dichrostachys glomerata*, la densité de souche n'est pas significativement différente au cours du temps de mise en culture (Figure 2). Quelques espèces

Tableau 1. Liste des espèces et les formes de régénération sur les 23 parcelles cultivées de 1 à 14 ans. Le temps de survie représente la durée maximale de la période de culture de la parcelle où l'espèce a été observée.

Species	Families	Arbres	A.morts	Drageons	Semis	Souches	Temps de survie (années)
Gardenia ternifolia K.Schum.	*Rubiaceae*					+	1
Spondias mombin L.	*Anacardiaceae*					+	2
Ximenia americana L.	*Olacaceae*					+	2
Acacia sieberiana DC.	*Mimosaceae*				+		7
Asparagus Pauli-Gulielmi Solms-Laub.	*Liliaceae*				+	+	8
Crossopteryx febrifuga (Afz.) Benth.	*Loganiaceae*	+		+		+	8
Heeria insignis (Del.) O. Kze.	*Anacardiaceae*					+	8
Hexalobus monopetalus (A. Rich) E. et D.	*Annonaceae*					+	8
Lannea acida A. Rich.	*Anacardiaceae*				+	+	8
Combretum nigricans Lepr.	*Combretaceae*				+	+	9
Lannea velutina A. Rich.	*Anacardiaceae*				+	+	9
Acacia machrostachya Reich.	*Mimosaceae*					+	10
Cassia sieberiana D.C.	*Caesalpiniaceae*				+		10
Vitex doniana Sw.	*Verbenaceae*					+	10
Daniella oliverii Hutch. Et Dalz.	*Caesalpiniaceae*				+	+	12
Terminalia macroptera G. et Perr.	*Combretaceae*	+			+	+	12
Bombax costatum Pell. Et Vuill.	*Bombacaceae*	+		+	+	+	13
Maytenus senegalensis (Lam.) Exell.	*Caelastraceae*			+	+	+	13
Annona senegalensis Pers.	*Annonaceae*					+	14
Combretum geitonophyllum Diels.	*Combretaceae*				+	+	14
Combretum glutinosum Perr.	*Combretaceae*	+			+	+	14
Combretum lecardii Engel. Et Diels.	*Combretaceae*			+	+	+	14
Cordyla pinnata (Lepr.) Miln.-Red.	*Caesalpiniaceae*	+			+	+	14
Detarium microcarpum G. et Perr.	*Caesalpiniaceae*				+	+	14
Dichrostachys glomerata (Forsk.) Chiev	*Mimosaceae*			+	+	+	14
Erythrophleum africanum (Welw.) Harms	*Caesalpiniaceae*		+		+	+	14
Hymenocardia acida Tul.	*Euphorbiaceae*					+	14
Icacina senegalensis A.Juss.	*Icacinaceae*				+	+	14
Pericopsis laxiflora (Benth.Ex.Bak) Van Meeuwen	*Papilionaceae*					+	14
Pavetta crassipes K.Schum.	*Rubiaceae*				+	+	14
Piliostigma reticulatum (DC) Host	*Caesalpiniaceae*				+	+	14
Piliostigma thonningii(Sch.) Miln.-Redh	*Caesalpiniaceae*				+	+	14
Prosopis africana (G. et Perr.) D.Dietz	*Mimosaceae*					+	14
Pterocarpus erinaceus Poir.	*Papilionaceae*	+		+	+	+	14
Securinega virosa (Roxb.) Baill.	*Euphorbiaceae*				+	+	14
Stereospermum kunthianum Cham	*Bignonaceae*				+	+	14
Strycnos spinosa Lam.	*Loganiaceae*			+	+	+	14
Terminalia avicennioides	*Combretaceae*				+	+	14

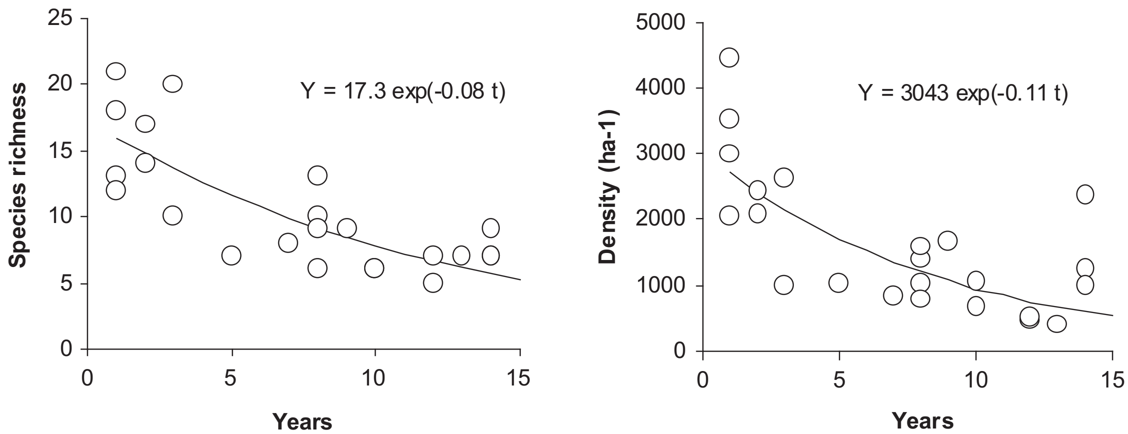

Figure 1. Richesse spécifique et densité des souches suivant la durée de la période de culrture (ans).

rares dans le cortège floristique des parcelles récemment défrichées, telles que *Combretum lecardii*, *Securinega virosa*, *Detarium microcarpum*, *Pavetta crassipes*, *Cordyla pinnata*, *Annona senegalensis*, *Piliostigma reticulata*, sont encore observées dans des parcelles cultivées depuis quatorze ans (Tableau 1).

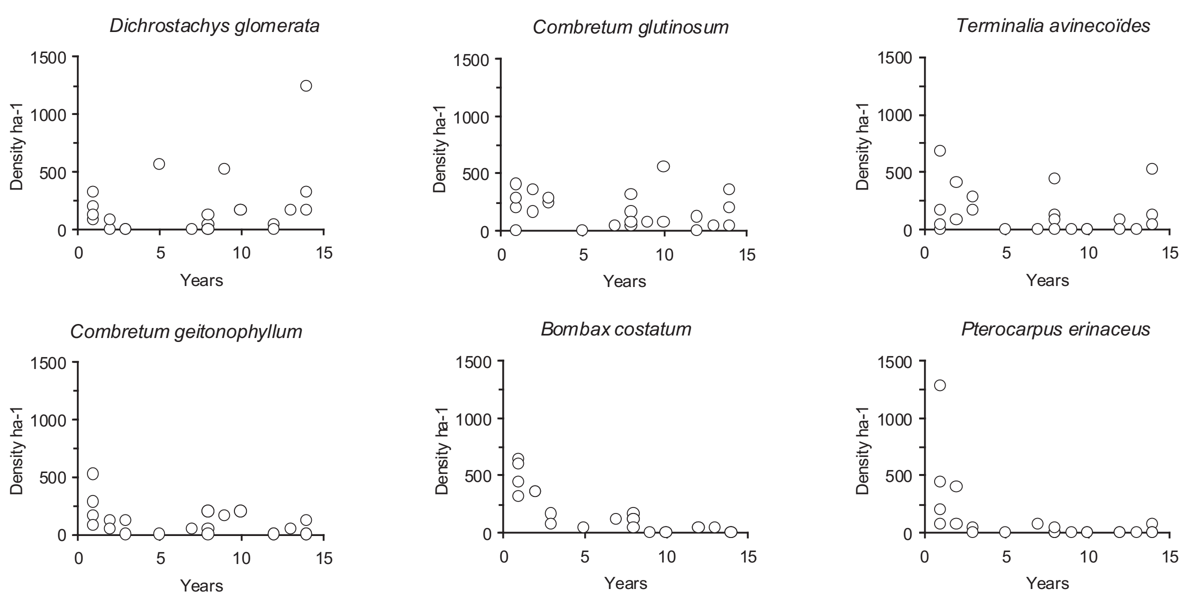

Figure 2. Densité des souches des espèces les plus abondantes suivant la durée de culture.

Parmi les espèces dont les souches sont les plus abondantes, celles de la famille des *Combretaceae*: *Combretum* spp et *Terminalia* spp (Figure 3) présentent les dimensions de souches les plus élevées. En revanche, pour *Dichrostachys glomerata* ou *Bombax costatum*, les diamètres moyens sont plus petits (Figure 3). En fonction des classes de diamètres, la dynamique des souches est identique. Par exemple, pour *Bombax costatum*, la densité diminue en fonction du temps de culture que ce soit pour les souches de diamètre inférieur à 0,5 m ou celle comprise entre 0,5 et 0,15 m. Pour C*ombretum glutinosum* qui présente un nombre relativement élevé de souches de diamètre supérieur à 15 cm, ne présente pas de dynamique différente en fonction des trois classes de diamètre. Cette observation concerne également *Dichrostachys glomerata* ou *Terminalia avicennioides*.

En terme de structure, deux groupes se dégagent (Figure 3):

- *Bombax costatum* et *Dichrostachys glomerata* sont marquées par l'absence de la classe de diamètre supérieure à 0,15 m au delà de 2 ans ; cela traduit sur le plan écologique un déséquilibre structural
- C*ombretum glutinosum* et *Terminalia avicennioides* présentent toutes les classes de diamètre durant la phase de culture, il y a donc un équilibre structural.

Les C*ombretaceae* semblent donc mieux adapter à la culture permanente avec les pratiques culturales y afférentes.

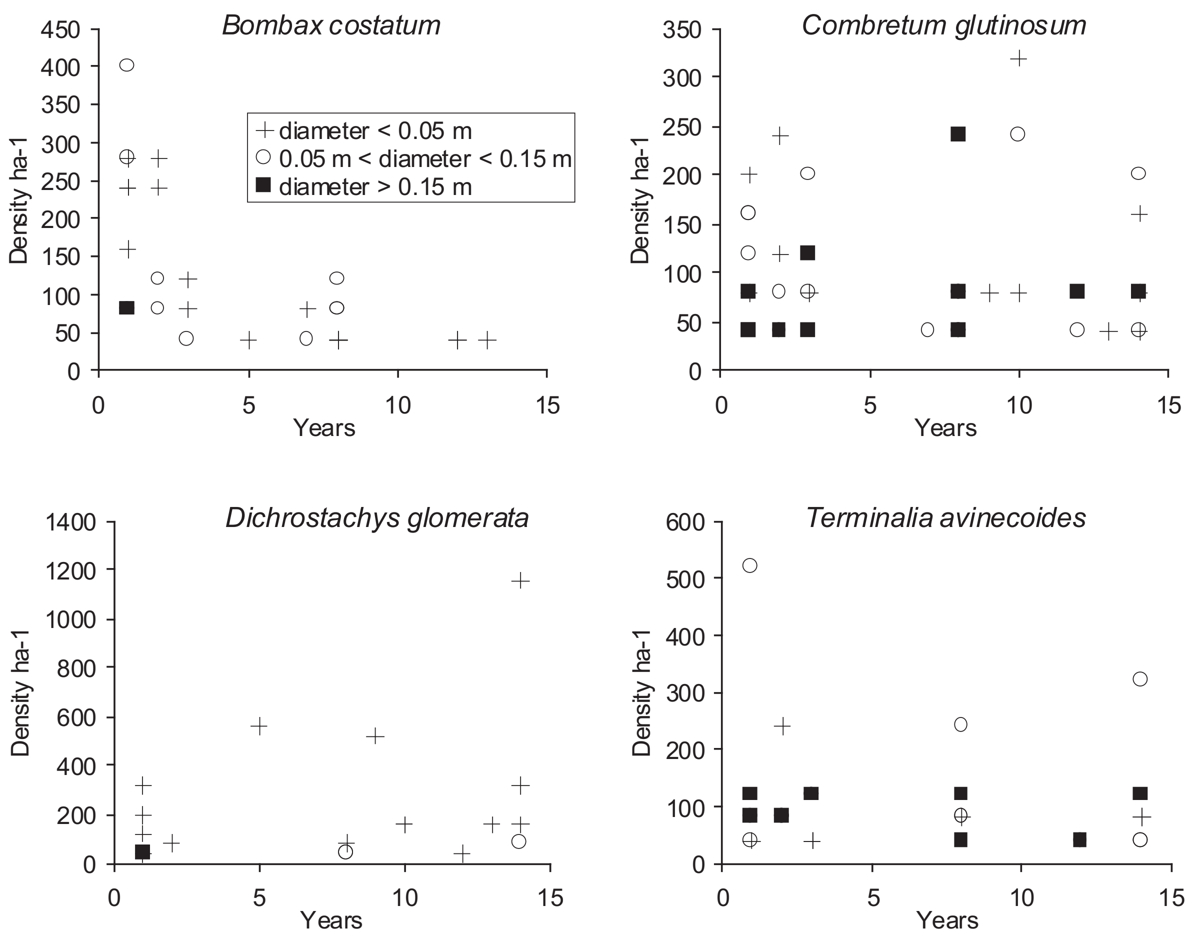

Figure 3. Densité de souches (N ha^{-1}) suivant trois classes de diamètres pour les plus importantes espèces.

Densité des repousses à partir de graines

La densité de repousses à partir de graines (Figure 4) diminue exponentiellement en fonction du temps de culture (avec un coefficient k = 0,19 (p<0,0001; limite de confiance à 95% = 0,14)). Il en est de même pour la densité des richesses spécifiques (avec un coefficient k = 0,13 (p<0,0001, limite de confiance = 0,08)).

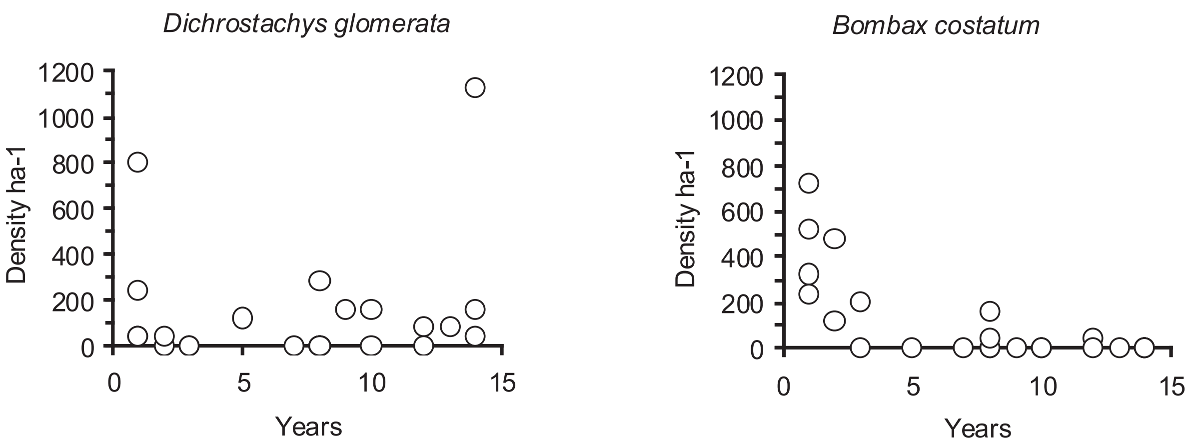

Figure 4. Richesse spécifique et densité des semis suivant la durée de culture (ans).

Les repousses à partir de graines concernent 26 espèces ligneuses sur les 23 parcelles observées (Tableau I) y compris les parcelles de 14 ans ayant connu un antécédent jachère dans le passé. Si ces parcelles ne sont pas prises en compte, alors seules 10 espèces présenteraient des germinations dont seulement 3 à 4 espèces entre 12 et 13 ans. Deux espèces, *Dichrostachys glomerata* et *Bombax costatum*, présentent des densités élevées. Seule, *Dichrostachys glomerata* présente des densités de repousses à partir de graines pour toutes les durées de mise en culture (Figure 5). Les autres espèces (*Pterocarpus erineaceus*, *Stereospermum kunthianum*, *Maytenus senegalensis*, *Combretum glutinosum* et C. *geitonophyllum*, *Strychnos spinosa*), à l'image de *Bombax costatum*, ont surtout des densités de repousses importantes dans les parcelles cultivées depuis moins de cinq années (Figure 5).

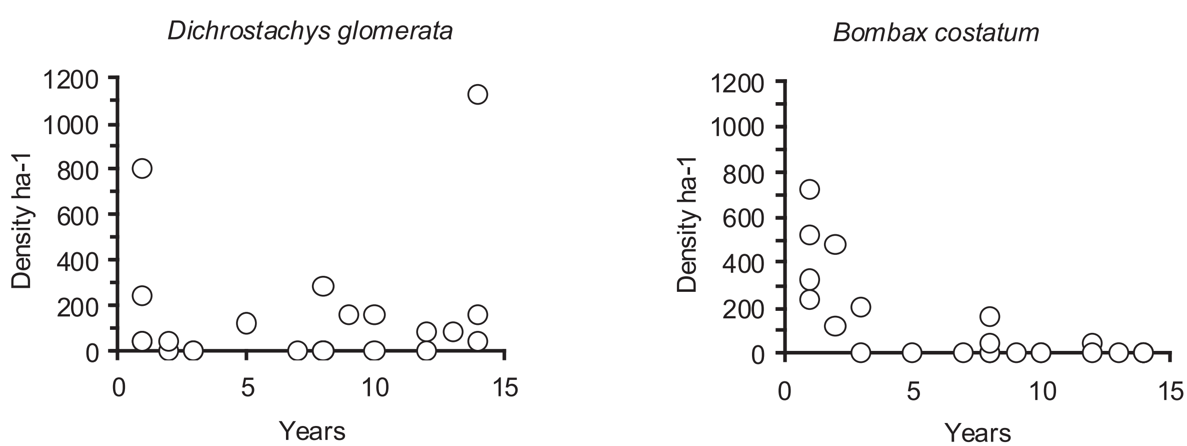

Figure 5. Semis naturels de deux espèces ligneuses suivant la durée de culture.

Densité et diversité des drageons

La régénération par drageonnage a été très peu observée sur toutes les parcelles (Tableau 1). Les espèces qui présentent les densités de drageons les plus élevées sont *Dichrostachys glomerata* et *Bombax costatum*. Les autres espèces qui drageonnent sont C*rossopteryx febrifuga*, *Maytena sengalensis*, *Pterocarpus erinaceus* et *Strychnos spinosa*, essentiellement rencontrées dans les parcelles cultivées depuis moins de 3 ans.

Discussion

Evolution globale des ligneux dans les champs

Au bout de 6 ans de culture, la densité des souches a diminué de 50% et de 80% au bout de 15 ans de culture. Dans le même temps, le nombre d'espèce sous forme de souche n'a diminué que de 50%. Les pertes des germinations sont deux fois plus importantes. Après 14 années de mise en culture, les germinations ne concerneraient que trois à quatre espèces. Il apparaît donc que la perte démographique des souches ligneuses est plus lente que celle des germinations. Les pertes spécifiques des souches sont moins importantes que celles des germinations. La disparition des espèces est plus lente que la perte démographique. Le facteur espèce est donc déterminant dans la dynamique des ligneux sous culture. Autrement dit, le potentiel séminal des espèces s'épuisent rapidement et le potentiel végétatif est le principale mode de conservation du potentiel de régénération à court ou moyen terme. En effet, la culture prolongée détruit la banque de graines du sol (De Rouw 1993). Donc les espèces sans aptitude à rejeter ou à drageonner sont menacées de disparition avec la longueur de la phase de culture. C'est pourquoi la conservation de la diversité floristique nécessite un repos cultural assez précoce. Il est estimé à un an par De Rouw (1993) en zone humide. En savane soudanienne du Sénégal, il ne doit pas atteindre 5 ans pour bénéficier du potentiel séminal. Selon Donfack (1998), certaines espèces éliminées des champs se maintiennent par des souches vivantes qui dans la culture émettent des rejets éliminés régulièrement par sarclage. Il ajoute que de trop longues périodes de culture sans jachère peuvent entraîner une disparition de certaines espèces. Ce qui semble arriver après 15 ans de culture sans jachère à Soboudé. Cependant, seules 50% d'espèces ne présentent pas de souches à cette date. L'effet de la durée de culture peut être accentué par certaines pratiques telles que le labour ou le dessouchage. Ces pratiques sont toutefois rare car demandant un effort important pour les grands arbres. En effet, selon Dallière (1995), le défrichage en pays Mossi, Bwaba et Dafing au Burkina Faso, est rarement suivi de dessouchage, souvent par manque de moyen et parce que la présence des souches ne gène pas la culture attelée ou manuelle. Bernard (1999) montre, au nord de la Côte-d'Ivoire et du Cameroun, que la végétation aérienne est détruite lors du défrichement (sauf les grands arbres d'espèces ayant un intérêt), mais les souches et racines sont laissées dans le sol. La présence des souches fait dire à Donfack (*op.cit*), qu'au nord Cameroun, l'absence de labour permet de maintenir dans les parcelles pendant la phase de culture un potentiel de ligneux qui favorise le retour des arbres après abandon cultural.

La vitesse de perte du potentiel de régénérations des ligneux semble plus forte en zone humide qu'en zone de savane soudanienne. Cette vitesse est influencée par les pratiques de culture (labour) mais aussi par les conditions édapho-climatiques.

Dynamique spécifique dans les champs: discrimination d'espèces typiques

Trois types de dynamique sont notés:

- celle de *Bombax costatum* caractérisée par des souches plutôt petites qui diminuent en fonction du temps de culture, ce sont des rabats de jeunes individus issus de semis ou de drageons qui ne résistent pas à la pression;
- celle de *Dichrostachys glomerata* caractérisée par une densité de souches ne diminuant pas avec une capacité à re-semer ou drageonner; les souches sont de petits diamètres mais résistent à la pression;
- celle de C*ombretum glutinosum* marquée par une densité statique même pour les grosses souches et donc une capacité à résister à la pression pour chaque individu quelle que soit sa taille.

Les individus de petits diamètres sont plus sensibles à la pression de culture que les individus adultes plus âgés. Cela peut s'expliquer par leur faible vigueur et leur manque d'aptitude à renouveler les tiges par voie végétative. La taille et la vitalité des souches sont importantes pour la production de rejets selon Rijks et al. (1998). Elles devraient aussi l'être pour la production de drageons. Or, il est admis que la régénération par voie végétative assure, mieux que la reproduction séminale, la reconstitution des formations soumises au régime de taillis (Ducrey et al.1992). On peut donc penser que le potentiel séminal ne permet pas un maintien efficace de la végétation pendant la phase de culture lorsqu'elle est plusieurs fois rabattue. Khan et Tripathi (1989) ont montré en Inde que les individus adultes (classes de diamètres intermédiaires) de quatre espèces des genres *Alnus*, *Quercus* et *Schima* présentent une meilleure capacité à rejeter par rapport aux individus trop jeunes ou trop vieux. Donc les souches de petites tailles (issues de semis naturels) ou très grosses (vieux individus) sont plus sensibles à la pression de culture. Il faut signaler que ce schéma n'est pas valable chez toutes les espèces. En effet, il existe des espèces caractérisées par une aptitude à résister quelle que soit la taille. On peut citer parmi celles observées à Soboudé *Dichrostachys glomerata* et C*ombretum glutinosum* qui sont des exemples typiques de résistance à la pression de culture. Il en existe certainement d'autres. Le facteur espèce est donc déterminant dans la dynamique d'un peuplement. En effet, il faut dire avec Donfack (1998) que la rareté ou la disparition des espèces peut être due à la non adaptation aux conditions du milieu, à l'inhibition de la germination des graines ou à l'absence de rejets. Ces catégories d'espèces doivent être traitées avec soin pour les préserver.

Conclusion

L'objectif global était d'étudier la dynamique des formes ligneuses en fonction du temps de culture ainsi que le rôle que peut jouer la diversité floristique dans cette dynamique.

L'analyse des résultats d'inventaire en mode synchrone permet de constater une régression des souches, des semis et drageons en fonction de la durée de culture. La taille des individus n'a pas globalement une influence positive sur cette dynamique régressive des régénérations ligneuses. Cependant, la diversité floristique joue un rôle important en ce sens qu'elle détermine les modes de régénération. Ainsi, la plupart des espèces se régénèrent par graine mais très peu drageonne. Ces formes de régénération se caractérisent par une survie relativement faible.

Parallèlement, les souches se comportent différemment suivant les espèces. Ainsi seules les *Combretaceae* présentent la capacité à résister à la pression de culture indifféremment de leur taille. *Dichrostachys glomerata* en dehors de sa petite taille (d) présente un comportement quasi similaire à celui de *Combretum*. Par contre des espèces telle que *Bombax costatum* ne supportent pas du tout la pression de culture. Il est évident alors que la prolongation de la mise en culture provoque la disparition des espèces savanicoles voire forestières. Par contre, les espèces de la famille des *Combretaceae* sont maintenues dans les mêmes conditions. Pour favoriser un retour à la savane voire à la forêt après l'abandon cultural, il est nécessaire de raccourcir la durée de la phase de culture au minimum (3 à 5 ans). A défaut d'une limitation de la durée, les jachères resteront dégradées après la culture et dominées essentiellement par des *Combretaceae* souvent bien adaptées aux conditions édapho-climatiques et à la pression culturale.

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Chapter 4

Building Sustainable Agriculture Systems

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Conditions for sustainable farming systems in sahelian drylands: What can we learn from 'Success Stories'?

Michael Mortimore[1]

Abstract

A long-term research methodology allows inter-annual rainfall variability to be controlled for studies of environmental management. Four district-level studies were carried out in Kenya (Makueni District), Senegal (Diourbel Region), Niger (Maradi Department) and northern Nigeria (Kano Region), with profiles of production data constructed over 40-year periods (1960–2000). Small-scale field-level studies were also conducted with sampling of standard fertility parameters in cultivated or non-cultivated soils. The two data series can be placed in relational context through profiles of change in other environmental, economic and social variables.

Against a background of rainfall decline (1960s–1980s) and rural population growth, the long-term district level data need to be interpreted with care, but instead of a monochrome portrayal of decline as suggested in much literature, they contain significant evidence of maintenance or improvement in some production parameters, so as to suggest that demand rather than supply factors alone explain low average productive achievements in rainfed systems. The soils data support what is already known, that rather than overall average decline in soil fertility, there is a spatially differentiated pattern of sustainability whereby even under severe input cost constraints, farmers can maintain or improve productivity in some areas relative to the low baselines at the beginning of the period. Given those achievements, the solution to soil fertility constraints appears again to lie with demand factors rather than with technical interventions which are inconsistent with the price environment.

The role of policy emerges as the key factor in achieving sustainable systems in rainfed drylands. This encompasses all aspects of rural livelihoods, not only the technical NR factors, and the overall aim of policy should be to enable economic environments (especially markets) that offer incentives for investing in NR and protection against risk of asset loss.

Introduction

Major biophysical constraints affect the drylands of sub-Saharan Africa, including the region known as the Sahelo-Sudanian agroecological zone. Commonly cited are the variable and low rainfall, and low bio-productive potentials (including soil properties, seasonality, and biomass productivity). They share these characteristics with other drylands. The 'thesis of unsustainability' frequently applied to dryland agriculture begins with these 'natural capital' constraints, whose potency in policy debate has been such that unrealized potentials such as solar or wind energy have been rather ignored. The thesis moves on to incorporate management limitations (such as deforestation, overstocking, over cultivation and nutrient mining). The rainfed agricultural or farming systems appear in many places or in some respects to be incompatible with sustainable resource management, under either present or predicted

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pressures - from the growth of the human population (household-produced food security), the livestock population (feed requirements), and market demand. Again, the influence of these ideas has distracted attention from the potentials of the human resources ('human' and 'social' capital). Finally, poverty (including a scarcity of 'financial' capital) appears to seal the fate of rural dry-landers who lack resources for investment.

The drylands of the West African Sahel are far from homogeneous in terms of physical, biological, social or economic variables (Raynaut et al. 1997). Variability occurs in many forms. It is found spatially (on scales from local to regional) and temporally (with wave-lengths from short-term or seasonal to medium or longer term). There is a geographical gradient from south to north, closely correlated with latitude, in the rainfall (both long term average rainfall and, usually, seasonal). Social and economic variability in rural population density, urbanization, and the nature or degree of dependence on agriculture, is weakly linked (if at all) with biophysical variables. Diversity in sources of income characterizes many livelihoods, but not to the same extent for everyone. Communities are notably differentiated in terms of wealth, by whatever criteria it is measured. There is considerable movement in these patterns from year to year. The resulting kaleidoscopic image should be borne in mind in the discussion that follows.

This paper reviews the question of sustainability in the light of some evidence on the long-term performance of agricultural systems in which, according to most views, farmers operate under extreme stress.

Materials and Methods

The need for a longitudinal method

The 'thesis of unsustainability' rests quite heavily on diagnostic evidence and *a priori* reasoning with regard to the future. For example, a current account 'banking' approach, when taken to soil properties – 'natural capital' - finds negative 'balances' (Oldeman and Hakkeling 1990; Stoorvogel and Smaling 1990), which, given certain assumptions about the supply constraints presently affecting inputs, lends support to a predicted downward spiral of nutrient mining, declining yields, and under-investment (Henao and Banaante 1999; World Bank 2003). Aside from critique of the methods used (Faerge and Magid 2003), this approach distracts attention from the adaptive characteristics of farming systems when viewed in dynamic terms. The fixed category 'natural capital' (implied in the expression 'nutrient mining') is rather misleading in a continent that nurtured the human race and has been affected by management for millennia, and in which the natural resources may be artifacts of management as much as pristine gifts of 'nature'. Prescriptions for corrective action (often in the form of top-down technical promotions) may thus be based on false notions of equilibrium rather than on the non-equilibrial behavior that characterizes natural and human systems in drylands (Mortimore 1998; Reynolds and Stafford Smith 2002).

To obtain a better grip on the dynamics of dryland systems, a long-term methodology is required. This can allow the possibility of assessing change, smoothed over short-term climatic variability. Until recently, the database could not support such efforts. The best long-term data were and remain those for climate and rainfall in particular. Data are still scarce or deficient with respect to critical components of the systems, notably primary indicators like those of soil fertility (where baseline data are exceedingly scarce). However, data series are available over periods of 40 years for production, demographic, and land use variables. Many of these are secondary variables, themselves aggregate indicators of system performance rather than primary indicators of the state of the environment.

It is proposed that the performance of farming systems over time is a valid way of testing the 'thesis of unsustainability', with regard to the past in the first instance, and using the findings to suggest a role for policy in improving the incentives for investing in sustainable land use in future. A second objective is to ask how responses to incentives in villages, households or production units are differentiated, and what approach to sustainability policy these patterns justify.

The method applied

This paper is based on findings from recent work by Drylands Research and colleagues in three districts in Senegal, Niger and northern Nigeria. In each one, the plan was to assemble data with national scientists who would write 'change profiles' across a range of themes (eg, crop/livestock production; tree management; soil fertility management; institutional change). The profiles were developed through a process of interaction, both with members of the research team in each country, and with coordinating scientists. The profiles at district level were supported by village level enquiries in chosen locations. Syntheses were constructed for each study area and validated in multi-level workshops from village to national level. The evolution of policy was treated as a theme in its own right, so that policy impacts and lessons could be derived, and used as inputs to policy debates at national level. Environmental change and farming system responses were thus placed in context, which included processes, institutions and policies.

The study districts were chosen because baseline data, published or grey literature, and long-term data at district, regional or departmental levels were available from government or other sources. All areas were considered, in the literature, to be stressed by environmental variables and by demographic, market or management pressures. In each, however, there was evidence of adaptation and/or investment.

The choice of scale (district or meso- rather than macro- or micro-scale) leaves partly unanswered the extent of differentiation hidden in system-wide performance. This question cannot be investigated over time for want of baseline or series data. But if it is ignored, policy lessons derived from average performance at the district scale run the risk of being less applicable to the economically weak. To control partially for this, limited investigations were also carried out among household production units in four village locations in each district.

The study districts

These are shown in Table 1.

Makueni District, Kenya, forms the south-western part of the former Machakos District which was the subject of an earlier study (Tiffen et al. 1994). From this study the hypothesis of a positive relationship between population growth, market demand and investment in sustainable environmental management was derived. Three West African studies were designed to test and develop this hypothesis as a guide to policy priorities for dryland areas. Makueni was

Area	Population (millions) [a]	Area (km²)	Persons/km² (average)	Cultivated fraction (%)	Annual rainfall (range in mm)
Makueni, Kenya	670	7,440	90	>29	598-669
Diourbel, Senegal	620	4,359	142	93	400-500
Maradi, Niger	1,389	39,219	35	73	250-450 [b]
Kano, Nigeria [c]	8,686	42,520			
Kano, rural [d]	6,169	41,970	145 (50-400)	55-88	500-700

Table 1. Study districts.

[a] Most recent census
[b] Maradi south of the Tarka Valley
[c] Kano and Jigawa States
[d] Excluding Kano Municipality

the subject of an updating study designed to link the Machakos findings better with the Sahel. It is not reported here.

The three West African areas are:

- Diourbel Region, Senegal. The three departments of Bambey, Diourbel and Mbacké form the central part of the historic groundnut or 'peanut basin' (*bassin arachidier*) and are occupied by Wolof farmers in the north and center and by Sereer in the south, with small numbers of Peul mixed farmers. All available land was converted to crop production by 1950, in response to the profits to be made from growing groundnuts, and cereals (mainly millet) grown for subsistence. After the collapse of the subsidized *Programme Agricole* in the 1980s, farming has suffered from under-investment, and out-migration has absorbed an increasing share of population growth.
- Maradi Department, Niger. This large department has a wide rainfall range from south to north with a shift from mixed farming in the south to livestock production north of the 250 mm rainfall isohyet. Although the south has long been settled, and there were scattered villages in the central areas as early as 1850, French colonization led to an influx of Hausa farmers into drier areas, which continued from the 1920s until the 1980s, and whose momentum was maintained by population growth and expressed in rapidly increasing population densities. This rapid dynamic has been followed by shifts in marketing, farming practice, and livelihood diversification partly in response to the recurrent droughts experienced after 1970.
- The Kano region, northern Nigeria. The great city of Kano attracted a vast rural population to its environs from ancient times. The Hausa population (with a minority of settled Fulani) has developed an impressively intensive farming system on holdings averaging < 0.5 ha/person, and at very high population densities. Farming is supplemented with extensive diversification into other occupations and high levels of seasonal migration, commuting, and involvement in trading. The Kano Close-Settled Zone surrounds Kano city, within a radius of about 50 km, but the urban hinterland of Kano is much larger, and rural population densities are rising rapidly everywhere. The long historical continuity of intensive farming in the Zone is highly relevant to the debate on sustainability.

Results and discussion

Does the long-term performance of smallholder production systems bear out the ‘thesis of unsustainability’? This question is based on the premise that the cumulative effects of unsustainable practices, including losses of nutrients, should have a discernible impact on agricultural productivity in the long term. Summarized below is an analysis of selected performance indicators for these areas, which has been presented in greater detail elsewhere (Mortimore et al. 2003).

The performance of the Diourbel, Senegal farming system

(Faye et al. 2001)
During the 1960s, Diourbel produced 120–150,000 tons of groundnuts a year, reflecting nearly a century of commercial penetration, state promotion and public sector investments in transport and marketing infrastructure. The state took a monopolist role in input supply (financed by credit), marketing and processing. It also tried to control the trade in grains, and was the main supplier of imported rice. Only livestock markets remaining outside the state’s purview.

Nutrient mining was diagnosed by observers of Senegalese agriculture during the 1970s, on the basis of nutrient exports in the groundnut crop, reports of declining yields, inadequate fertilization, and shortening or disappearing fallows (Copans 1975; Franke and Chasin 1980). The semi-arid soils have low productive potential. However, it was hard to control for the effects of droughts, which increased in frequency with declining rainfall after 1967. These factors in turn were compounded by policy changes. The government was forced, by the deterioration of its finances, to withdraw many of its services from 1983-85, in particular the supply of inputs on credit. The sudden withdrawal of support resulted in an abrupt fall in groundnut production. In 1994 the CFA franc, which is linked to the French franc, was devalued by 50%. The state-controlled oil mills thereafter operated below their capacity. World prices stagnated or fell. Farmers diverted their groundnuts to consumption, sold hand-manufactured oil in local markets, and used the residues for feeding livestock.

Senegalese farmers did not have a growing market for their millet, since urban consumers, and rural families in deficit, had come to prefer cheap and more convenient rice. The most profitable farm enterprise was livestock fattening, and most households came to rely on non-farm earnings, and invested in the social networks that gave access to these.

Production of millet per capita, therefore, declined between 1960/61 and 1995/96 (Figure 1). On the other hand, we may ask what trends were apparent in the use-efficiency of scarce factors? Here, the evidence is strongly positive. Millet yields/ha/mm of available (rainfall roughly doubled after the 1960s, and yields per agricultural worker recovered after the drought cycles of the early 1970s and mid-1980s.

Groundnuts, on the other hand, went into a rapid decline in output/ capita, a rather slower decline in yield/ ha, but a noticeably rising trend in yield/ mm of rainfall, a trend that is believed to reflect changes in the varieties and agronomic methods used. Given the growing scarcity of fertilizers, these trends make sense better as responses to weak economic incentives than to soil constraints.

Livestock production however showed a buoyant trend. Incomplete data show that while the numbers of cattle, donkeys and horses in the Region fluctuated around mean values that did not change significantly over the 30 years, small ruminants roughly doubled in number. Thus the

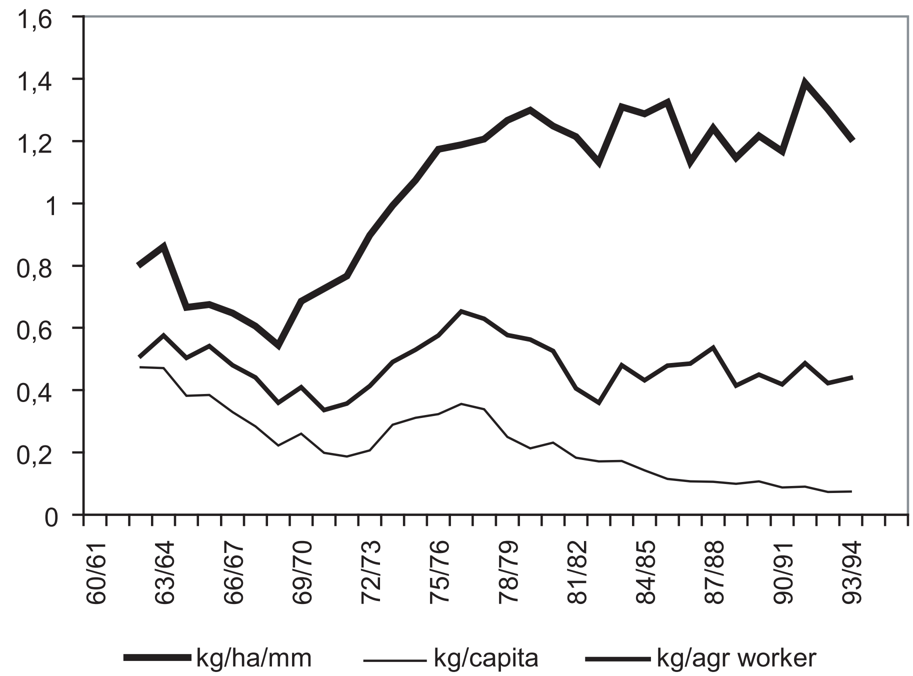

Figure 1. Millet production in Diourbel Region, 1960/61 - 1995/96 (5-yr means).

hectares available per Tropical Livestock Unit (TLU) declined (Figure 2). Such trends reflected buoyant meat prices since 1980, and an increasing capacity among poor people, including

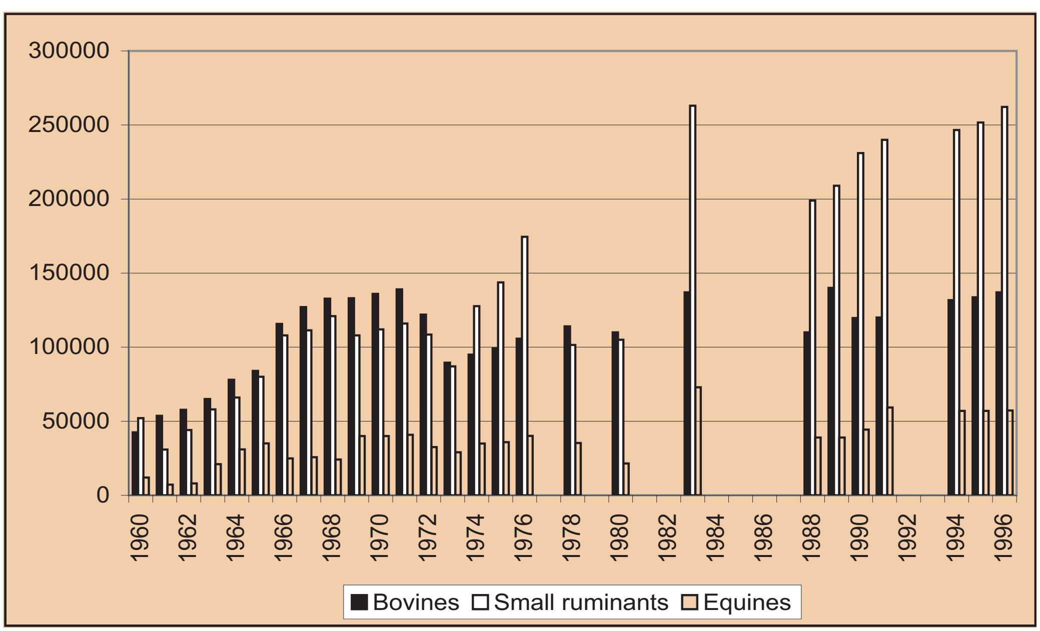

Figure 2. Hectares per TLU in Diourbel, 1960-96.

women, to buy or rear goats or sheep for economic gain. Fodder supply proved to be elastic in response to increased stocking rates. The integration of crops and livestock in the system included intensive use (and commercial exchange) of crop residues, and also benefited soil fertility through manuring or composting.

The Diourbel experience suggests that policy and economic incentives were the major determinants of farming system performance, and that even under the impact of major fertility and moisture constraints, there are signs of demand response in a system that was considered by some observers to have already mined its nutrient reserves 30 years ago. This response, including the switch to livestock, took place notwithstanding a collapse in the state-supported groundnut sector, the producer disincentive created by rice importation, high rates of rural-urban migration and the export of rural capital.

The performance of the Maradi, Niger farming system (Mortimore et al. 2001)

Niger's agricultural policy moved through three main phases between independence in 1960 and 1998. The first of these was characterized as 'modernization' (1964-1974). The aim was to produce and export groundnuts, the mainstay of the economy, through co-operatives supplying inputs and marketing. But there was an increased frequency of drought from the early 1970s, together with rising population densities and the exhaustion of the supply of new land. After 1971, groundnut production was affected by drought and rosette disease. Production fell from over 100,000 tons per year to an average of about 30,000 tons after 1974. The groundnut had fixed a proportion of its own N requirements. But evidence of degrading soils and vegetation, shortening fallows and declining crop yields, with claims of overgrazing by armies of cattle and small ruminants, combined with 'monetisation', individualization, migration and diversification out of agriculture to provoke very pessimistic assessments of the sustainability of the system (De Miranda 1979; Grégoire and Raynaut 1980; Raynaut 1980; Raynaut et al. 1988).

Cutting back its hopes for the groundnut, the government adopted a 'food self-sufficiency' strategy for agriculture (1975-1985). Additional resources for cereal production, inputs and marketing, and the costs of several major development programs, were financed from new uranium revenues. Among these was the *Programme de développement rurale du Maradi* (PDRM, 1978-86). However, unsustainable external debts accumulated.

The third phase was an inevitable structural adjustment program (1986-1998), with a reduction in public investment in rural development, the ending of state buying monopolies, and currency devaluation (1994).

The Maradi data suggest that while the population increased from 1960 to 1988 by a factor of about 1.5, the output of cereals (millet and sorghum) per capita was maintained or improved, 1964-1998 (Figure 3). After 1975 it did not fall significantly below the estimated food requirement per capita (200 kg). There was a strong link with the three policy phases. After stagnating under 'modernization', millet production trended strongly upward throughout 'self-sufficiency' and also under structural adjustment. Meanwhile, the groundnut gave place to cowpea as the primary market crop, in response to the Nigerian market.

These achievements were only partly based on exploiting the extensive margin. Areas planted to the major crops increased most rapidly under the incentives provided by 'self-sufficiency', and also during the 1980s there was a process of revision in land tenure (the *Code*

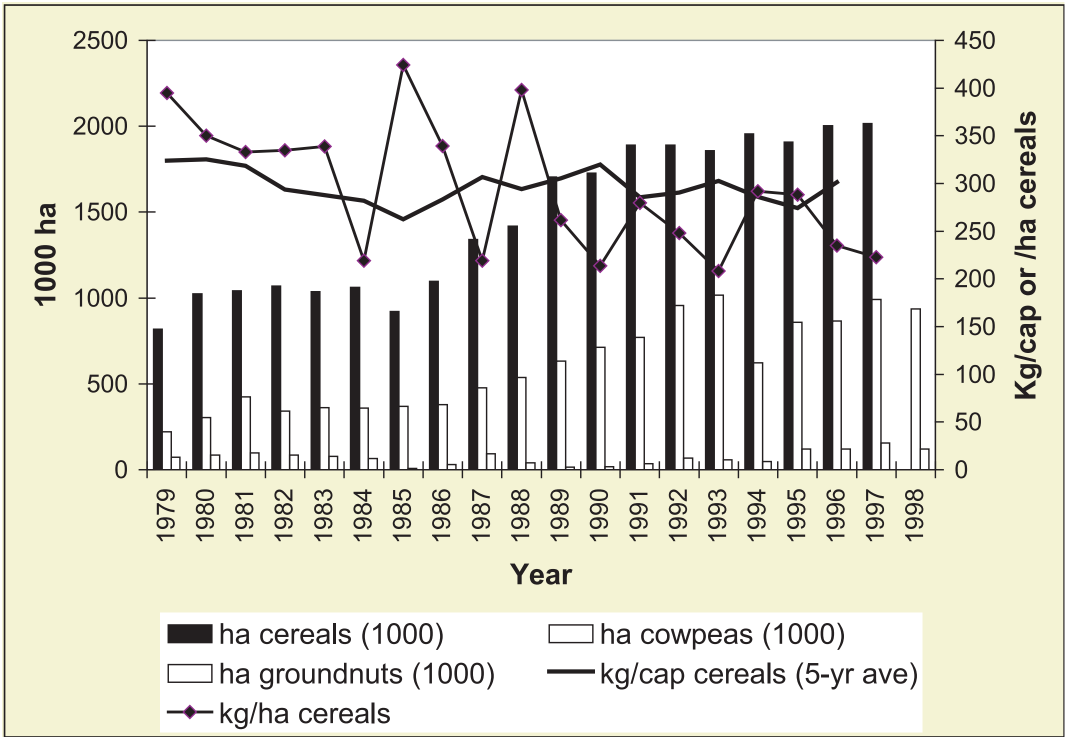

Figure 3. Crop production in Maradi Department, 1979-1998.

rural) which motivated farmers to claim private rights by clearance and cultivation. But this expansion leveled off after 1994. Cultivation increased from 59% of the total area in 1975 to 73% in 1996; in some southern *arrondissements* it was higher than this. Despite declines in both open rangeland and fallow grazings, available data show no evidence of a decline in the livestock population. Animal production also benefited from buoyant prices in Nigeria.

When the data are disaggregated, the north shows increasing areas planted, but stagnant or declining yields, while the south shows little change in areas planted, but an upward trend in yields (Figure 4)(Tiffen and Mortimore 2002). This suggests an incipient transition towards more intensive land use, which is supported by other evidence, including: a growing popularity of the practice of protecting valuable trees on cleared farmland; a range of indigenous soil fertility practices; adaptations of the customary land tenure system to take care of land scarcity and increasing individualization; new seeding, cultivation and conservation measures; investments in livestock, ploughs, planters and carts; and increasing roles for women in farm investments.

The performance of the Kano, Nigeria farming system

When our period of analysis began, in 1961, state marketing boards took a substantial proportion of the relatively high prices for agricultural exports. In return, the state delivered some benefits in the forms of improved roads, a state-sponsored input supply system, and agricultural research aimed at raising productivity. However, when world prices turned down in the 1960s, the state maintained its revenue streams from the crops, resulting in producer prices falling even more than world prices (Helleiner 1966). Meanwhile, grain tuber and livestock markets remained unregulated.

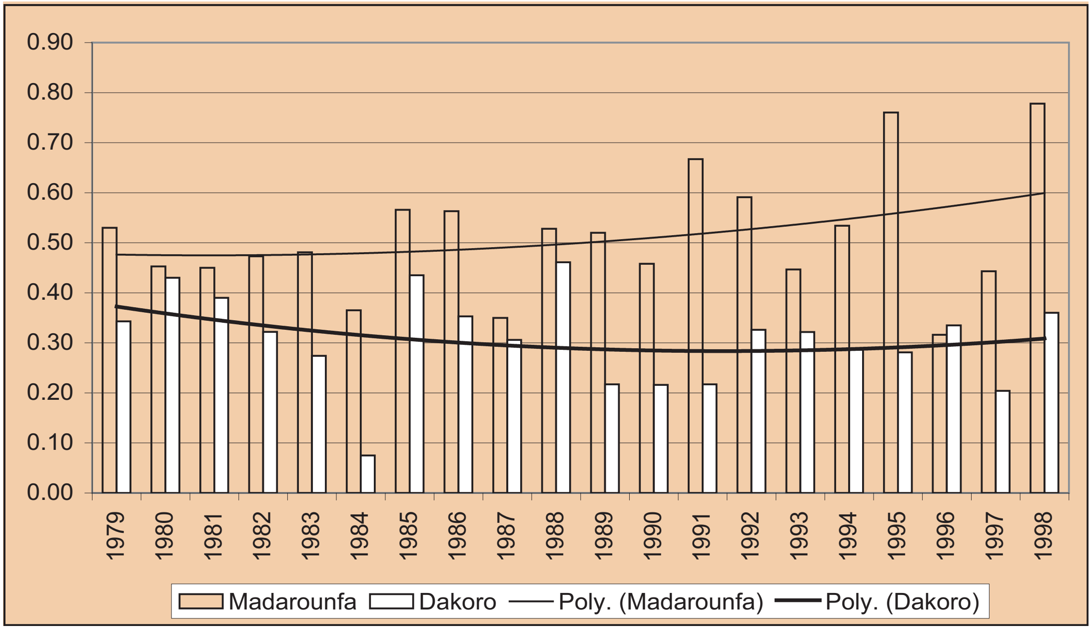

Figure 4. Trends in millet yields in northern (Dakoro) and southern (Madarounfa) arrondissements in Maradi Department, 1979-1998.

The oil boom (1970-1978) introduced major distortions, including a decline in the real prices of imported food, a bias in public investments toward the urban sector, speculative economic activity, urban migration and increasing costs of agricultural labor (Forrest 1993; Mustapha and Meagher 2000). There were severe reversals in agricultural exports (groundnuts, cotton, palm oil, rubber), and environmental shocks (drought, and rosette disease in groundnuts), while farmers' incentives to produce food and industrial crops for internal markets were reduced by cheap imports (Pinto Toye et al. 1998). By most indicators, the agricultural sector went into decline.

Ineffective 'austerity' measures after 1978 failed to arrest the distortions in the economy but the exchange rate declined as Nigeria was forced into successive devaluations. The watershed was in 1986, when Nigeria introduced a structural adjustment program. However, this program departed from orthodoxy in several ways. Most important were the retention of subsidies on fertilizers and of restrictions on certain imported foods (notably wheat and rice). Devaluations affected input costs adversely, but had the effect of reducing food imports, and improving the real prices of locally produced food products. There were improvements in output. During the 1990s, controls were further liberalized, corruption increased, and civil unrest contributed to economic stagnation (Moser et al. 1997).

In the densely-populated Kano Close-Settled Zone, aerial photographs show that cultivated land increased from 78% in 1950 to 88% in 1981 (Mortimore and Adams 1999). The remaining land is occupied by villages, roads and cattle tracks. Fallowing now only occurs on a small proportion of fields. Not much of urban Kano's food comes from within the densely populated zone, where many households are in deficit; nevertheless, market relations are integral to its rural livelihoods. Farm productivity and sustainability, family interests in keeping livestock, and wide-ranging income diversification are directly influenced by demand in its huge and easily accessible markets. Expectations of a collapsing farming system, under market and demographic pressures, have not been fulfilled: instead, increasing product values ensured investment and conservation in trees and other natural resources (Cline-Cole et al. 1990).

The Kano hinterland extends beyond this zone, however. Notwithstanding a six-fold increase in its population since 1962, the city obtained its grains (millet, sorghum and cowpeas) largely from the same northerly regions in 1999 as it did in 1966, except that maize grown for food and industry has increased in subhumid areas. The markets occupy a nodal position in national and international trading circuits. Root and tuber imports from further south have increased; while southern demand for cowpeas is fed from the north. With regard to millet, the preferred food staple of northern areas, a declining trend in real prices suggests that Kano markets work efficiently in the long run (Figure 5)(Ariyo et al. 2001), and that dryland farming systems in the hinterland have increased their output capacity.

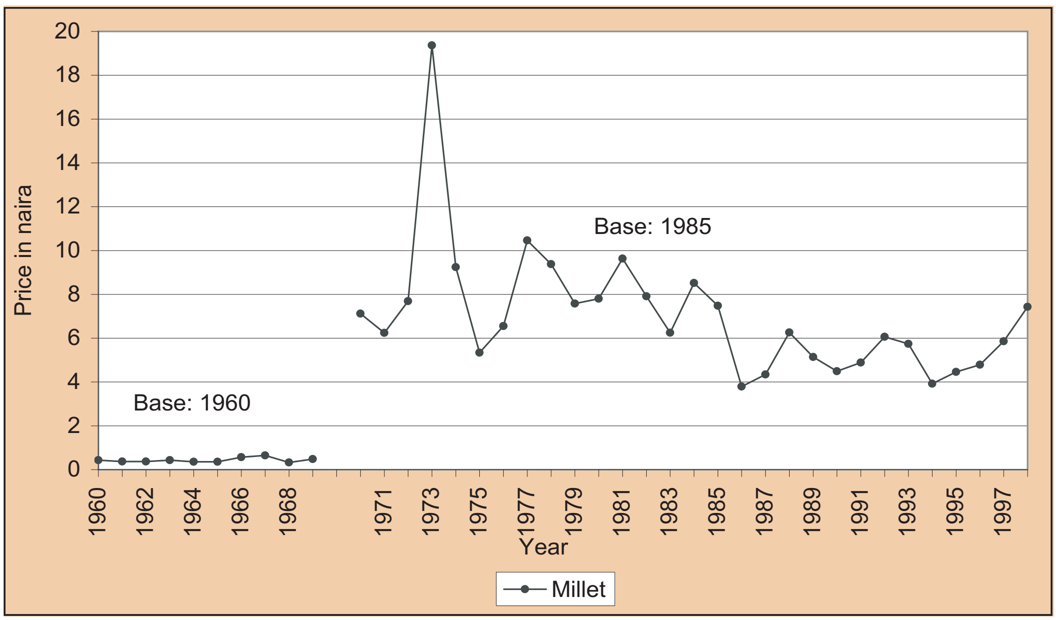

Figure 5. Millet real prices in Kano markets, 1960-1998.

The transition to sustainable soil management

Given an increasing demand for cultivable land, extensive systems of land use must evolve to permit increasingly frequent use for crop production. Within the framework proposed by Boserup, Ruthenberg and others (Boserup 1965; Ruthenberg 1980), it is useful to distinguish two steps in this transition to intensive land management in rainfed dryland farming systems:

- Step 1, from shifting to permanent fields, as the *cultivated fraction* increases beyond the threshold level sustainable under shifting cultivation or bush fallowing, causing the reduction and eventual disappearance of fallows, and their substitution by annual cultivation. Readily visible on sequences of maps or images, this step causes a reduction in average yields/ha, which may, however, be tolerated for some time before embarking on:
- Step 2, from old to new technology in annual cultivation, as farmers compensate for lost fertility by new fertility management techniques and additional inputs. The supply of these

determines the *intensively cultivated fraction* that can be managed more sustainably within the economic constraints of a given system. This fraction (Hausa: *karakara;* Wolof: *toll keur*) may correspond locally to a permanent infield zone, *aureole*, or *champ de case*, or it may be rotated around a farmer's fields from year to year.

The two steps are not synonymous, nor does Step 2 necessarily follow Step 1. The distinction is helpful for the purpose of spatial and social mapping of sustainable land use at the micro-scale.

The cultivated fraction, as determined from air photo or satellite image interpretation, does not necessarily correlate either with population density or the adoption of step 2. Two examples will illustrate this:

- In central Maradi very high fractions under cultivation are observed (>70%) although population densities are low (15-35/km^2), whereas under similar rainfall conditions at Dagaceri in northern Nigeria, a lower cultivated fraction may be observed (<55%) with a higher population density (>43/km^2). The explanation lies in an institutional factor: in Niger, the C*ode rural* has added to the demand for farmland, while in Dagaceri, 30-year old agreements between farmers and livestock breeders has slowed the advance of the farming frontier. Consequently, in Dagaceri a larger proportion of fields have undertaken Step 2.
- In both the Kano Close-Settled Zone and the *bassin arachidier* in Diourbel the cultivated fraction exceeds 80%, but the densities of population are very different: >225 on-farm residents/km^2 in rural Kano but <150 people/km^2, on- or off-farm, in Diourbel. However, the intensively cultivated fraction differs between an estimated >70% in Kano and <20% in Diourbel (Sob)(Garin et al. 1999).

Step 1 may be expected to be accompanied by a negative change in standard soil fertility indicators (N, P, K, Ca, C, OM and clay), and the second by an increase. In 98 samples of topsoils taken from farmers' fields in Maradi, Issaka found this pattern at four sites across a rainfall range from 450 mm to 250 mm, although the absolute values decline with increasing aridity (Issaka 2001). Four fertility management regimes were identified:

- land left fallow for >50 years (a proxy control – equivalent to never cultivated)
- rangeland
- cultivated land without fertilization, and
- cultivated land under some form of fertilization (usually organic).

At all four sites, the levels achieved with fertilization might equal or exceed those found in the control. Figures 6 and 7 illustrate this pattern, with reference to organic C, and K (where the rainfall declines from left to right in the four villages).

Very similar findings resulted from analyzing cultivated soils for clay, organic C, and N at Dagaceri (Table 2). Land use mapping shows 33% of the surface under grassland (fallows) used for grazing, and 55% under cultivation. Thus nutrients are transferred from grassland to manured fields, but we do not know the intensively cultivated (manured) fraction of fields.

Table 2. Properties of cultivated white soils of farmers' fields at Dagaceri, Nigeria (top 20 cm).

Management	Clay%	Org C%	Total N%
Uncultivated	8.5	0.26	0.08
Fallow >5 yrs, grazing	7	0.16	0.05
Cultivation >19 yrs	5.7	0.14	0.02
Long cultivation with rotational manuring	5.7	0.27	0.04

Source: Yusuf 1999 cited in (Harris 2000)

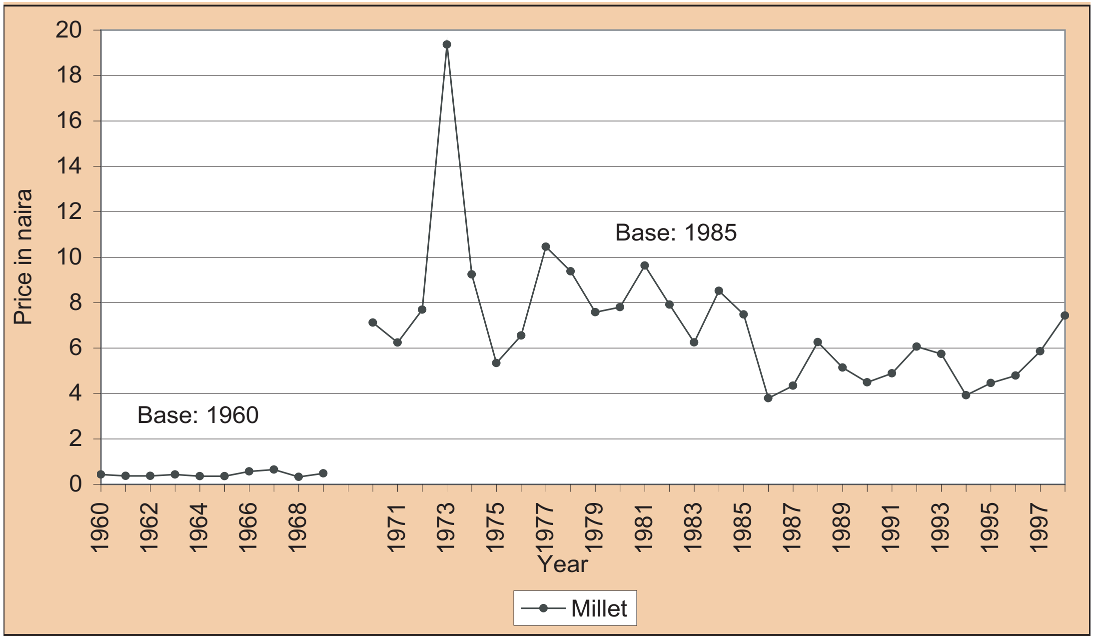

Figure 6. Organic matter (%) as a function of management in 100 soils from farmers' fields in four villages in Maradi Department.

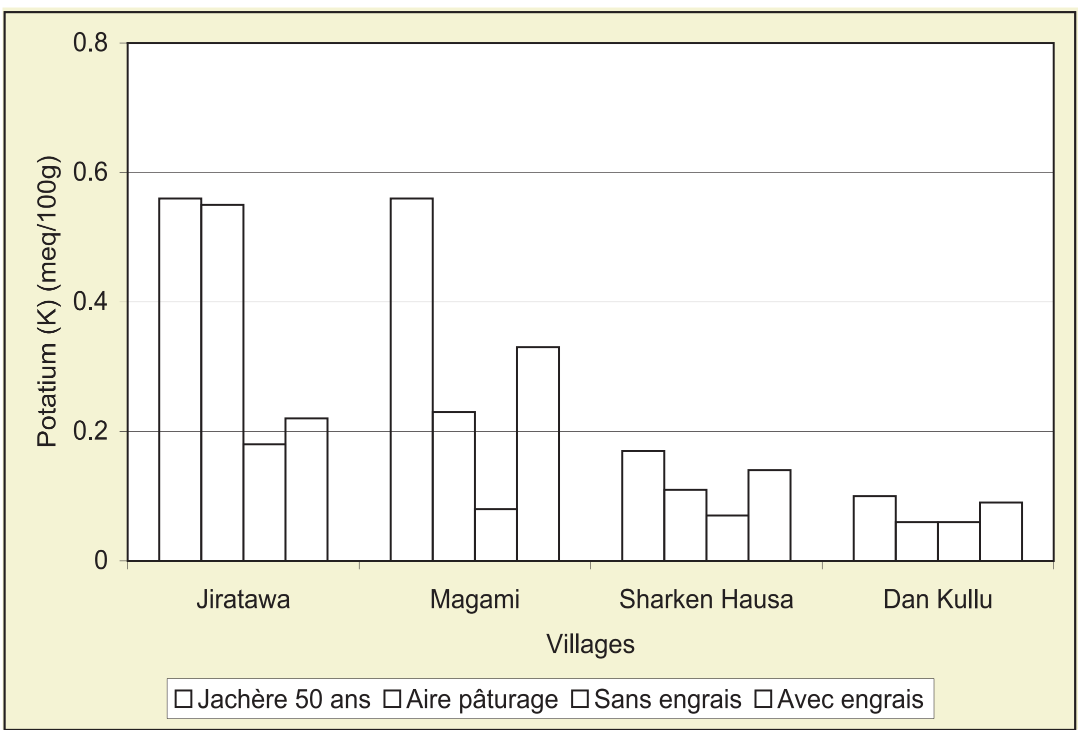

Figure 7. Potassium (meq/100gms) as a function of management in 100 soils from farmers' fields in four villages in Maradi Department.

Sustainability (measured for the moment in terms of standard fertility indicators) is put to the test over time. However, using a 'spatial analogue' of temporal change, by comparing one management regime with another, the evidence reviewed above points to the conclusion that sustainability is not a technical constraint, because with known methods of organic fertilization (crop residues, legumes, manuring and composting) plus occasional use of inorganic fertilizers, farmers can raise the fertility levels of cultivated soils and even restore them to levels equivalent to those found in uncultivated land.

Let us turn now to systems where cultivated fractions exceed 80%, and where baseline data on soil fertility indicators are available. In Diourbel, fields benefiting from regular fertilization are categorized as *champs de case* (Wolof: *toll keur*), as they tend to be found closer to the house (the source of transported organic materials), in distinction from the *champs de brousse* where distance discourages such transporting. In addition to this management differentiation, the soils are naturally divided between superior *sols dior* and inferior (more sandy) *sols deck*. Comparing small samples (with limited representivity) taken from farmers' fields in 1966-67 and 1999, Badiane (Badiane et al. 2000) found that

- On the naturally superior *sols dior*, the *champs de case* had maintained or improved their productive potential measured by C, N and P (Table 3),

Table 3. Properties of cultivated soils (champs de case) at Ndiamsil and Sob, 1966-67 and 1999 (top 10 cm).

	Ndiamsil		Sob	
	1 sample, 1967	3 samples, 1999	4 samples, 1966	2 samples, 1999
pH water	6.7	7.4	6.2	8.0
Clay/loam%	5.7	3.7	7.2	8.5
Total C%o	1.6	7.3	3.2	4.0
Total N%o	0.14	0.7	0.3	0.3
P_2O_5 ppm assim.	30	350	15.5	195

Source: (Badiane et al. 2000), Tables 8, 15

- On *champs de brousse*, they had slowly declined, and
- On the inferior *sols deck*, where only *champs de brousse* are found, the productive potential had declined severely.

But how much of their land can farmers afford to sustain? For the village terroir of Sob, Garin's data show that the fraction of land receiving manure was about the same in 1985-87 as 20 years earlier (Table 4)(Garin et al. 1999). However, the data show other significant changes in fertility management. There was a reduction in the amount of land receiving manure from wet season grazing (*parcage*), and this was replaced by an increase in the amount fertilized from manure transported from penned animals. Pocthier also found a 50% fall in the percentage of land used for wet season *parcage* (Pocthier 1993). This reflects a reduction in the practice of transhumance – cattle now stay in sub-humid pastures throughout the year. A second change was the near-disappearance both of fallowing and of inorganic fertilization (the survey was carried out just after the termination of subsidies). Thus the two decades in question saw a reduction in the intensively cultivated fraction from a third to less than a fifth of the terroir. Given the evidence that farmers know how to sustain the fertility of their fields, the constraints appear to be

Method	1965-67	1986-87
Fallowed	17.1	3
Wet season *parcage* + manure	8.1	1.1
Dry season *parcage* + manure	6.3	6.8
Manure carried to fields	2.1	8.9
Total manured	**6.5**	**16.8**
Inorganically fertilized	**13**	**< 1**
Intensively cultivated	**29.5**	**17.8**

Table 4. Methods of fertility management annually, for two reference periods, in Sob (percent of terroir).

Source: (Garin et al. 1999).

Note: remaining land is assumed to include (a) non-farm uses, and (b) land cultivated without using any of the above methods of fertilization

economic, and 'the fertility crisis, if there is one, is geographically bounded on the *champs de brousse*' (Faye et al. 2001).

This conclusion makes it noteworthy that farmers in the Kano Close-Settled Zone have succeeded in extending the intensively cultivated fraction to the greater part, if not all of the cultivated fraction - their fields which have long ago negotiated Step 1. Admittedly this claim rests on subjective and anecdotal rather than quantified evidence: the antiquity of annual cultivation, with yields reportedly twice as high as those obtained further north, and the universal acceptance by the farmers of the necessity to fertilize them regularly in order to obtain any yield at all. Fallowing only occurs by accident, on perhaps one field in 50, owing to sickness, death, or input scarcities. Tiny fragments of derelict land are urged back into production with the use of extra inputs.

Superior soils and rainfall may have contributed to this achievement. However, it is considered that demand factors operating over several centuries have played a critical role. Until the twentieth century, Kano City was fed from the grain produced in its Close-Settled Zone, and its cooking fires were supplied with fuel from the farm trees that grew in great numbers. Migrants settled in rural as well as urban places in order to pursue their specialized callings - for example, trading in *kola* nuts, weaving and dyeing cloth - thereby adding to the demand for home-produced grain. Taxation (*zakkat*) took a very significant fraction of output. When the railway arrived in 1911, farmers switched to growing groundnuts for export, and the urban hinterland for food commodities was expanded to compensate. As the value of wood and tree products increased, the farm woodlands were replaced by distant forests whose exploitation was facilitated by new road infrastructure (Cline-Cole et al. 1990). When groundnut production failed in the 1970s, farmers began to sell grain again but, more importantly, diversified their incomes further in the burgeoning urban sector. Thus the sustainability of land management is not merely a matter of soil chemistry.

The labor-intensity of farming in the zone is illustrated by the fact that peak labor inputs/ha are from 2.5 to 5 times higher than in Dagaceri (which has smaller fractions both cultivated and intensively cultivated) during the critical operations of weeding, thinning and harvesting (Mortimore and Adams 1999). Analyses of 59 soils from the same farmers' fields in 1977 and 1990, within the expected high variance of the results, confirmed an expectation of little significant change in clay or silt content, organic C, total N, and CEC on cultivated fields (Mortimore 1993). Average manure applications are 4 t ha^{-1} but some farmers achieve up to 12 in individual years in the village of Tumbau (Harris, 1998). Inorganic fertilizers became widely used until the early 1980s thanks to subsidies, and declined in the 1990s. Livestock (principally small ruminants) play a critical role in converting biomass to organic manure under close and efficient management (zero grazing, cut-and-carry, harvesting of weeds, etc during the growing season). Livestock ownership is an indicator of wealth, along with size of land holding. Livestock density rises with that of the human population.

Given the importance of these assets (land, livestock, manure, ability to buy inorganic fertilizers), sharp differentiation occurs among households in ability to capitalize farming operations and in relative dependence on off-farm incomes. Differentiation between holdings and fields occurs as a consequence of year-by-year choices in fertility management (frequency and amount of manuring or inorganic fertilization, planting of legumes, residue incorporation, etc)(Harris 1998; Yusuf cited in Harris 2000). Notwithstanding an impression of homogeneity in the meticulously managed and bounded fields, there is a correlation between the economic circumstances of households or individuals and the quality of management, sometimes giving rise to startling contrasts in biomass production on adjacent fields. To be obliged to fallow, or to cultivate annually for several years without fertilization, is a social admission of agricultural incapacity (Table 5).

Table 5. Effect of management on soil properties in Tumbau, Kano Close-Settled Zone.

Management	Silt/clay (%)	Org C (%)	Total N (%o)
Uncultivated	19.1	0.56	0.02
Short fallow	17	0.27	0.02
Long cultivation	15.4	0.65	0.02
Cultivation with annual manuring	16.7	0.42	0.03

Source: Yusuf, 1999, cited in (Harris 2000)

Thus the spatial patterning of fields with their fertility management regimes shadows the distribution of income, economic power and opportunity in the community. It is tempting to see the map of sustainability as the converse of that of poverty. However, the smallest holdings may be the most productive, while those with assured off-farm incomes may choose to neglect their farms.

Conclusion

These districts demonstrate significant performance achievements over the long term. Although at low yield levels (from a production perspective), they need to be seen against a background of rainfall decline, rapid population growth, and policy failures. Even in Maradi, where land was abundant until the 1970s, these achievements cannot simply be attributed to 'extensification'. In Diourbel land 'saturation' was a fact of life at least half a century ago and in Kano, more than a century ago.

Transition depends on investment

The transition to more sustainable land management (Step 2 described above) depended on *investment*, and that investment depended on *incentives*. Increased production can be attained with the use of new or improved technologies, and the potential for sustained productivity can be raised. But time and again, promotion of new technologies failed to achieve expectations because of failings in economic environment or other non-technical parameters (eg cultural preferences, livelihood competition). On the other hand, there are 'success stories' of positive responses to demand incentives, from historical examples in export agriculture to the swings from exporting to producing for internal markets illustrated above in Senegal, Niger and Nigeria. These swings respond to rapid social change and urbanization.

What such achievements suggest is that policy and effective demand, rather than constraints on supply, may have been key determinants of agricultural performance over the longer term. The challenge for policy, therefore, is to strengthen incentives for investment in increasing production while also ensuring sustainable management of natural resources. The record suggests that market demand can be compatible with such management (Tiffen et al. 1994).

There is an unanswered case that increasing effective demand will ensure the private investment necessary not only to increase output (and therefore improve livelihoods), but also to sustain productivity in producers' best long-term interests. There are many ways in which policy can improve the incentive structure, in particular the indirect incentives that work through institutions and markets (FAO 1998). The case has been made that human potentials in drylands can be released through better attention to holistic and flexible policies, including the promotion of income diversification, empowering institutions, and a rights-based approach (Anderson et al. 2003).

Investment and income diversification

What is actually achieved by particular farmers, however, is determined by their economic resources or competitive strength in local factor markets, as there is a general scarcity of affordable inputs, land, and (at certain times of the growing cycle) of farm labor. Farmers have shown how far they can go, given existing incentives and constraints. Therefore, *at these low levels of productivity*, extending sustainable management to more farmers and fields depends on changing the investment incentives and on relaxing the economic constraints. To *raise* the level of productivity more rapidly than hitherto, access to new technologies (including fertilizers) will be necessary.

If a narrow goal of ecological sustainability is replaced by a broader one of livelihood sustainability - for increasing numbers of rural people still partially dependent on agriculture - income diversification enters the picture. It is reported to be increasing rapidly in some areas of Africa (Bryceson 2002). In the West African drylands, where it has always played a role in rural livelihoods, diversification both migratory and *in situ* contributes to differentiation between households and individuals. This reflects the size, security and status of the income sources tapped. Although diversification is sometimes declaimed as insecure, low-paid, demeaning or in other ways 'desperate' or 'forced', there is no doubt that dryland people regard diverse portfolios as advantageous in reducing risk. There is evidence that income streams from off-farm activities, though small, do contribute to farm investment (Faye and Fall 2000; Nelson 2000).

A critical factor is the capacity of the informal sector to offer opportunities of income diversification, usually associated with out-migration, sometimes abandoning claims to the use of natural resources. Such structural transformations (Tiffen 2003; Tomich et al. 1995), which have run their course in the industrial-urban economies, appear to be proceeding more slowly in African economies as urban people retain social and economic links with their rural roots. This may reflect greater levels of risk (owing to the weakness of the formal sector, the low incomes achievable in urban informal employment, or a sense of political insecurity outside one's ethnic territory). However, as the human populations continue to grow, dryland futures will depend increasingly on the resolution of such sources of risk. This is an appropriate goal for policy.

Strategies for the poorest

Given the diversity and dynamics, which we have observed in dryland production systems, it is unrealistic to expect that everyone can respond equally to improved economic incentives. For example:

- land productivity parameters vary from place to place and even from one part of a field to another,
- the level of household dependency on primary resources (livestock and crop production), as opposed to off-farm revenues, varies, and
- the wealth of households or individuals, whether measured in demographic terms, in land, livestock or other capital, varies temporally and socially.

It is common knowledge that the better-off can capitalize and respond to market opportunities and thereby further capitalize. However, there are some whose competitiveness - whether in the agricultural sector or outside it - is so weakened by poverty that their responses to incentives are constrained. Although the average performance of a farming system may improve over the long term, as shown in the Machakos study and in our subsequent studies in West African drylands, it has always been clear that differentiation characterizes the response patterns at the household level, that there are 'winners' and 'losers' and that some may go under in the longer term (Murton 1999). The poorest may become vulnerable to land sales or other forms of redistribution of the means of production.

If the goal of policy is to retain the poorest rural people in rural places (for whatever reason), technical interventions that increase productive capacity and real income, and/or sustainable land use solutions, can only be appropriated on condition that finance is provided from outside. Traditionally this was done through credit schemes. But credit misses the point. For poor people, debts increase risk and in a dryland environment this can be disastrous. In Malawi, where rural poverty is general, the government attempted to break out of the cycle of low productivity and under-investment by providing all households with free seeds and fertilizers.

On the other hand, if the goal of policy is to promote livelihood development, the structural transformation referred to above needs to be accelerated. But increased urban migration and informal sector proliferation tend to be obstructed rather than encouraged, and would be surprising candidates for prioritization in agricultural policy. Yet the question must be confronted whether such priorities indeed reflect the aspirations of rural dryland people. After a decade of economic stagnation, urban areas still score lower than rural ones in certain poverty indicators.

At the policy level, a two-prong approach to sustainable dryland agriculture therefore would

- increase the demand and investment incentives necessary to secure uptake of sustainable technologies by the better off and middle income farming households (those able and willing to invest), and,

- pursue macro-economic policies to hasten growth outside the agricultural sector and facilitate inter-sectoral financial flows.

Given relatively modest expectations offered by new technologies, sustainable dryland livelihoods cannot be assured by sustainable dryland agriculture until the demographic transition to a stable or declining rural population is passed. This conundrum summarizes the dilemma of policy choice. Dryland agriculture cannot be dealt with in isolation from the economy as a whole, nor by generalized 'blueprint' policies. The long-term objective should be the *capitalization of farming landscapes* via releasing human and investment potentials of poor people – and ensuring their ownership of the benefits (Anderson et al. 2003).

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I should like to acknowledge the collaboration over several years of Kenyan, Senegalese, Nigèrien and Nigerian scientists in work, which has been reported in *Drylands Research Working Papers*, 1–41 available at www.drylandsresearch.org.uk. In particular, Mary Tiffen (with whom I have been privileged to work on the Machakos study and its successors) has made a major contribution to the ideas put forward in this paper.

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Importance de la biodiversité agroforestière dans les agrosystèmes du Bassin arachidier du Sénégal

Maguette Kaire[1]

Résumé

Dans le contexte de forte pression foncière et de péjoration climatique qui caractérise la zone semi-aride du Sénégal, la survie des agrosystèmes reste liée à leur capacité à évoluer en adoptant de nouvelles stratégies de valorisation de la biodiversité.

Outre les multiples rôles de l'arbre dans la gestion et la conservation de l'eau et du sol, le développement de technologies agroforestières constitue une alternative intéressante pour les producteurs dans la recherche de solutions aux nombreuses contraintes liées directement ou indirectement au déficit pluviométrique et à la dégradation des sols.

Dans cette étude, la biodiversité agroforestière a été abordée en cherchant à relier les structures observées aux processus c'est-à-dire aux mécanismes qui peuvent conduire localement à la mise en place, au maintien, à la réduction ou à la restauration de cette biodiversité.

L'expression la plus simple de la diversité est la simple énumération des unités (nombre d'espèces) peuplant un espace donné. Mais une bonne mesure de diversité doit non seulement tenir compte du nombre d'espèces, mais aussi de l'abondance relative de chaque élément dans l'échantillon. Pour cette étude l'indice de diversité de Shannon Weaver a été utilisé; il prend en compte à la fois la richesse spécifique et les distributions d'abondance. Cet indice montre une faiblesse de la biodiversité agroforestière dans les unités de gestion des différents terroirs étudiés.

Face à l'érosion de la biodiversité agroforestière dans le Bassin arachidier, le Centre National de Recherches Forestières (CNRF), en collaboration avec le Centre International pour la Recherche en Agroforesterie (ICRAF), développe des stratégies pour une reproduction des fonctions agroforestières perdues par le système. Cela s'est traduit par un criblage d'espèces et le développement de technologies agroforestières en fonction des variantes de système d'utilisation des terres dans le Bassin arachidier.

Abstract

In the context of strong land pressure and climatic pejoration which characterizes the semi-arid zone of Senegal, the survival of agrosystems remains related to their capacity to move by adopting new strategies of biodiversity valorization. In addition to the multiples roles of trees in land and water management and conservation, the development of agroforestry technologies constitutes an interesting alternative for producers in research of solutions to the numerous constraints bound directly or indirectly to the pluviometric deficit and land degradation. We approached agroforestry biodiversity by trying to link the observed structures to the processes and to the mechanisms that locally can influence the maintenance, the reduction or the restoration of biodiversity. The simplest expression of diversity is the simple enumeration of units (number of species) populating a space. But a good measurement of diversity must not only take into account the number of species, but also the relative abundance of each element in the sample. For this study the Shannon Weaver diversity index was used; it takes into account at once the specific richness and the abundance distributions. This index shows a weakness of agroforestry biodiversity in the management units of the different village lands. Facing the agroforestry biodiversity erosion in the groundnut basin, the National Center of Forest Researches (CNRF), in collaboration with the International Center for Research in Agroforestry (ICRAF),

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developed strategies for a reproduction of the agroforestry functions lost by the system. That resulted in a species screening and the development of agroforestry technologies according to the different land use systems in the groundnut basin.

Introduction

Roles de la biodiversite agroforestiere dans les agrosystemes

Naturel ou planté, local ou introduit, l'arbre et l'arbuste assure des fonctions multiples et diversifiées au bénéfice des populations rurales (Griffon et Mallet 1999) :

- Fonctions environnementales (protection des sols, régulation des eaux, maintien de la diversité biologique…) et agroécologiques (maintien de la fertilité des sols, effet microclimatique sur le milieu…)
- Rôles de productions (bois, fourrages, aliments et condiments, gommes, produits de pharmacopée, …) ou de structuration de l'espace rural et du paysage (délimitation foncière, organisation des espaces agro-sylvopastoraux…)
- Dimensions économiques (revenus, capitalisation…), sociales (arbre à palabre…), culturelles et religieuses (bois sacrés…)

L'arbre est donc une composante forte mais souvent sous-estimée du monde rural

Par rapport à l'eau

L'absence de couvert végétal pendant de longues phases culturales favorise le ruissellement des eaux de pluie aux dépens de l'infiltration et donc l'assèchement progressif du milieu. Les arbres jouent un rôle très important dans le cycle hydrique : Ils constituent sur les pentes un obstacle au ruissellement par la couverture et leur enracinement ; ils maintiennent aussi des microclimats humides sous leur couvert, depuis une échelle microlocale jusqu'à une échelle régionale par la participation au cycle journalier d'évaporation-condensation (Roupsard 1997).

Dans la protection contre l'érosion et l'amélioration de la structure du sol

Le couvert boisé protège le sol contre l'agression par la pluie et le vent. L'installation de réseaux de haies vives dans un bassin versant réduit l'érosion hydroéolienne ; on s'intéresse généralement aux espèces fixatrices d'azote et qui ont un rôle dans l'accumulation d'éléments nutritifs et la production de bois et de nourriture. Les arbres améliorent la structure du sol par une action mécanique : fragmentation par les racines des horizons compacts et indurés, réseau dense de racines, effet volumique des mycorhizes, apport de matière organique par la litière.

Dans le cycle biomasse - matière organique, dans la reproduction de la fertilité

La matière organique issue de la décomposition de la biomasse joue un rôle essentiel dans l'apport nutritif, la structure et le degré d'humidité du sol, donc dans la fertilité générale de celui-ci. Sur sol nu, les agressions de la haute température et des radiations solaires ne permettent pas une bonne décomposition de la biomasse. L'agroforesterie peut reproduire en s'en approchant les conditions qui permettent la formation et l'entretien de la couche fertile d'humus forestier. L'intégration dans la jachère de légumineuses ligneuses apporte au sol une importante quantité de matière organique (Peltier et al. 1995).

En réduisant les extrêmes des températures, l'ombrage tempère la vitesse de décomposition de la matière organique, réduit et étale les pics de minéralisation que l'on observe en sol nu et découvert et qui font perdre des éléments nutritifs par lessivage ou émission gazeuse. Selon Swift (1985), le couvert arborescent permet une meilleure répartition dans le temps de la décomposition de la litière d'autant plus que l'on peut en partie gérer le phénomène (en ajoutant par exemple de la litière par émondage) de façon à synchroniser la libération des éléments nutritifs issus de la décomposition avec les besoins des plantes cultivés sous les arbres.

Par leur enracinement profond et l'architecture de celui-ci, les arbres peuvent réassimiler les éléments lessivés dans les horizons profonds des sols, et contribuer par le feuillage à leur réintroduction dans le cycle. Certaines légumineuses ligneuses comme les Acacias, en association avec des Rhizobium, peuvent contribuer grandement à la fixation de l'azote atmosphérique.

Dans la gestion des attaques parasitaires, maladies et ravageurs

La spécialisation de la production agricole et, souvent même, l'emploi d'une seule variété favorisent les pullulations et propagations rapides, particulièrement dans les paysages ouverts où les phénomènes sont rapides et massifs. Le compartimentage du paysage par les arbres ralentit et réduit les risques de prolifération. Par ailleurs, certains arbres peuvent s'intégrer dans des stratégies de lutte biologique en raison de leurs vertus particulières (rôle répulsif, piégeage d'insectes. Certaines espèces arborées peuvent avoir un effet dépressif sur la population de certains nématodes.

Dans le gestion de l'alimentation animale

Dans les régions à forte densité de population, les arbres fourragers du système agroforestier participent grandement à l'alimentation du bétail de façon à limiter la contrainte d'assolement (qui consisterait à réserver une partie de l'assolement à leur alimentation). Les espèces fourragères à usages multiples comme *Leucaena leucocephala*, pouvant jouer un rôle de haies vives, de lutte anti-érosive, et de production de fourrage d'appoint, sont particulièrement intéressante dans cette optique.

Dans la gestion de la sécurité alimentaire et financière

Au Sahel, les populations des zones rurales et urbaines ont toujours tiré des parcs forestiers des produits destinés à la consommation et à la vente. Certains arbres fournissent de la nourriture de complément en période de soudure comme aliment de recours. Les jardins agroforestiers de case, enrichis en espèces fruitières et en espèces produisant des condiments, participent largement à l'approvisionnement alimentaire et vitaminique des populations rurales.

Bonkongou (2001) souligne que dans la région Ouest du Burkina, les études menées dans cinq marchés ont permis de comprendre comment les ménages utilisent et commercialisent les produits. 30 produits provenant de 17 espèces ont été recensés. Il s'agit principalement de l'huile, du beurre, du savon et des chenilles de Karité (*Vitellaria paradoxa*), des graines et du

“Soumbala” (boule fermentée ou poudre de néré (*Parkia biglobosa*), de la feuille, de la farine et du fruit du baobab (*Adansonia digitata*), du fruit du tamarinier (*Adansonia digitata*), du vin de rônier (*Borassus aethiopium*). Ils constituent d’importantes sources de revenus et fournissent des vitamines essentielles. Les produits des 3 principales espèces (néré, karité et rônier) ont rapporté à chaque vendeur en moyenne entre 100000 et 200000 FCFA par an, ce qui est supérieur au revenu moyen par habitant dans la région.

Au Mali, dans deux marchés des régions de Fana et de Tignole, chaque vendeur a pu obtenir, entre mars et octobre 1996, en moyenne 50000 FCFA par mois sur le beurre de karité, 11120 FCFA par mois sur les noix de karité, et 4250 FCFA par mois sur les graines de néré.

Au Sénégal, la vente du charbon a rapporté à chaque ménage 180000 CFA, la vente du bois de chauffe 248000 FCFA, celle de la gomme arabique 101700 FCFA, et celle des fruits de baobab 18000 FCFA par an.

Un programme de domestication d’espèces fruitières constituant les principales sources de revenus des populations est mis en route dans plusieurs pays. Au Sénégal, la recherche forestière travaille sur la domestication d’espèces comme *Ziziphus mauritiana, Tamarindus indica, Anacardium occidentale, Balanites aegyptiaca, Adansonia digitata, Saba senegalensis, Detarium senegalensis*…Concernant *Ziziphus mauritiana,* les travaux ont montré qu’une voie rapide d’amélioration de la production fruitière consistait à introduire les variétés indiennes (Gola ou Seb) améliorées ainsi que l’ensemble du paquet technologique (gestion de l’arbre, fertilisation, lutte contre les parasites…).

Materiel et methodes

Sites d’étude

Le Bassin arachidier du Sénégal s’étend sur une superficie d’environ 41000 km^2 soit le 1/3 du territoire national et couvre les régions administratives de Thiès, Diourbel, Fatick et Kaolack. Il occupe plus de 60% de la population rurale et 75% de la production arachidière.

Notre zone d’étude qui correspond à sa partie méridionale concerne les terroirs villageois de Ndienguène Keur Ali Dièye (130 habitants), Keur Layine Gueye (365 habitants), et Darou Mougnaguène (700 habitants) dans le département de Nioro du Rip, région de Kaolack (Figure 1). Ces villages bénéficient de l’encadrement de l’ONG AFRICARE en matière de gestion des ressources naturelles. La population est essentiellement composée de wolofs (90%), toucouleurs (7%), Sérères (3%).

Du point de vue géomorphologique, la zone est marquée par une monotonie du relief constitué essentiellement de glacis et de bas fonds, et par endroit quelques affleurements de cuirasse sur plateau, avec une prédominance de sols ferrugineux tropicaux. L’essentiel du glacis est cultivé. C*ordyla pinnata* est l’espèce caractéristique des parcs.

Sur le plan climatique, cette partie méridionale du bassin arachidier est caractérisée par un climat soudano- sahélien marqué par une longue saison sèche (8 à 9 mois) et une saison humide d’environ 3 à 4 mois. La pluviosité moyenne se situe autour de 700 mm, mais présente des fluctuations importantes sur 30 ans.

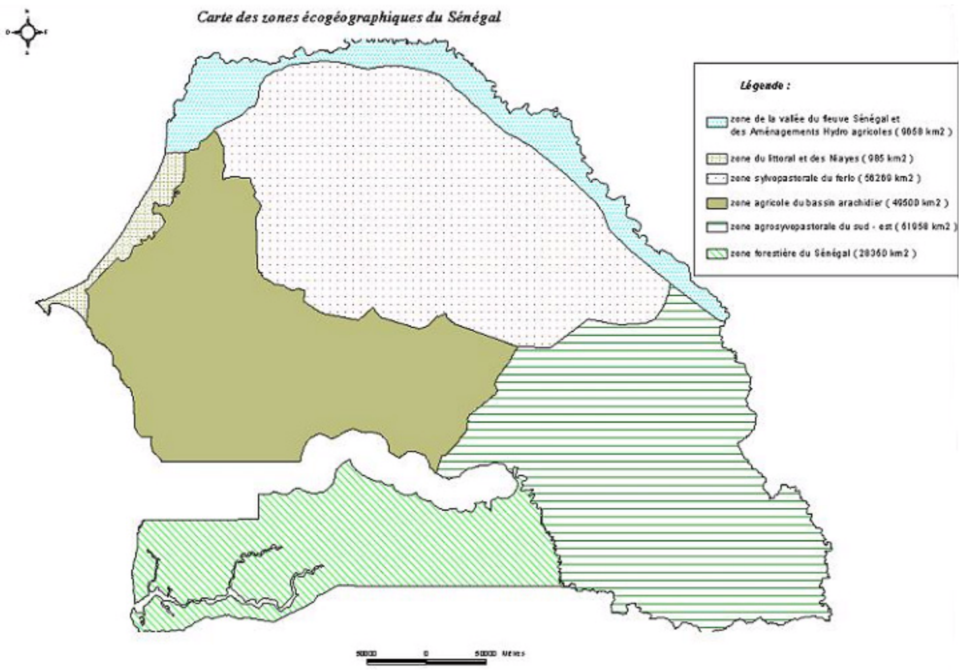

Figure 1. Situation de la zone d'étude.

Inventaire de la biodiversité agroforestière

L'inventaire a été effectué dans trois terroirs villageois suivant des transects allant du début à la limite de chaque terroir et orientées dans les directions cardinales (nord, sud, est, ouest, nord-est, etc.). Huit transects ont été ainsi délimités dans chaque terroir. Sur chaque transect, des parcelles d'un hectare distantes de 20 m ont été inventoriées dans le sens champs de case - limite du terroir. L'inventaire consiste à identifier les espèces et à mesurer le diamètre (à 130cm) de tous les ligneux et de toutes les souches présentes dans chaque parcelle.

Enquêtes sur les modes d'utilisation des ressources agroforestières

Des enquêtes ont été menées au niveau des trois terroirs selon la démarche suivante :

Des entretiens individuels avec des personnes ressources des collectivités locales, des organisations à la base, des autres producteurs dans les trois terroirs; une enquête proprement dite auprès de trente (30) chefs d'exploitation sur la base d'un questionnaire simple centré sur les éléments suivants: la socio-démographie (personne enquêtée, âge, ethnie, activités principales, personnes en charge, chef de famille, etc.), les ressources agroforestières existantes et leurs usages, les périodes et modes d'exploitation des ressources, la perception de la population sur la dynamique de ces ressources, la tenure foncière.

Analyse des acquis de la recherche agroforestière

Depuis 1989, le CNRF et l'ICRAF ont travaillé sur un certain nombre de technologies agroforestières pour la réintroduction de l'arbre dans des espaces entièrement occupés par l'agriculture: Haies vives, Brise-vent, Banques fourragères, Cultures en couloir (DRPF, 1993), et sur les modes de gestion des formations ligneuses du système cultures-jachères. Ainsi, en fonction des variantes de système d'utilisation des terres, le criblage d'espèces pour chaque technologie a abouti à la sélection de celles présentant les meilleurs comportements et recommandables aux services de développement. Les études menées dans le système culture-jachère ont porté sur l'enrichissement des parcs et sur la dynamique des formations ligneuses naturelles des jachères.

Resultats

Indices de diversité ligneuse dans les unités de gestion des terroirs étudiés

Une liste d'espèces a l'inconvénient d'attribuer le même poids à chacune d'entre elles, quelles que soient leur probabilité d'apparition dans une collection d'individus (Rippert 1996). L'indice de diversité de Shannon Weaver prend en compte à la fois la richesse spécifique et les distributions d'abondance.

L'évolution de l'indice de diversité de Shannon Weaver à travers les différentes unités de gestion du terroir (Figure 2) montre une biodiversité ligneuse faible dans l'ensemble des terroirs, même s'il existe des différences entre terroirs et entre unités de gestion.

Si on ne considère que les espèces locales (non introduites) dans la zone, les structures et le niveau de dégradation des parcs sont très proches dans les trois terroirs et partout ailleurs dans la zone. La valeur de l'indice est donc, en partie, fonction du nombre d'espèces (et leur fréquence) introduites dans les terroirs à travers les technologies agroforestières proposées par les différents projets qui interviennent dans la zone; plus le nombre de paysans adoptant ces technologies est important, plus l'indice de diversité est important. La valeur de l'indice indique en même temps le choix de l'emplacement (champs de case, pleins champs ou champs de brousse) des espèces introduites à travers les technologies agroforestières. L'impact des projets sur l'indice de diversité

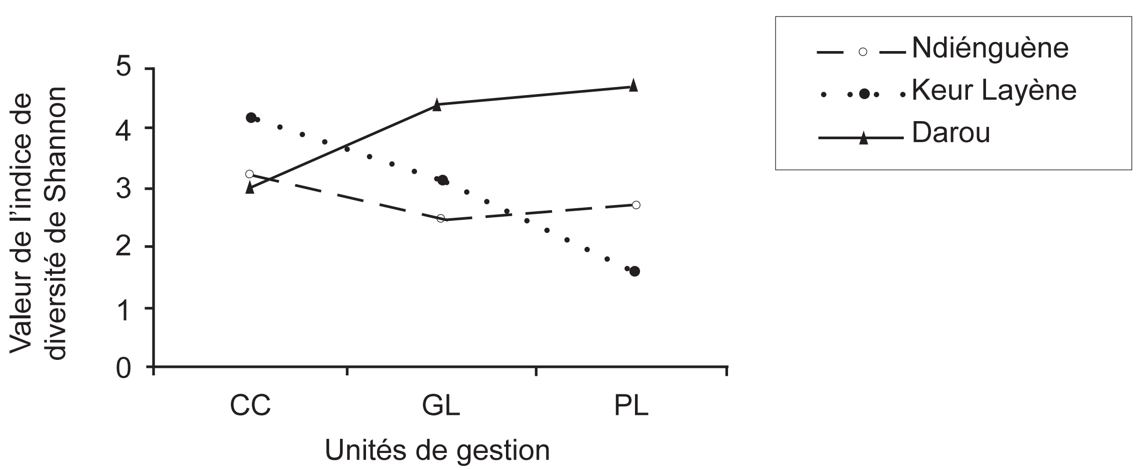

Figure 2. Evolution de l'indice de diversité de Shannon Weaver dans les différentes unités de gestion des terroirs au Sud du Bassin Arachidier. CC= champ de case; GL= glacis; PL= plateau.

est donc très significatif. La valeur relativement élevée de l'indice sur le plateau de Darou s'explique aussi par l'existence d'une zone de parcours non cultivée avec une densité ligneuse assez élevée et une forte dominance des combrétacées;

Le niveau d'implication des populations dans les activités de gestion de la biodiversité agroforestière n'est pas significativement différent en fonction des ethnies (wolofs, toucouleurs, sérères)

Enquêtes sur les modes d'utilisation des ressources agroforestières

Les ressources agroforestières existantes et leurs usages

Parmi les espèces ligneuses constituant les peuplements des parcs agroforestiers, les plus citées sont: C*ordyla pinnata, Piliostigma reticulata, Prosopis africana, Acacia nilotica, Acacia albida et Ziziphus mauritiana*.

Ces espèces fournissent différents produits: bois de chauffe, bois de service, fruits, feuille, fourrage, pharmacopée, etc. 86 à 92% des enquêtés soutiennent qu'ils tirent peu de revenus financiers de la vente des produits; cette vente concerne principalement le bois de service (perches).

Quelques espèces sont jugées importantes mais en voie de disparition: *Ficus iteophylla* (phamacopée), C*eltis integrifolia* (ombrage et pharmacopée), *Acacia albida* (fourrage et fertilisation des champs), *Detarium microcarpum* (fruit), *Pterocarpus erinaceus* (bois d'œuvre et fourrage et pharmacopée, *Adansonia digitata* (fruit, feuille), *Mytragyna inermis* (phamacopée).

Les périodes et modes d'exploitation des ressources agroforestières

Le bois est récolté en saison sèche avec constitution de stock pour l'hivernage; le fourrage est principalement cueilli en période de soudure (début hivernage); les fruits sont cueillis à maturité; les produits de pharmacopée sont récoltés toute l'année.

Les outils de récolte peuvent être: la machette, la perche, le râteau; certains fruits sont cueillis à la main.

Les récoltes sont effectuées principalement par les femmes et les enfants, et rarement par les hommes chefs de famille.

La perception de la population sur la dynamique des ressources agroforestières

Plus de 90% des enquêtés sont conscients de la dégradation continue de ces ressources et pensent qu'elles sont insuffisantes pour satisfaire leurs besoins. A Ndiénguène, près de 80% des personnes interrogées attribuent cette dégradation continue aux facteurs climatiques (sécheresse, érosion hydro-éolienne, etc.), contrairement à Keur Layène et Darou où 60 à 75% des enquêtés l'attribuent à la surexploitation.

L'enquête a aussi montré que les populations de ces zones ont pour la plupart perçu l'importance de la gestion des ressources naturelles grâce à l'encadrement des projets; L'eau n'étant pas une contrainte majeure dans la zone, la non disponibilité du matériel végétal est le facteur, le plus cité, qui empêche d'entreprendre des actions de plantation d'arbres.

La tenure foncière

L'héritage reste le principal mode d'accès à la terre selon 77% des personnes interrogées. Très peu y ont accès par don ou achat. 71% pensent qu'ils ne peuvent céder ou vendre leurs terres et ont l'obligation de les transmettre à leur descendance.

Les populations sont conscientes des dispositions de la loi sur le domaine national qui stipule que le conseil rural peut exproprier une personne de sa terre en cas de non mise en valeur. Cela limite les possibilités de mise en jachère de certaines parcelles dans les stratégies "d'ajustement" des facteurs de production suite aux contraintes économiques et édapho-climatiques.

Analyse des acquis de la recherche agroforestière

Haies vives

Leur objectif est de lutter contre la divagation du bétail, les incursions humaines dans les champs de cultures et les périmètres maraîchers. Elles permettent également le marquage des parcelles dont la délimitation est toujours source de conflits dans la zone, et l'approvisionnement des populations en produits ligneux (bois) et non ligneux (pharmacopée, fourrage, fruits…). Les fiches techniques (Roussel 1995) sont disponibles pour toutes les espèces concernant les techniques de récolte des semences, de production de plants et de plantation.

La liste des espèces présentant les meilleurs comportement et utilisables en haies vives par zone éco-géographique est présentée dans la tableau 1 suivant. Les paramètres d'évaluation de l'efficacité des espèces dans la technologies sont:

- Taux de survie
- Hauteur moyenne après coupe à 30 cm
- Nombre de rejets
- Hauteur du premier rameau

Tableau 1. liste des espèces utilisables en haies vives par zone agro-écologique

Espèces utilisables en haies vives	Zone Nord du Bassin Arachidier	Zone Sud du Bassin Arachidier
Ziziphus mauritiana		*X*
Acacia mellifera	X	X
Bauhinia rufescens	X	X
Acacia tortilis	X	
Acacia nilotica var adansonii	X	
Dichrostachys glomerata	X	
Acacia ataxacantha	X	X
Acacia laeta		X
Acacia senegal		X
Acacia macrostachya		X

Brise-vent

La liste des espèces utilisables en brise-vent par zone agro-écologique est présentée dans la Tableau 2 suivant.

L'objectif est de réduire l'érosion éolienne en protégeant le sol et les cultures. Les espèces utilisées fournissent également des produits ligneux et non ligneux (bois de feu et de service, fourrage ligneux, fruits, pharmacopée...).

Les paramètres suivis sont: taux de survie, hauteur, diamètre au collet, nombre de rameaux.

Tableau 2. liste des espèces utilisables en brise-vent par zone agro-écologique.

Espèces utilisables en Brise-vent	Zone Nord du Bassin Arachidier	Zone Sud du Bassin Arachidier
Eucalyptus camaldulensis	X	X
Anacardium occidentale	X	X
Azadirachta indica	X	X
Acacia holosericea	X	
Acacia tumida	X	
Melaleuca leucadendron	X	X
Acacia bivenosa	X	X

Réhabilitation des systèmes à parcs

L'objectif est évidemment l'amélioration de la fertilité des sols par enrichissement avec des espèces fixatrices d'azote et par régénération des peuplements existants.

Des travaux sont effectués sur la caractérisation, la dynamique et l'importance socio-économique des parcs agroforestiers de la zone aride et semi-aride du Sénégal (Sall, 1996). Exemples: Parc à *Faidherbia albida* au Centre, Parc *à Cordyla pinnata* au Sud, Parc *à Acacia tortilis* au Nord. Leur densification se heurte toutefois à des contraintes pratiques liées à la culture attelée. NDIAYE (1997) a étudié l'influence de C*ordyla pinnata* sur la fertilité d'un sol ferrugineux dans un système agroforestier traditionnel au Sud de la zone semi-aride.

Un des grands facteurs de dégradation des parcs est le manque de régénération. Cela est en partie dû au fait que les paysans n'épargnent pas les jeunes pousses lors des travaux champêtres. La régénération assistée pourrait beaucoup contribuer à rajeunir les parcs. L'introduction d'espèces fixatrices d'azote constitue une voie intéressante pour leur enrichissement. Mais les techniques mises en œuvre doivent être accessibles et basées sur le savoir-faire des populations. Le semis direct et la plantation de plants élevés en pots constituent aussi des voies de régénération et d'enrichissement des parcs. Dans le Nord du Bassin arachidier et sur sols « diors », le semis direct de graines prétraitées de *Faidherbia albida* a donné de meilleurs résultats que les plants en pots (76% de taux de survie après 6 mois pour le semis direct contre 66% pour les plants en pots). Cependant la réussite du semis direct est déterminée par la suppression de toute concurrence des adventices et la non survenue d'une période de sécheresse de plus de 10 jours.

Pour la multifonctionnalité des parcs du Bassin arachidier, la liste d'espèces à usages multiples à proposer est longue mais on peut citer :

- Pour la variante nord : *Ficus gnaphalocarpa*, *Lannea acida*, *Detarium microcarpum*, *Balanites aegyptiaca*, *Adansonia digitata*, *Ziziphus mauritiana*, *Azadirachta indica*, *Cassia siamea*, *Maerua crassifolia*,…
- Pour la variante centre-est : *Sclerocarya birrea*, *Tamarindus indica*, *Cordyla pinnata*, *Ziziphus mucronata*, *Ficus capensis*, *Parkia biglobosa*, *Piliostigma reticulatum*,…
- Pour la variante centre-ouest : *Lannea acida*, *Parinari Macrophylla*, *Detarium microcarpum*, *Adansonia digitata*, *Ziziphus mauritiana*, *Ficus gnaphalocarpa*, *Borassus aethiopium*, *Tamarindus indica*,…
- Pour la variante sud : *Parkia biglobosa*, *Ziziphus mauritiana*, *Ziziphus mucronata*, *Ziziphus spina-christi*, *Lannea acida*, *Sclerocarya birrea*, *Phoenix dactylifera*, *Moringa oleifera*,

Butyrospermum parkii, *Ficus capensis*, *Ficus iteophylla*, *Piliostigma thonningii*, *Piliostigma reticulatum*…

- Pour l'enrichissement des tannes (sols salés) : la recherche forestière a identifié quelques espèces susceptibles de bien se comporter dans ces milieux comme : *Melaleuca leucadendron*, *Melaleuca viridiflora*, *Prosopis juliflora*, *Melaleuca acaceoides*, *Acacia seyal*, *Casuarina equisetifolia*, *Acacia holosericea*, *Acacia tortilis*, *Eucalyptus microtheca*, etc.

Cultures en couloirs

Cette technique agroforestière a pour but fondamental d'améliorer la fertilité des sols spécialement avec l'utilisation d'espèces améliorantes. Elle peut également contribuer à réduire les effets de l'érosion et produire du bois de feu, du bois de service, du fourrage, etc. Il s'agit d'une technique peu commune sauf dans le sud mais qui peut s'avérer intéressante si les espèces plantées ne concurrencent pas trop les cultures surtout pour l'eau et la lumière. La méthode consiste à cultiver entre des lignes d'arbres dont la biomasse produite est restituée au sol sous forme d'engrais vert par retombées foliaires ou par un système de taille périodique. Les espèces à utiliser devront avoir :

- Un enracinement pivotant et une croissance du pivot rapide qui puisse permettre à l'espèce de s'alimenter à partir de la nappe et de ne plus dépendre des précipitations annuelles
- Un ombrage assez léger à nul en période hivernale pour la plupart des cultures
- Une production foliaire importante en quantité et en qualité (éléments nutritifs) et surtout facilement décomposable
- Une bonne réaction à la taille
- Des rôles et usages annexes (productions de bois de feu, pharmacopée, etc.)

Les études menées depuis 1990 en station dans le sud du Bassin arachidier montrent que les 4 espèces : *Leucaena leucocephala*, *Gliricidia sepium*, *Cajanus cajan*, *Cassia siamea* présentent une bonne capacité de production de biomasse et de bonnes réactions à la taille. Des différences non significatives sont observées dans les premières années sur le rendement de l'arachide (gousses et fanes) entre les parcelles en couloirs de ces espèces et les témoins non fertilisés. Par contre au fil des ans, on assiste à un maintien du niveau de rendement dans les couloirs et une baisse dans les témoins.

Banques fourragères

L'insuffisance des ressources fourragères est générale dans le Bassin arachidier bien que moins importante dans le sud où la taille des troupeaux est relativement petite. Les banques fourragères, par le surplus de fourrage ligneux qu'elles produisent, peuvent contribuer à atténuer le déficit fourrager en saison sèche et améliorer la ration alimentaire du bétail en hivernage. Elles produisent par ailleurs du bois de feu et de service, et même des fruits (*Ziziphus mauritiana*).
Sites d'implantation : zones de parcours, tannes (terres salées), jachères.

Cinq espèces testées en station depuis 1992 présentent de bons comportements. Il s'agit de : *Gliricidia sepium*, *Leucaena leucocephala*, *Bauhinia rufescens*, *Moringa oleifera*, *Caesalpinia ferrea*, *Hardwickia binnata*.

Dynamique des formations ligneuses des jachères dans le Sud Bassin Arachidier

Dans une optique de gestion durable des ressources ligneuses, la connaissance de la dynamique des formations ligneuses naturelles est une étape essentielle pour la proposition de modes de gestion qui préservent les ressources:

La mise en défens a été utilisée comme méthode pour mesurer la vitesse de cicatrisation d'un écosystème dégradé. Elle a consisté à mettre au repos, par des rotations périodiques, des surfaces dégradées afin d'y favoriser la régénération des couvertures végétales et du sol. Dans des parcelles dégradées situées dans les zones de parcours (plateau du bassin versant), la mise en défens se traduit au bout de 5 ans par :

- une augmentation de 50% de la richesse floristique,
- le retour d'espèces ayant disparu des zones pâturées comme *Bombax costatum*, *Pterocarpus erinaceus*, *Detarium microcarpum*, *Commiphora africana*, *Maerua angolensis*, *Baissea multiflora*, *Strophantus sarmentosus*, C*issus vogelii* (Diatta, 1994),
- une augmentation de la densité des ligneux (multipliée par un facteur 2,4)
- une augmentation de la surface terrière (multipliée par un facteur 6)

Conclusion

Face à la péjoration climatique, à l'explosion démographique et la saturation foncière qui caractérisent les agro-systèmes des zones arides et semi-arides du Sénégal, l'agroforesterie constitue une alternative entre la déforestation et la conservation des formations ligneuses au sens strict du terme. Ce système d'utilisation des terres peut être, s'il est raisonnablement mené, à la fois viable économiquement et durable écologiquement. La capacité des agro-systèmes à évoluer en adoptant de nouvelles stratégies de valorisation de la biodiversité sera décisive pour la survie de ces systèmes.

Selon Griffon et Mallet (1999), la gestion durable des systèmes agroforestiers recouvre deux grands aspects:

- La reproduction des fonctionnalités de l'écosystème, c'est à dire la maintenance de l'ensemble des relations entre éléments du système assurant la continuation durable de son fonctionnement, ce qui revient à entretenir le renouvellement des ressources naturelles qui entrent dans les cycles vitaux des écosystèmes (cycle de l'eau, du carbone, des principaux nutriments…) tout en pilotant cette gestion dans le sens d'une production maximale
- La limitation des risques d'atteinte à l'environnement, c'est à dire la réduction des éventuels effets externes négatifs, résultant de l'activité productive, donc de la gestion des cycles de renouvellement des ressources (pollutions chimiques) ou de ses conditions d'exercice économique et institutionnel (épuisement des ressources d'accès libres).

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Scaling up of agroforestry technologies for smallholder development in the marginal areas of Tabora and Shinyanga in Tanzania

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Abstract

In order to improve household nutrition, income, and reduce environmental degradation in miombo areas, there is a need to provide rural farmers with opportunities through training, provision of appropriate planting materials, information on markets and integrated farming methods. Tanzanian farmers are increasingly unable to produce sufficient food and cash income to satisfy basic family and community needs. The smallholder farmers meet their needs by clearing virgin miombo woodlands and cultivate crops. The crop yields are high in the freshly cleared fields, however, continuous cropping over years leads to decline in soil fertility resulting in low crop yields. The farmers then continue to clear new areas to sustain their livelihoods, which results in the deforestation of the miombo woodlands. Tanzania Agroforestry Project was initiated in Tabora in 1986 and Shinyanga in 1991. The purpose of the project is to integrate agroforestry technologies into smallholder farms in order to improve living standards of small-scale resource-poor farmers by increasing agricultural production and conserving the environment through scaling up adoption of agroforestry technologies and innovations. The project uses participatory approaches and works directly with farmers and policy makers; in addition the project pursues strategies which "scale out" agroforestry adoption by training, supporting and networking with partner organizations. The project has developed viable agroforestry technologies that include rotational woodlot technology using indigenous and exotic tree species, especially Australian acacias, which have been widely accepted in Tanzania. The second most widespread innovation has been improved fallows with nitrogen-fixing leguminous trees such as Sesbania sesban and Gliricidia sepium intercropped with maize to improve soil fertility and maize yields. Fodder bank technology based on supplementary feeding has been well accepted and is well suited to small-scale dairy farmers who have improved breeds of dairy cattle. The domestication and commercialization of indigenous fruits and medicinal trees is an emerging industry for Tanzania, having the highest diversity of indigenous fruits. These fruits are edible and rich in sugars and vitamins. Farmers are now processing indigenous fruits into products like jams, juices and wines. The World Agroforestry Centre (ICRAF) is promoting the domestication of indigenous fruits along with the popular exotics like improved mangoes, guavas, passion fruits and oranges and has embarked on post harvest and processing by training women and other local entrepreneurs in product development and marketing. This will contribute to food security, poverty alleviation and conserving biodiversity. This component has direct relevance to nutrition and HIV/AIDS as well as empowerment of women and development of entrepreneurship at community level. Germplasm availability to farmers is a critical factor in scaling up of the above agroforestry innovations. ICRAF is identifying farmers' seed-production methods and is establishing seed orchards of different species in Tanzania. It is anticipated that these agroforestry practices will be adopted by at least 100,000 farmers across Tanzania by the end of this project period in 2006 and that by improving productivity on the farms best suited for agriculture it will help protect miombo's forests, grasslands, wildlife habitats and watersheds. This paper describes the different participatory

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approaches, mechanisms and achievements with partners in scaling up/out these agroforestry practices in the marginal areas of Tabora and Shinyanga regions in Tanzania.

Introduction

Tanzania faces several development challenges that include increasing levels of poverty, food insecurity, deteriorating human health, malaria, HIV/AIDS and degradation of the natural resource base. The population of Tanzania currently stands at 34,569,232 with annual growth rate of 2.9% (Census 2002). The livelihoods of over 80% of the population in Tanzania rely on agriculture. Among the constraints in farming system, prolonged drought period, degradation of natural resource base as a result of increasing human population and unsustainable farming practices have resulted in the increase in soil erosion, decline in soil fertility, shortages of fuelwood, fodder and food. There is an urgent need to address these problems. Agroforestry (AF) options have the potential to contribute to food security, generate income and arrest the degradation of the environment.

Farming system in Shinyanga and Tabora

The natural vegetation in Shinyanga and Tabora is mainly miombo woodland. Trees belonging to the legume family, Caesalpiniaceae, dominate these woodlands. The dominant tree species belong to *Brachystegia*, *Julbernardia* and/or *Isoberlinia* genera. The shrub and grass layer is variable in density and composition. Fires are a characteristic feature of the miombo.

Shinyanga region is located in northwestern Tanzania, 3 °S 10 °E, covers 50,764 sq km with a population of 2.8 million. The altitude ranges from 1200-1500 m above sea level, receiving an average rainfall of 700 mm per year (November-April). The soil types are shallow red clay (*eutric cambisol*) and shallow black cotton soils (*vertisol)*. Most of Shinyanga region was cleared of natural woodlands in the past in an effort to eradicate tsetse fly and to expand livestock production. Main crops grown are maize, rice, sorghum, millets, cotton and tobacco.

Tabora region is located in western Tanzania, 30 °S 33 °E, covers 76,500 sq km, with a population of 1.7 million. The altitude ranges from 1100 – 1300 m above sea level and average rainfall is between 700-1000 mm (November – April). Soils are mostly sandy soils (*ferric acrisol*). Main crops grown are maize and tobacco. Both Shinyanga and Tabora region experience prolonged drought period of 7 months from May to November.

In general, both cropping as well as livestock keeping is practiced extensively; measures to replenish soil fertility and to conserve the land are rarely taken into consideration in traditional farming systems. Crop production takes place in the same field for a number of years until the fertility of the soil is exhausted. It is then followed by several years of natural fallowing. Due to population increase the length of fallowing periods are gradually decreasing, with permanent cropping becoming commonplace. Since little external inputs such as fertilizers or livestock manure is used, this trend is often accompanied by a decline in soil fertility and degradation of the land. Eventually this renders fields useless for further crop production leading to large areas of degraded wastelands of limited value for livestock grazing. Livestock production is very important in Sukuma farming systems. Shinyanga region ranks second, nationally, in terms of numbers of cattle, goats and sheep. Management of livestock is extensive and free range grazing is widely practiced. In response to increasing shortages of natural pastures, which become particularly severe during the yearly dry season, the Sukuma have developed a traditional system of conserving pastureland, known as Ngitiri. Ngitiri involves demarcating grazing areas, which are then seasonally closed to act as pasture reserves. A number of useful fodder trees and shrubs such as indigenous acacias are protected for use as fodder for livestock during the dry season.

Tabora is one of the most important flue-cured tobacco growing regions in Tanzania, providing an important source of income to thousands of smallholder farmers. Tobacco ranks fifth in terms of export volume and foreign exchange earnings for Tanzania.

Today, the major constraints to farming in Shinyanga and Tabora region can be summarized as declining soil fertility, shortage of wood for fuel and construction, and limited supply of livestock fodder especially during dry seasons. All these constraints can be directly related to population increase and an overuse of limited natural resources.

Deforestation in Shinyanga and Tabora

Deforestation of natural woodlands is a major environmental problem in Shinyanga and Tabora today. The key problems and driving forces of deforestation in Shinyanga and Tabora are, (a) expansion of agricultural land, (b) increasing urban consumption of charcoal and fuel wood and (c) increasing demand for fuel wood for tobacco curing and other processing industries such as brick making, fish curing and beer brewing. Trees are the major supply of energy in rural as well as urban communities in Tanzania.

Every year Tanzania looses between 130,000 and 500,000 hectares of natural woodlands, while in Tabora region over 24,000 hectares of forests are exploited each year mainly for fuelwood, which is used for curing tobacco, making charcoal and for domestic purposes (MNRT 1998).

Shinyanga region today is one of the most deforested regions in Tanzania due to the systematic clearing of woodlands in the past. This was done as part of a national program to eradicate tsetse fly infestation during the first half of the 20th century. Today, this large-scale deforestation is still felt by farming families every day. Forest and tree products that are part of daily livelihoods have become scarce, such as construction wood, fuel wood, fruit and traditional medicines. Furthermore, intangible services provided by trees such as the restoration of soil fertility and the provision of shelter from wind and sun have been compromised with, thereby causing serious problems for people who try to sustain a living from agriculture. Many farmers believe that the negative effects of this wholesale deforestation outweigh by far the claimed benefits of having controlled tsetse flies and weaver birds (*Quelea sp.*), the latter also being considered a threat to agricultural expansion in the past.

Materials and Methods

Agroforestry research and development in Shinyanga and Tabora regions

The World Agroforestry Centre (ICRAF) started Tanzania Agroforestry Research Project in Tabora in 1986 and Shinyanga in 1991. This was in response to the massive environmental degradation due to deforestation efforts that were geared to the eradication of tsetse flies and weaver birds in Shinyanga region and for tobacco curing in Tabora region. The project is part of the SADC's (Southern Africa Development Community) *'Agroforestry Project for Sustainable Rural Development in the Zambezi Basin'*, funded by Canadian International Development Agency (CIDA) and covers 5 countries, Malawi, Tanzania, Zambia, Zimbabwe and Mozambique. Phase II of the project commenced on 1 April 2001 and will end on 31 March 2006. The goal of project is to improve living standards of small-scale resource-poor farmers by increasing agricultural production and conserving the environment through scaling up adoption of agroforestry technologies and innovations in the Zambezi Basin.

The World Agroforestry Centre is implementing the project in Shinyanga and Tabora regions in collaboration with Ministry of Natural Resources and Tourism through Tanzania Forestry Research Institute, Tabora Centre and Ministry of Agriculture and Food Security through the Agricultural Research and Development Institute, Tumbi. Other partners include World Vision-Tanzania, Sokoine University of Agriculture (SUA), Tanzania Women Leaders in Agriculture and Environment (TAWLAE), Association of Tobacco Traders in Tanzania (ATTT) and district councils of focal scaling up areas of Uyui, Tabora municipality, Nzega and Igunga districts in Tabora Region and Shinyanga rural in Shinyanga Region.

Promising AF technologies have been developed with farmers and national institutions that provide significant benefits to smallholder farmers. These technologies need to be scaled up to many farmers in order to yield impact at a national level.

For agroforestry to have impact on rural poverty, food security and environmental conditions, it has to be spread widely across the landscape and to have a critical mass of capacity at grass root levels, availability of germplasm, several products, diversity of species, provenances, practices, technologies and options that can be adapted to a multitude of situations. To have an impact on rural poverty and environmental degradation there is need to build human capital and social capital in rural development.

We need to ask ourselves how much of these technologies have actually reached the farming world through technology transfer, which has been the mode of extension service in the country. The results of green revolution were realized in targeted homogenous cropping systems such as rice and maize in south Asia but failed to have an impact in smallholder farming systems in Africa. In southern Africa and Tanzania, biophysical conditions are more marginal and variable socio-cultural settings that require the need to develop diversity and often complex farm innovations such as AF that meet farmers multitude needs. There is need to understand the complex interdependencies of biophysical, economical, social and cultural factors that operate in communities so that AF innovations, development and extension can be brought at a wider scale. The farmers have to drive the process, in this case the technical options and learning tools that bring change. Thus in scaling up agroforestry we need to look at the wider context of agricultural transformation towards ecologically sound, sustainable and profitable practices. This transformation takes the following dimensions (1) ecologically sound practices (2) learning (3) facilitation (4) support to institutions and networks and (5) enabling policy environment (Rolling and Jiggins 1998). All these five dimensions have to be put together, thus making AF scaling up a complex process. Since AF can address several problems it makes it attractive to many groups, like those interested in afforestation, those that want to improve food security and rural livelihoods. This wide demand offers opportunities for creating collaborative advantages and for scaling-out AF through partnerships and networking.

Participatory approaches, mechanisms, and achievements in scaling up

Purpose of scaling up

The goal of scaling up is to reach farming families in Tanzania with AF technologies in order to improve food security, eradicate rural poverty and enhance environmental resilience in the region. The purpose of "scale up" is to increase the adoption of diversified and improved AF solutions to reach a much wider group of resource-poor farmers with a particular emphasis on women farmers (60%). The project works directly with farmers and policy makers, in addition the project pursues strategies which "scale out" AF adoption by training, supporting and networking with partner organizations that undertake complementary work on their own through,

- Creating sustainable networks for dissemination of AF innovations and linking with others working on HIV/AIDS, gender issues, water, and education throughout the region.
- Improving the policy framework for adoption of AF.
- Improving farmer experimentation and participation in AF development, with a special focus on involving women.
- Creating sustainable seed delivery systems for AF.
- Improving the marketing of AF products and services so that greater socio-economic benefits can be derived.

It is anticipated that this will lead to the adoption of AF practices by at least 100,000 farmers across Tanzania by the end of this project period in 2006.

In scaling up, we are involved in the direct facilitation of local innovation processes by engaging farmers, development agents and researchers in participatory development cycles that are characterized by stages of community mobilization, planning for action, experimentation and analysis of outcomes. Support functions in scaling up include creating collaborative advantage, promoting better policy options and understanding the wider impact of scaling-up. Creating collaborative advantage through scaling up is fundamental for the successful widening of the use of AF, as one development agent can only directly facilitate innovation development in limited number of locations. Another challenge for facilitation is in creating multiple local innovation centers and linking them up, in order to allow the emergence of effective grassroots level networks, driven by farmer-to-farmer extension.

The agroforestry (AF) options being promoted are those that,

- Contribute to food security.
- Improve nutrition.
- Alleviate poverty.
- Sustain the environment.

Strategies for scaling up

- Identification of constraints in scaling up AF.
- Establishment of strategic linkages (public, private sector and civil society partnerships).
- Capacity building.
- Resource mobilization.

What technologies are we scaling up?

a. Rotational woodlot technology

Rotational woodlot technology involves three stages; tree establishment phase, where trees are planted with crops for about 2-3 years, the trees benefit from the tending being given to crops; a tree fallow phase, here trees are left to grow without crops; and post fallow phase where trees are harvested and crops re-established, starting the whole cycle again. Tree species that produce between 40 and 90 t ha^{-1} wood in 5 years have been identified. These include Australian acacias, *Acacia crassicarpa*, *A. leptocarpa* and *A. julifera* and local species such as *A. polyacantha and Albizia lebbeck*.

Introduction of rotational woodlots in Tabora and Shinyanga has been beneficial to farmers and has a great potential in rehabilitation of the degraded land in the country. For example, in Isikiziya village that has 360 households and a population of 3828 (1217 children), so far 130 households have adopted this technology. These farmers have increased their income by selling seed and seedlings and reduced costs for buying fuel wood for curing tobacco as they now produce wood on their own farms. The landscape is changing due to tree planting. This area was a bare land previously as trees were cleared for controlling tsetse flies and quelea birds. So far, nearly 5000 farmers have adopted this technology in Tabora and Shinyanga region. Since farmers are looking for alternative wood sources, we anticipate that another 50,000 farmers will adopt and use this technology by 2006.

b. Improved fallow technology

Improved fallow technology aims primarily at improving the fallow period (duration about 1–3 years) of a traditional shifting cultivation system. During the fallow period, fast growing, high soil-enriching trees, shrubs and herbaceous species are planted in the field to replenish nutrients removed by the arable crop. Trees improve soil fertility through provision of nutrients (major nutrients are nitrogen, phosphorous and potassium) and addition of organic matter, which in turn improves soil structure, water infiltration and percolation, and nutrient retention capacity. Nitrogen fixing tree species such as *Sesbania sesban*, *Tephrosia vogelii*, *Tephrosia candida*, *Leucaena spp* and *Gliricidia sepium* are used in improved fallows and mixed intercropping systems resulting in increased crop production (Kwesiga et al.1999).

Most of the farming land in Tabora has sandy soils with low fertility. Maize yields are generally low with an average of 300-500 kg ha^{-1} compared to a potential of 2000 kg ha^{-1}, a factor attributed to the low soil fertility. Majority of the farmers cannot afford the expensive mineral fertilizers as inputs for maize. Research conducted at Tumbi Research Institute and at ICRAF in Tabora and Shinyanga has shown that improved fallows of *Sesbania sesban* could increase maize yield from 300-500 kg ha^{-1} to 1500-1800 kg ha^{-1} (Otsyina et al. 1997).

About 500 farmers in Tabora region have tested and realized the benefits of this technology. In Mpenge village, which has 120 households with a population of 850, so far, 11 households have adopted this technology. This is a proven technology that can greatly benefit more farmers in the region. We have not been able to reach more farmers due to the inadequate resources available for scaling up this technology. With adequate resources for dissemination another 50,000 farmers could adopt this technology in the region and increase maize production by 30% by the year 2006 and at the same time conserve the environment.

c. Fodder bank technology

Livestock are an important component of the agro-pastoral production systems of Shinyanga and Tabora. Over 80% of households own and manage livestock that provide milk, meat, hides and skins, draught power, manure and are a source of security and living bank.

In Tanzania many dairy development projects have mushroomed as dairy is seen as a strategic pathway to alleviate poverty and overcome malnutrition and improve soil fertility.

Constraints to livestock production include low supply of feed and scarcity of water especially in the dry seasons, poor fodder quality, animal parasites and diseases and low genetic potential for milk production of the Zebu cattle. Supplementary feeds such as seed cakes are expensive and cost Tshillings 500 per kilogram (US$0.5) and not readily available at village level. Supplementing dairy animals with leaf meals from these trees has been found to raise milk production by 30% in Shinyanga.

A fodder bank technology involves a plot consisting of high quality tree/herbaceous fodder species established to provide cheap supplementary nutritional feed to dairy animals in place of costly protein concentrates. Apart from providing quality livestock feed, the species involved also have high potential for improving soil fertility. Suitable fodder tree species are planted in a woodlot and managed for maximum foliage production.

Research in Tabora and Shinyanga has identified different tree species that are useful as supplementary feed for zero grazed livestock. These species include *Acacia angustissima*, *Leucaena pallida*, and *Gliricidia sepium* and herbaceous legumes such as *Centrosema pubescens*, *Macrotyloma axillare* and *Macroptilium atropurpureum*

The potential for adoption is great around peri-urban areas and already hundreds of farmers are benefiting from this innovation around Tabora and Shinyanga in Tanzania.

Domestication of Indigenous fruit trees and medicinal trees

The miombo woodlands of Tanzania are endowed with a rich diversity of indigenous fruit and medicinal trees which have, for many years, played an important role in the well being of rural communities as source of food, fuel wood, timber, poles, fodder, medicine, income and providing food security during seasonal food shortages and in times of famine (Karachi et al. 1991; Temu and Chihongo 1998). These under-exploited fruits are rich in essential vitamins, minerals, sugar, proteins, oils and fibre (Ndabikunze et al. 2000) and contribute significantly to the nutritional well being of the rural communities. About 80% of rural people in Tanzania depend on traditional medicine mostly derived from indigenous tree species, for their primary health care needs (Mahunnah 1990).

The domestication process is to bring the wild fruit and medicinal trees to the farm in order to enhance food security, improve income, health and nutritional status of the poor rural and urban communities while safeguarding the biodiversity and protecting the environment. Range wide collections of germplasm of fruit trees *Sclerocarya birrea* and *Strychnos cocculoides* have been established in order to identify superior genotypes for establishment of seed orchards and clonal banks. Nine priority medicinal tree species that include *Combretum zeyheri*, *Turrea fischeri*, *Securidaca longipendulata*, *Cassia abbreviate*, *Zanthoxylum chalybeum*, *Albizia antelmintica*, *Entanrrophragma bussei*, *Entada abyssinica* and *Terminalia sericea* are being evaluated on farmers fields.

Processing of indigenous and exotic fruits

Miombo woodlands dominate the western part of Tanzania and have more than 50 indigenous species that bear edible fruits. Indigenous fruits have for a long time made a significant dietary and nutritional contribution to the rural families as source of vitamins, minerals, calories, protein and oil. Indigenous fruits are widely available in Tabora region. Out of 22-39% of indigenous fruits harvested from the forests only 10% of the fruits are consumed. Most of these fruits are eaten raw. Income generated from these fruits is very low because of poor markets and processing technologies leading to huge fruit wastage.

ICRAF and Tumbi Agriculture Research Institute over the last 3 years have trained about 2,000 farmers from 30 farmer groups in Tabora region. Using standard recipes for processing indigenous fruits, different products such as jams, juices and wine have been produced both on-station and on-farm. Edible fruits from *Parinari curatellifolia*, *Strychnos cocculoides*,*Vitex mombassae*, *Flacourtia indica*, *Sclerocarya birrea* and *Syzigium guinensis* are being used to produce products that are good, acceptable and that can be commercialized. Apart from increasing consumption, processing will cut down wastage and add value to indigenous fruits. With assured market out-let, farmers will be motivated to conserve forests and manage the indigenous wild trees thereby enhancing biodiversity and reducing environmental degradation.

Sustainable germplasm supply

One of the major constraints to scaling up is the availability of quality germplasm for planting (Simons 1996; Kwesiga et al. 1999). ICRAF and partners are establishing seed production units for most tree species on farmers fields to solve this problem. Farmers are interested in planting high value trees on their farms, however a large number lack the necessary skills on how to grow trees. In order to overcome this limitation, our strategy is to build grassroots capacity by training farmers and farmer groups on seed collection, seed handling and nursery establishment, and management. In addition we are also establishing seed orchards/production areas and also involving the private sector in seed production and marketing. We plan to explore new indigenous leguminous plants, fruit and medicinal trees that can be used in agroforestry technologies. The services of national tree seed centers are being sourced to provide farmers with high quality timber tree seed.

Where are we scaling up?

The scaling up areas are the districts of Igunga, Nzega, Uyui, Tabora municipality in Tabora region and Shinyanga rural in Shinyanga region (Table 1).These districts have 252,004 households with a population of 1,491,242. These areas were selected due to the prevailing problems of low soil fertility, fuelwood scarcity, food insecurity, prolonged drought, deforestation, and land degradation. Secondly, the presence of willing collaborating partners, previous agroforestry work and the potential for agroforestry interventions resulting into positive impacts.

Table 1. Some characteristics of the scaling up sites, in Tabora and Shinyanga regions.

	Igunga	Nzega	Tabora municipality	Uyui	Shinyanga rural
Area (sq km)	4490	9225	1092	14,340	8906
Rainfall (mm)	600-800	700-1000	700-1000	700-1000	450-900
Soil types	Sandy (*ferric acrisol*)	Sandy (*ferric acrisol*)	Sandy (*ferric acrisol*)	Sandy (*ferric acrisol*)	Shallow red clay (*eutric cambisol* Shallow black cotton soils (*vertisols*)
Main crops	Maize, Sorghum Millet	Maize	Maize	Maize Tobacco	Maize, rice, groundnuts, sorghum, cotton, millet
Households	51,176	73,579	38,566	43,166	45,517
Population	325,547	417,097	188,808	282,272	277,518

What is our guideline to scaling up?

- The national agroforestry strategy for Tanzania and scaling up strategy for Tabora region are guiding our scaling up operations.
- Agroforestry Project for Sustainable Rural Development in the Zambezi Basin, Project Implementation Plan (PIP) for Phase II.
- The agroforestry interventions in these areas include training, participatory planning, exchange visits, establishment of demonstrations, provision of inputs (eg seeds), product development and linking farmers to markets.
- We are targeting farming households, local leaders, teachers in primary and secondary schools, religious leaders, agricultural extension officers, ministry of natural resources, ministry of education personnel, policy makers, and our partners.

What is our scaling up strategy?

- Expand the area of operation through collaborative interventions with partners.
- Develop Memorandum of Understanding between ICRAF and partners with clearly defined roles and dimensions of partnerships.
- Create awareness on importance of AF at all levels, including policy makers.
- Building capacity of extension and field technicians in government and non-governmental organizations on AF skills.
- Build capacity of farmers on AF technologies and management.
- Establish demonstration plots, farmer field schools and interactive learning centers.
- To enhance networking with organizations and farmers working on AF.
- Establish a clear participatory monitoring and evaluation system of dissemination activities with all partners.
- Diversify farmers options through the integration of other farming activities and enterprises such as bee-keeping, aquaculture, mushrooms, oil crops, soybean, passion fruits and indigenous vegetables, indigenous and exotic fruits as sources of vitamins.

- Introduce energy saving cooking stoves to the villagers.
- Determine the factors influencing the dissemination of AF technologies.
- Assess the impact of AF technologies on farmers.
- Promote conservation of woodlands.
- Develop local capacity of seed and germplasm supply (tree nurseries and seed orchards).
- Lobby for the enforcement of relevant laws and by-laws.
- Resource mobilization at all levels.

Scaling up through farmer groups

The use of farmers and rural people as principal agents of change is to increase the effectiveness of meeting farmer's needs and improve sustainability of the services. This allows farmers to play a more active role in decision-making and planning, build local capacity to manage and control services, allow area-specific service delivery and facilitates equity in delivery by targeting poor farmers.

- Working with farmer groups will ensure that farmer interests are taken care of and assist in mobilizing resources and participation in technology development and testing.
- Working with groups will ensure greater farmer-to-farmer dissemination and exchange of information.
- Dissemination through farmer groups instead of individual farmers economizes on the scarce training skills and resources.
- Working through partner organizations, instead of directly with farmers, will enable us to build on local organizational skills and knowledge and reach far more farmers than would have been possible.
- The establishment of strong partnership between researchers, extension officers, and farmers will facilitate the flow of information.

Scaling up through partnerships

AF technologies are knowledge intensive; they require a holistic approach in their transfer. The farmers normally have a wide array of demands that cannot be solved by AF alone. In order to solve some of the farmers needs, there is need to build partnerships among a range of stakeholders and ensure that farmer's interests are taken care of. Mechanisms that enable researchers, government extension officers, NGO partners, and private enterprises are needed to disseminate these technologies. The use of partnership in scaling up enables the sharing of skills, knowledge, experiences and resources, thus reaching a wider number of people. The current partnership comprises of various government agencies, research centers, educational institutions, international and local NGOs, CBOs, farmer groups, and private sector. The new challenging areas of HIV/AIDS, gender, market and enterprise development, calls on us to seek out for those agencies that have the expertise in these areas. Currently there are a few NGO and development agencies operating in Shinyanga and Tabora region. Some of our partners regard ICRAF as a donor, while others just want to use ICRAF to enhance their funding. There is need to be careful while selecting the partners to work with. We are now seeking for partners in the private sector and outside Tabora region.

The advantages of working through partnerships and networking are,

- Organizations rarely achieve their development goals on their own; partnerships facilitate the achievement of the goals when efforts and resources are pooled together.
- It enhances organization learning as it enables sharing of information, skills, experiences, lessons and opportunities.
- Local and national capacities are built, which increases the sustainability of program and projects.
- The overall efficiency of scaling up the use of AF technologies and innovations is increased.

For successful partnership there is need to have,

- Clarity of objectives and roles in the partnership.
- Sufficient resources and capacity.
- Equal and timely access to reliable information.
- Transparency of processes.
- Respect for each other and equity among the major groups.
- Availability of effective structures and mechanisms for consultation and participation at all levels of decision-making.

Communication as a tool in scaling up

Traditionally, transfer of information to farmers has been the responsibility of government extension services that have focused on crops and livestock services. This has been a linear extension used to transfer information of agricultural research and their delivery to farmers by extension agents. Farmers are normally regarded as users of research findings. This approach is useful in some aspects but cannot serve all extension practices. In addition, this approach does not meet the need of marginalized farmers due to the diversity of their activities and financial constraints in service delivery, declining extension budgets and poor communication between research institutions, extension services, and farmers. With AF technologies, small-scale farmers need information on technology development, management, how to add value to farm products and marketing and in inputs such as credit. Thus, there is need for new scaling-up methods that takes into account farmers as innovators and researchers.

Resource-poor farmers in Tabora and Shinyanga fail to benefit from new technologies due to various reasons. One of the constraints is the inadequate access to and exchange of information among farmers. In addition, poor uptake of innovations is also a major problem hindering dissemination of research results among farmers. Most of the farmers practice destructive farming systems such as shifting cultivation and are yet to be introduced to modern farming methods. There is need for effective communication mechanisms for researchers to link farmers and extension agents to identify research problems, to adapt recommendations to local conditions and to provide feedback about the technologies.

Farmer learning is facilitated by communication with other farmers as well as effective linkages with research and extension agents. We are exploring different aspects of farmer-to-farmer dissemination that will enable us to develop innovative communication routes that build on existing indigenous channels for information to be relayed to other farmers. Building effective links between farmers and research extension, using partners' networks, will allow farmers to increase their output through farming innovations. We hope that by understanding how farmers communicate with others, it will be possible to use these channels and networks to spread AF technologies (scaling-up/out) especially when collaborating with government agencies, NGOs and private sector.

Planning with partners in scaling up

We plan with partners and stakeholders at all levels. These include policy makers, farmers, and extension agents. At these meetings major problems, potential solutions, species and technologies preferred are presented. In addition, we conduct sensitization meetings on agroforestry activities at grassroots levels (villages). Men and women attend these meetings.

Production of training and extension materials

The lack and availability of relevant extension and training material is among the factors limiting technology transfer. Access to and exchange of information among farmers is another limiting factor. AF technologies are complex and most of the species being introduced are new to the farmers. The available extension and training materials are in English, a language that is not understood by majority of the target farmers. Thus, there is need to avail relevant extension and training materials in languages that are easily understood by the farmers, in order to facilitate scaling up. In addition we need to reach a wider audience in our scaling up. There is diverse literacy levels among our target groups, thus the need to produce written materials and media creating awareness among stakeholders that include literature for farmers, grassroots level change agents and general public. We use oral communication and performing arts in reaching out to the target groups to produce awareness, extension and training materials that are more appropriate to our target groups of farmers, especially women. These include pictorial extension materials (cartoon booklets), picture codes, etc. The following materials have been produced and tested; a training guide in Swahili for Training of Trainers (TOT) *"Mwongozo wa mafunzo kwa viongozi wa vikundi vya wakulima"*, Rotational woodlot manual and booklets on key AF species such as *Gliricidia sepium*, *Acacia crassicarpa*, *Moringa oleifera*, *Leucaena pallida* and *Sesbania sesban*, in Swahili. The target audiences for these extension materials include our partners ie trainers, school teachers, extension agents and farmers who have no knowledge on the species we are working with. These materials provide information on the species, their establishment and management and are used in grassroots level extension and capacity building thus improving the scaling-up of AF technologies.

Capacity building

There are inadequate numbers of extension officers to go around the farming communities. There are currently 196 agriculture extension officers who are supposed to cover 252,004 households with a population of 1,491,242 people in Uyui, Tabora municipality, Igunga, Nzega and Shinyanga rural districts. Some of these extension officers were last trained in the early 1990s, thus practice the old doctrine of extension. They are not equipped with skills in modern agricultural practices. Their knowledge on AF is very limited. Currently there are no refresher courses being conducted for these extension officers. They generally lack access to modern information, have no transport and training materials. They urgently need refresher courses for them to deliver effectively.

Thus there is need to come up with an innovative, demand-driven and systematically sustainable training system for scaling up AF technologies in Tabora and Shinyanga. Our strategy is to conduct training at all levels. The training of trainers focuses on AF technologies and other development issues such as HIV/AIDS, gender and marketing. The training is designed to fit into current existing systems in the districts where we are working. This includes training of partners ie government officers, teachers, NGOs, CBOs, farmers and local leaders. Our current training strategy is based on the following needs: assessment of who is to be trained? what sort of training is needed? what is the duration of training? The training is then designed to suit the client's needs. These training sessions are now being carried out within the villages, where farmers, both male and female, have easy access.

We have undertaken the following capacity building activities:

- Direct training of farmer trainers and local change teams (teachers and village leaders) through training village extension facilitators, community development facilitators, teachers and local leader trainers.
- Training of trainers among partner staff, (agriculture extension staff and partners' staff), for example, we have trained agriculture extension officers from participating districts and World Vision.
- Facilitating direct farmer-to-farmer exchange program, farmer-to-farmer training and exchange visits between farming communities. To this end, farmer tours of on station and on farm exchange visits have been conducted in farmer's fields, target for field days have been grassroots level change agents, that is farmers, traditional and community leaders, extension staff and development workers.
- Supporting national extension initiatives on sustainable farming. For example, we have supported extension officers in their work by providing inputs, training individual scientists at Bachelors, Masters and Doctorate levels at local and foreign universities.

Establishment of Demonstration Plots

We established demonstration plots in schools and farmers fields in Igunga, Nzega and Uyui districts. These are currently being used as centers for learning.

Germplasm supply

- We have established seed orchards on station, on farm and in schools.
- *Procured seed from National Tree Seed Center for the following species* Afzelia quanzensis, Albizia lebbeck, Acacia Senegal, Senna siamea, Acacia polyacantha, Grevillea robusta, Eucalyptus camaldulensis, Balanites aegyptica, Pterocarpus angolensis.
- Procured seed from farmers for the following species *Terminalia sericea*, *Albizia lebbeck*, *Acacia angustissima*, *Acacia crassicarpa*, *Vitex mombasae*, *Vitex doniana*, *Adansonia digitata*, *Flacourtia indica*, *Scelerocarya birrea*, *Securidaca longipedunculata*.
- Procured seed from external sources; *Tephrosia candida* and *T.vogelli* seed were obtained from Chipata, Zambia and *T.candida* from Maseno, Kenya. Australian acacias from Commonwealth Scientific Industrial Research Organisation (CSIRO). These species are being tried in schools and farmers field.

- Seed distribution for high value timber trees, fuelwood species, improved fallow, fodder and fruit trees to schools and farmers and farmers groups in all districts. Species include *Afzelia quanzensis*, *Albizzia lebbeck*, *Acacia senegal*, *Senna siamea*, *Acacia polyacantha*, *Grevillea robusta*, *Balanites aegyptiaca*, *Pterocarpus angolense*, *Terminalia sericea*, *Acacia crassicarpa*, *Acacia angustissima*, *Leucaena pallida*, *Gliricidia sepium*, *Sesbania sesban*, *Vitex doniana*, *Vitex mombasae*, *Sclerocarya birrea*, *Flaucortia indica*, *Adansonia digitata*, *Parinari curatelifolia*.
- Established tree nurseries for individual farmers, farmer groups, schools and district councils. Problems encountered in these nurseries include lack of polythene tubes, lack of watering cans, damage of seedlings by chicken, rats, cutworms, caterpillars, grasshoppers and termites, fungal diseases, theft of seedlings, lack of water, saline water at some sources (Igunga), labor shortage during watering, poor germination of tree seed, lack of markets for tree seedlings and generally lack of technical know-how.

Resource mobilization

We need additional funds to support our scaling up operations. We are involved in fund raising and in collaboration with our partners. We have managed to secure $50,000 from Farm Africa to support our indigenous fruits processing technology to rural communities. Staffs have been trained on how to develop winning proposals for funding.

Constraints to scaling up

- Lack of adequate human and financial resources for AF research and development activities.
- Lack of adequate dissemination channels.
- Inadequate training of farmers and extension agents.
- Inadequate coordination of research and development activities.
- Lack of awareness among stakeholders and farmers.
- Human and financial resources.
- Very few partners, unreliable and incapable.
- Long distances between sites.
- Inadequate availability of quality germplasm.
- Drought.
- Policy conflicts.

Sustainability

- Involvement of farmers in planning and implementation at grassroots.
- Capacity building at all levels.
- Establishment of demonstrations in villages.
- Training of farmers as trainers.

Lessons learnt

- Continuous engagement with partners and continued planning.

- Activities that generate income and diversification.
- Need for farmer responsive technologies.
- Working at grassroots level.
- Follow up.

Future plans

- Forging stronger partnership.
- Resource mobilisation.
- Diversify options for farmers.
- Product quality improvement and marketing with Commercial Products from Wild (CP Wild).
- Formation of consortium for scaling up in Tanzania.
- Developing participatory monitoring and evaluation system and impact assessment.
- Synthesis of experience.

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Conservation agriculture as an approach to agricultural development in dryland areas of Mali

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Abstract

This paper examines the prospects for implementing the principles of conservation agriculture characterized by no tillage, permanent soil cover, and crop rotation under dryland farming conditions in Mali. Results are drawn from a project on Integrated Plant Nutrition Management and review of research papers. Increased stover production to produce a permanent soil cover is essential in order to develop conservation agriculture. Hill application of fertilizer has been shown to be a low cost method for increasing grain and stover yield and must be considered an entry point for the development of conservation agriculture. Results from Bafaloubé in Kayes region showed that sorghum yields, as compared to the control, increased by 40% for an application of 0.3 g NPK per hill and 68% for an application of 6 g NPK per hill. In Macina, yields of pearl millet showed an increase of 72% for an application of 0.2 g fertilizer per hill and 121% for an application of 6 g fertilizer per hill.

Oxen-tillage is in widespread use in millet and sorghum production. Ploughing often increases yields in experiments, but results under farmers' conditions are more contradicting. The introduction of animal traction for ploughing in Mali is questioned because it also skews the composition of the livestock herd toward males and older animals. If conservation agriculture is introduced, it opens the possibility for replacing oxen with small ruminants or milking cows. This is likely to increase the overall productivity of the livestock system.

The traditional way of building capital in the Sahel has been through investing in livestock. An alternative approach for capital accumulation is to invest in trees. Silviculture development in Mali can contribute to development of conservation agriculture by producing mulch, fodder, and by generating income that can be used for the purpose of agricultural development.

Introduction

Agriculture is the dominant economic activity in Mali and almost 50% of the gross domestic product has agriculture as origin (CSLP 2002). In the Poverty Reduction strategy of Mali, infrastructure development and support to productive sectors has been identified as one of the three pillars of development (CSLP 2002). Restoration and maintenance of soil fertility will be a priority area for intervention. The objective of this paper is to present trends in dryland agricultural development in Mali and to discuss the development of an alternative pathway for agricultural development based on the principles of conservation agriculture (CA). This paper presents results from a project on Integrated Plant Nutrition Management Project that was implemented through the Dryland Coordination Group in Mali This report presents work related to hill application of fertilizer and land reclamation through the use of the zai water harvesting technique.

These results are analyzed and discussed in the light of other research findings.

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Materials and methods

The study was undertaken in the county of Bafaloubé in the Kayes region in Western Mali and in the county of Macina in the Segou region in central Mali. Sorghum is the major rainfed crop in Bafaloubé while pearl millet is the major rainfed crop in Macina. At both locations, focus was on increasing food production through development of low cost methods for Integrated Plant Nutrition Management.

Experiments were undertaken on hill application of fertilizer in plots in farmers' fields. Each farm was considered a replicate. The following three treatments were tested in each farm:

1. Control –no application of fertilizer.
2. Mixing seeds and fertilizer in the ratio of 1:1 prior to sowing. This corresponds to 0.3 g fertilizer per planting hill in sorghum (9 kg fertilizer ha^{-1}) and 0.2 g per planting hill in pearl millet (4 kg ha^{-1}).
3. 6 g fertilizer per planting hill equivalent to 180 kg fertilizer ha^{-1} in sorghum and 120 kg ha^{-1} in pearl millet.

Population density was approximately 30 000 and 20 000 plants ha^{-1} for sorghum and millet respectively. The type of fertilizer used was 15-15 –15. Each plot (treatment) occupied an area of 50 * 50 m and there was one replicate per farmer.

The second experiment was on the zai water harvesting technique. The zai is a whole in the ground, 15 – 20 cm deep and with a diameter of 30 - 40 cm Approximately 200-500 g compost was added to each zai to improve nutrient supply. The distance between the zai is about 75 cm in both direction corresponding to a plant density of about 8 000 zai (plants) per ha. At each site two treatments were tested, without zai and with zai. Each treatment was tested on plots 20 * 10 meters. Each farm was considered a replicate.

Data were collected on price of cereals and price of grains in order to undertake an economic assessment of the treatments. Labor used to establish the zai treatment plots was calculated based on interviews with the farmers.

The FAO statistical database was used to analyze trends in Malien agriculture. A literature review on conservation agriculture and livestock development was also undertaken. This review together with the results of the IPNM study formed the basis for analysis and conclusions in this study.

Results and Discussions

Development trends in Malian dryland agriculture

During the last decades, Malian dryland agriculture has undergone significant changes. Size of arable land has greatly expanded from 2.0 million hectares in 1985 to 4.6 million hectare in 2001 (FAOSTAT 2003). Changes have also occurred in the cropping systems, particularly in southern Mali where cotton production has expanded since the 1960s. Pearl millet and sorghum are the major crops in the sahelian zone of Mali. Pearl millet yield has decreased from about 1 t ha^{-1} in 1985 to currently about 0.9 t ha^{-1}, while sorghum yields decreased from about 1.1 t ha^{-1} to currently about 1.0 t ha^{-1} (FAOSTAT 2003). Fertilizer use is still extremely low, averaging 10 kg

ha^{-1} for the last 15 years. Even though cultivated areas have increased, cereal production per capita has been fairly stable, around 100 kg per capita. This lack of progress in agricultural productivity can probably be explained by declining soil fertility. A nutrient balance study in Mali conducted in millet and sorghum based systems found a mean net removal of nitrogen at 18 kg N ha^{-1} $year^{-1}$ (Powell and Unger 1998).

Livestock production has also greatly expanded in recent times. Total number of cattle has increased from 4.3 million heads in 1985 to 6.8 million in 2002 (FAOSTAT 2003). The livestock sector in Mali has fairly low productivity. A study of Sudanese Fulani cattle in agropastoral system in Mali showed that the age at first calving was 4 years, calving interval was 2 years and a 365 day calf weighed less than 80 kg ha^{-1} (Wilson 1989). It is, particularly, the inaccessibility to fodder during the dry season that causes low productivity.

The development of animal traction has strongly influenced crop and livestock production in Mali. Animal traction was introduced in Mali between 1928 and 1930, but expanded in the 1950s in relation to the increase in cotton production (Bosma et al. 1996) and has later also spread to millet and sorghum producing areas. About 10% of the total cattle population in Mali was draught animals in 1995 (Harvard et al. 1998; FAOSTAT 2003). Number of draught animals has increased from below 100 000 animals in 1965 to about 600 000 in 1995 (Figure 1).

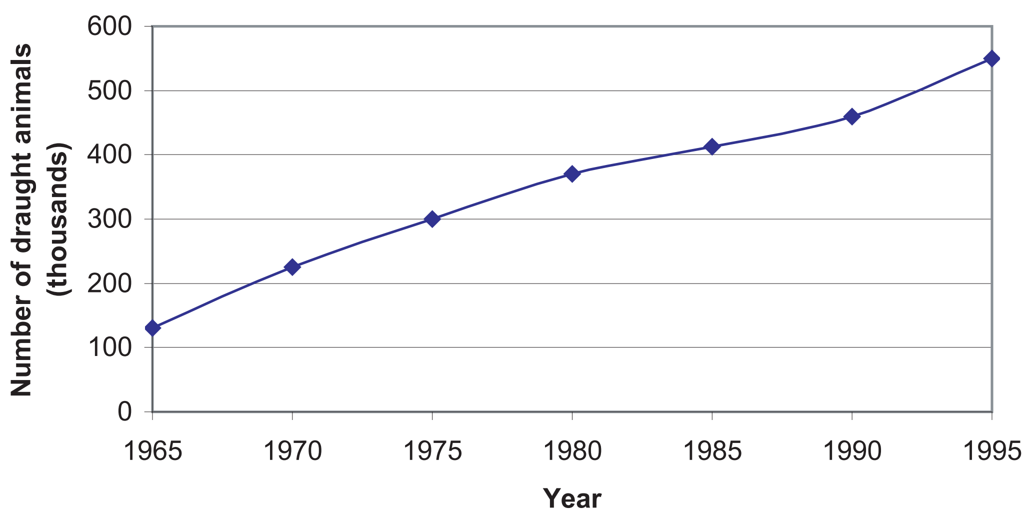

Figure 1. The trend in draught animals in Mali. (Harvard et al. 1998)

A survey from 1985 in a semi-arid area showed that 95% of the farmers used oxen for at least a part of their crop production activities (Bartholomew et al. 1995).

Conservation agriculture as a pathway for agricultural development in Mali

What makes agricultural development and intensification so difficult in the Sahelian context is that the different components of farming systems are so closely interlinked. There are strong linkages between the crop and livestock systems through fodder production, recycling of plant nutrients and animal traction. Sale of livestock may also provide cash for buying inputs. For these reasons, it is difficult to make changes in one component of the farming system without influencing the other. Widespread poverty also makes changes in the farming difficult, as poor farmers are generally averse to risks. We will, in the following sections, discuss agricultural development in dryland areas in Mali in relation to (1) crop and soil management, (2) livestock management and use of animal traction and (3) silviculture. The approaches to agricultural development proposed in the following sections are very much inspired by the principles of conservation - no soil tillage, permanent soil cover, and use of crop rotations (FAO 2003a). CA will contribute to building soil organic matter thereby making the soil more resistant to drought.

1. Crop and soil management

Judicious use of inorganic fertilizer will have to play a major role in relation to implementing the principles of CA in the Sahel, because fertilizer will make more stover available for mulching. Use of organic fertilizer is also crucial for maintaining the quality of the soil, but the problem is its limited supply (Powell and Unger 1998). Inorganic fertilizer can build soil organic matter by increasing overall biomass production. Inorganic fertilizers alone can double grain and stover yield. Quadrupling of yields was observed when fertilizer application was combined with stover retention (Yamoah et al. 2002). Even though studies have shown that fertilizer use is economically profitable in rural areas in the Sahel with good infrastructure (Shapiro and Sanders 1998), its use is still low due to cash constraints and limited access. In remote areas, fertilizer use based on broadcasting has not been found to be profitable (Shapiro and Sanders 1998). However, recent studies both from Niger and Mali show that profitability of fertilizer application can be greatly improved by hill application. Hill application is characterized by applying seeds and fertilizers in the same hill or planting pocket.

Results from our project on IPNM in the Sahelian zone of Mali show that it is economically attractive for the farmers to use hill application of fertilizers. Two application rates of fertilizers were compared to a control without fertilizer in 35 farmers' fields (one replicate per farmer) for three years in Bafaloubé. In Macina, yields were measured in 31 farmers' fields in 2001. The application rates tested was applying 6 g inorganic fertilizer (15-15-15) per planting hill as recommend by ICRISAT and the other method tested was mixing fertilizer and seed in the ratio of 1:1 corresponding to about 0.3 g fertilizer per planting hill. Average sorghum yield in Bafaloubé was 646, 906 and 1090 kg grain ha^{-1} for the treatments control, 0.3 g fertilizer per hill and 6 g fertilizer per hill respectively. The method of applying 0.3 g fertilizer per planting hill gave an efficiency of 28 kg of grains per kg of fertilizer in Bafaloubé. Pearl millet yields in Macina were 211, 361 and 467 kg grain ha^{-1} in the treatments control, 0.2 g fertilizers per hill and 6 g fertilizer per hill respectively . In 2002 the Value Cost Ratio for application of fertilizer in Bafaloubé was 12.4 and 0.87 applying for 0.3 g and 6 g fertilizer per hill respectively The value cost ratio should be above 3 in order to interest farmers. At initial stage of fertilizer use it therefore appears more appealing to the farmers to mix seed at fertilizer in the ratio of 1:1 because of its higher value cost ratio and lower risk due to less cash expenditures. It is also less labor demanding to apply 0.3 g per hill because use of 6 g of fertilizer per hill will necessitate one extra person for application of fertilizer. The method of mixing fertilizer and seed in the ratio of 1:1 also makes mechanization of the method more feasible as the disk in the sowing machine can be modified for sowing seeds and fertilizer simultaneously. Some farmers in Bafaloubé have been testing this on their own initiative. It was also observed that the plants were more exposed to drought where the 6 g fertilizer was used as compared to where 0.3 g fertilizer was used because of more vigorous growth with the application of 6 g fertilizer.

More encouraging than these yield results is the fact that the farmers have started to apply these methods of fertilizer application on their own initiative without any support from the project. In 2002, farmers in more than 70 villages had started testing and using the new fertilizer application methods. These new villages have joined the project on their own initiative without asking any financial support from the project.

The positive results with hill application of fertilizer are confirmed in studies by ICRISAT in Niger. From Niger it is reported that hill application of 4 kg P ha^{-1} as NPK (15-15-15) increased yields between 50 to 220% across all sites (Buerkert et al. 2001). The results from the IPNM project in Mali show that it is possible to obtain considerable yield benefit with lower application rates of fertilizers than those reported by ICRISAT in Niger. The benefits of this extremely low dose of fertilizer are a higher value cost ratio, reduced risk, less cash expenditure, less problems with seedling emergence and less exposure to drought.

Hill application of fertilizer, in the long run, may not be a sustainable practice because the supplied N only constitutes 10–20% of the millet plants' total N uptake. However, multi site experiments on hill application indicate no clear affect on the trend in yield across four years (Buerkert et al. 2001). This indicates that hill application of fertilizer can be used as an entry point while introducing complementary measures for building soil fertility. The N balance can be rectified by combining hill application of fertilizer with cowpea/millet rotation or with millet/cowpea intercropping or recycling of crop residues. A review of different fertilizer experiments have shown that inorganic fertilizer alone cannot sustain yields, but if inorganic fertilizer is combined with crop residues and manure, sustainable production can be obtained (Bationo et al. 1998). Chemical fertilizers applied alone on poorly buffered soil will reduce pH and base saturation and increase aluminium toxicity (Pieri 1992).

Another method for CA that was tested in the IPNM project was the "zai" method for water harvesting. In 2001, average sorghum yield in the IPNM project in Bafaloubé for 12 farmers increased from 969 kg ha^{-1} to 1506 kg ha^{-1} whereas in 2002, average sorghum yield for 4 farmers increased from 567 kg ha^{-1} to 1517 kg ha^{-1}. The zai method is an excellent tool for reclaiming land that is degraded due to crusting. The bottleneck with the zai method is its high labor requirement. According to farmers' estimates, it takes about 40 man-days to treat one hectare. It can therefore be calculated that one day of work generated 13 kg of grain in 2001 and 24 kg of grain in 2002. This return is probably satisfactory, and spontaneous adoption of this method has been seen in several locations in Mali. One advantage with the method is that the zais do not have to be dug every year.

Retention of crop residues as a surface mulch is crucial for the long-term sustainability of agricultural systems in the Sahel. Fortunately there are synergies between hill application of fertilizer and stover retention, as hill application of fertilizer will increase stover production. Research by the ICRISAT Sahelian Centre showed that application of 2 t crop residues ha^{-1} increased yield by 15 to 75% (Buerkert et al. 2000). Part of this stover can be used to feed animals while the remaining part used as mulch. The leaves and the upper part of the stem is the most palatable and should be used as animal feed (Powell and Unger 1998). The lower part can be used for mulching. This way of using stover can be a good comprise between using residues for animal feed or for mulch. However, such a system is very dependent on the increase in stover yield through hill application of fertilizers. The effects on soil properties due to addition of crop residues have been found to be a) improved phosphorous availability, b) increased infiltration rate, c) decreased soil surface temperatures, and d) trapped eolian material (Buerkert et al. 2000).

Stover retention increases yield more than ploughing or ridging. In a long-term experiment across nine years at the ICRISAT Sahelian Centre, average millet yield on plots where stover was retained was more than double of the yields on plots where the stover was removed (Yamoah et al. 2002) and in another series of experiments across four sites in the sahelian zone in Niger, stover retention increased millet yields by 73% (Buerkert et al. 2000). The latter study also showed that the effect of stover retention increases with time. Mulching also increased soil water and reduced surface temperatures. Tillage has been found to increase yields by only 20-30%. In Senegal, ploughing has been found to increase yields by 19% for millet and 24% for sorghum (Pieri 1992). In Niger, tillage increased millet yields by 30% (Ikpe and Powell 2002). The effect of mulching and ploughing on the physical properties of the soil seems to be quite similar under Sahelian conditions. Both methods will increase water infiltration, reduce bulk density, promote root growth, and increase soil water holding capacity (Ikpe et al. 2002; Buerkert et al. 2000; Bationo and Buerkert 2001; Powell and Unger 1998). The mechanism for action is, however, not similar. Mulching as compared to tillage will also have a pronounced effect on chemical properties of soil and soil surface temperatures. Mulching is thereby a more sustainable practice than tillage because mulching will build soil organic matter as compared to ploughing, which will reduce soil organic matter (Pieri 1992). Mulching is therefore a much more sustainable practice than tillage.

2. Livestock development and use of animal traction

Free roaming animals during the dry season makes development of CA in Mali difficult because very limited quantities of stover is retained in the field. Changes in the grazing system are therefore needed if part of the stover is to be retained in the field. Animals must be contained in parts of the dry season. In these months, they could be fed on harvested stover, hay and pruning from trees. Other possible sources of feed are molasses and cotton cake. If animals are only fed on stover they lose weight. A successful program (widespread adaptation) with seasonal stabulation of animals is reported from southern Mali where zebu cattle were stall fed with chopped cereal straw mixed with urea, molasses, cotton-seed cake and minerals (Bosma et al. 1997). This system proved more cost-efficient than providing grazing cattle with supplementary rations. The economic feasibility of introducing stall-feeding in Mali has also been examined using a modeling approach. It was found that free grazing is most economically attractive for the farmers, but a low level of pasture tax (US$3 per tropical livestock unit) would be sufficient to induce stabulation of animals (Dalton and Masters 1998). The effect of stover retention on yield was not included in this modeling approach. Stall-feeding of animals should be combined with programs for upgrading fodder quality such as urea-treatment of straw, hay, cowpea haulm, and tree fodder banks. Such a system will assure milk production throughout the year and will create possibilities to develop fattening programs for animals. Continuous milk production can also contribute to improve human nutrition, as lack of vitamin A is one of the most important deficiencies in human nutrition in Mali (FAO 2003b). A more intensive livestock system based on stall-feeding of the animals during the dry season will also produce more manure that can be used in gardens and millet fields. Seasonal stall-feeding in the hot and dry season becomes more realistic if small ruminants or milking cows replace oxen, because such a livestock system will generate more income. Increased emphasis on small ruminants and particularly goats will also make the livestock system more resistant to drought. Goats have been found to have higher survival rates than cattle under drought (Williams et al. 1995). It is also much more rapid to reconstitute a herd of small ruminants after a drought.

Stall-feeding of animals in the hot and dry season can also contribute to regeneration of degraded pastureland and increased manure collection. If stabulation of animals is not feasible, increased use of shepherds is recommended to avoid excessive grazing of stover. Use of shepherds will also reduce the problems of animal theft. The changes in the livestock system proposed above will however be difficult to introduce if animal traction based on oxen is continuing to develop.

Various forms of pastoralism will continue to exist parallel to sedentary livestock keeping. Nomadic pastoralism is the best way to utilize the vast grazing areas in Mali and it is also important for providing manure to agricultural land. Nomadic livestock keeping is likely to continue for foreseeable future, but grazing of nomadic livestock should be controlled to ensure that some stover is left on the ground. In years of extreme drought all the stover can be used to feed animals.

The introduction of animal traction in Mali can be questioned, particularly in the millet and sorghum producing areas. Field experiments generally find that ploughing increases yield. However, the yield effects of tillage in farmers' fields have often been less than in experiments (Adesina 1992). An analysis of productivity gain from animal traction in southern Mali showed that the effect of animal traction was to increase the cultivated area, but yield of cereal crops decreased (Jolly and Gadbois 1996). Income per active labor unit was also highest for households without animal traction. In another study in southern Mali it was found that yield of cereals increased as a result of animal traction, but improved market access is required to ensure the profitability of the system (Adesina 1992). Investment in animal traction is often restricted by high initial investment cost of animal traction, high interest rates and the risk of price collapse of agricultural products (Adesina 1992). Animal traction may also cause delayed sowing if the ploughing is too heavy for the starved animals at the beginning of the rainy season (Jolly and Gadbois 1996). Draught animals in Mali are only used for a very short period of the year. Oxen are not used for draught until they reach 4-5 years and in average the oxen is used only for draught purposes for about 4 years (Wilson 2003). A pair of oxen in average is only used for about 22 days for primary cultivation and 11 days for weeding during a year. Introduction of animal traction may decrease livestock productivity because the herd structure will be skewed towards higher percentage of males and towards older animals (Aune et al. 2001; Wilson 2003). In millet based system in Mali it has been found that castrated oxen account for about 30% of population of cattle and that males constitute about 65% of the cattle population (Wilson 2003). When oxen constitute 30% of the cattle population, it is likely that 40-50% of the fodder resources are consumed by the oxen since they are bigger, have higher energy demands due to the work and are given the best quality feed. The introduction of oxen tillage is therefore likely to constrain the overall livestock productivity since so much of the fodder resources are used for feeding the oxen. It is also very demanding to ensure recruitment of new oxen. In Ethiopia it has been found that an ox based tillage system requires about10 heads of cattle: two oxen, two young apprentice bulls, four or five milking cows and a stud bull (McCann 1995). It is therefore time to rethink the process of agriculture intensification through the use of oxen tillage.

3. Silviculture development

Silviculture development in Mali can contribute to development of CA by producing mulch, providing fodder to the animals, and by generating income that can be used for the purpose of agricultural development. The traditional way of building capital in the Sahel has been through investing in livestock. There are, however, limits to how much capital can be invested in livestock, as too much livestock will cause degradation of pastures. The livestock sector in the Sahel has also a fairly low productivity (Wilson 1989). An alternative strategy for building capital for the farmers is to invest in trees. A study of non-timber products in southern Mali identified 55 different non-timber products and 68% of these products generate income (Gakou et al. 1994). The non-timber products can be categorized into food, fodder, firewood, utensils, tools, construction material, and medicines. Some trees will also produce products with a high market value. Trees can also provide environmental services such as maintenance of biodiversity, reducing soil erosion, and help in sequestering carbon. Investing in trees also increases the value of land. Income diversification through silviculture development will, in addition, contribute to buffer the agricultural system against risks such as drought and price collapse. However, establishment of trees is often difficult because of free roaming animals. Better control of animals is therefore essential if tree planting and natural regeneration is to become successful.

Conclusion

There is a need to change the vicious circle characterized by residue removal, net nutrient losses, low water use efficiency, declining or stagnated yields, and reduced or stagnant per capita production of cereals to an upward spiral characterized by residue retention, hill application of fertilizer, changes in herd structure, improved grazing management, up-grading of fodder resources, silviculture development, and increased farm productivity. It is difficult to introduce these principles in a step-wise fashion, as there are strong synergies between these different interventions. These principles are in line with principles of CA, an approach to agriculture development currently advocated by FAO.

Achieving these principles in Sahelian environment will be a challenging task. There are difficulties with regards to spread of technologies, access to input and credit, infrastructure, market opportunities, etc. Widespread poverty also makes it difficult to introduce new technologies because poor farmers are generally averse to risks. However, failing to implement these principles will imply a continuous degradation of the Sahelian environment and limited prospects for agriculture development in dryland Mali.

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Conservation agriculture pilot trials in Kenya – impacts and options for scaling up

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Abstract

Intensive soil tillage involving cutting and inversion of soil has been shown to accelerate degradation of soil fertility. Conservation Agriculture, on the other hand, has proved to be an effective vehicle for halting and even reversing rapid soil and environmental degradation. The gains of Conservation Agriculture have been ably demonstrated throughout researches and extension and development work the world over. In Kenya, on-farm adaptive Conservation Agriculture pilot trials conducted since 1999 and supplemented with on-station trials have shown a great potential in increasing land productivity and reducing environmental degradation. This paper presents some of the results from both on-farm and on-station trials. The results are clearly in favor of Conservation Agriculture. Ripping and direct planting on previously subsoiled plots consistently gave higher yield at lower production costs. In seasons with adequate rainfall, yields were comparable between treatments but the low production costs still meant Conservation Agriculture systems were more attractive. The process of adoption is however hindered by cost and availability of Conservation Agriculture equipment, insufficient packaging of the Conservation Agriculture technology, credit access for farmers, and lack of policy support at national level among others. Options for scaling up are therefore being explored.

Introduction

Impacts of conventional tillage

Over use or inappropriate use of land resources by communities are the basic causes of degradation. This is particularly so with intensive soil tillage involving frequent and intensive soil cutting and inversion as practiced by most farmers. Intensive soil tillage leaves the soil surface bare and loosens soil particles making them susceptible to the erosive forces of wind and water. Furthermore, repeated mouldboard ploughing encourages pan formation at shallow depths, which further inhibit water infiltration. Under intensive cultivation, most of the crop residue is removed or buried thus depriving the soil the much-needed protective ground cover. The frequent cutting and pulverization destroy the soil structure, soil fauna and associated benefits of microbial activity to plant growth. Oxidation of organic matter is accelerated leading to excessive production of greenhouse gases. The soil eventually loses its capacity to support plant life. This phenomenon is particularly obvious in tropical climates and explains why continued decline in soil fertility and degradation is evident even in the best-conserved lands in terms of soil and water conservation, resulting in physical structures such as terraces.

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The case for Conservation Agriculture

Borrowing from experiences of Latin America and USA where over 55 million hectares (a figure that is still growing) are under Conservation Agriculture (CA), focus is now shifting to an integrated soil and water management approach. CA stands out as an effective vehicle of halting rapid soil and environmental degradation. CA relies on three integral principles: minimal soil disturbance, permanent soil cover, crop rotations and mixes.

Under minimal soil disturbance, tine based implements are used to open a small slot in the soil for seed insertion. Permanent soil cover protects the soil from erosion agents, high temperatures, and radiation among other effects. Crop rotations and mixes refer to selection and sequencing of mixes and rotations for mutual benefits such as nitrogen fixing, disease and pest management and nutrient recycling.

A true CA system involves direct seeding into permanent soil cover, which may be mulch, grass or cover crop, using special seeders. In Kenya, we are essentially in transition to a CA system. Corrective measures such as de-compacting (breaking hardpans) the soils, establishing adequate soil cover and adding lime to the soil are required before full transition is achieved. Benefits of CA system include the following among others:

- Improved soil fertility and reduced weed infestation.
- Reduced labor requirements.
- Reduced soil and nutrient losses.
- Improved biodiversity.
- Higher yields.

These benefits have been ably demonstrated through various researches, extension and development work throughout the world. In Kenya, CA is known to several large-scale wheat farmers who have reported huge reductions in production costs and significant increase in yields. But the system is yet to become part of the smallholder farming practice. CA, therefore, has a new focus in eastern and southern Africa, particularly so, for the highly vulnerable semi-arid lands where animal traction is an important power source.

Recently, animal drawn CA equipment has become available in Kenya through exchanges with Brazil, USA, and from within the region – Zambia, Zimbabwe and South Africa. This development has made the difference and CA is now being adapted to Kenyan farming and socio-economic conditions. Tine-based equipment such as the Magoye Subsoiler and Ripper and direct seeding attachments are changing the way farmers till their land. Animal drawn direct seeding equipment and sprayers from Brazil and USA have made zero tillage under smallholder farming a reality.

CA piloting trials in Kenya were started in 1999 under the umbrella body of Kenya Conservation Tillage Initiative (KCTI) through the support of the Regional Land Management Unit (RELMA), African Conservation Tillage Network (ACT) and German Technical Cooperation (GTZ).

The initial CA trials covered three areas: Machakos, Laikipia and Rachuonyo. Four more areas were later added with the support of Food and Agricultural Organization (FAO) to bring the tally to seven. Selection of areas for the pilot trails was based on geographical and agro-ecological representation.

Aim of pilot trials

The aim of CA pilot trials is to work with farmers to develop appropriate CA systems by comparing conventional plough based cultivation with selected CA systems. Emphasis is on farmer-led approach with simple trials from which farmers can clearly discern CA benefits and learn the practice.

Built around the pilot trials are additional activities aimed at bringing together stakeholders of CA to exchange views with practitioners and document the learning generated.

Materials and methods

The trials, which are largely on-farm, center on observations and discussions with farmers regarding farming systems and practice differences hence the benefits in power, labor and crop performance over the traditional practice. Emphasis is put on farmer participation as a way of transferring knowledge and ownership.

Site and farmer selection

Initially, 4 to 6 farmers were involved in each of the three farmer pilot sites in Rachuonyo, Machakos and Laikipia Districts to represent variable geographic and agroecological zones. Selection of participating farmers was based on their willingness to participate in research and share information and knowledge with others.

Training support

It was necessary to re-train farmers because under CA system everything from minimized soil manipulation, seeding, weeding and animal handling required a new approach. The training included the concepts of CA and the associated equipment, their adjustments and handling. They were also trained on the handling of their work animals.

Tested Contil systems and experimental layouts

Through 1999 when the trials got under way, experimental layouts tended to be a complex of attempts to compare traditional and Contil practice next to each other but this was easily overshadowed by the many possibilities of CA and the need to fit into the farmers crop rotation system and calendar.

After several seasons and managerial discussions and decisions with farmers and site scientists, several adjustments were made along the way culminating in site-specific practices thus abandoning earlier attempts to harmonize trials between the various pilot sites.

Eventually, focus narrowed to comparing best contil practice(s) with traditional practice. Care was taken not to alienate farmers without access to animal power by including treatments such as pickaxe to manually break the hard pan. Chart 1 highlights the nature of treatments tried out on-farm.

Chart 1. On-farm trials for Machakos, Rachuonyo and Laikipia with maize crop.

Treatment	Description	Comment
Conventional ox-ploughing	Mouldboard plough tillage and planting followed by plough weeding.	Eventually adopted as recommended traditional practice.
Subsoiling + direct planting	Subsoiling done with Magoye subsoiler to depths in excess of 20cm followed by direct planting using Magoye ripper planter attachment. The ripper widens the narrow subsoiled furrow for easy placement of seed.	High draft requirements were accommodated by making several passes with increasing depth. Direct seeding was an interesting treatment with major labor savings for women farmers whose job it is to do the seeding. Three tine, duck-foot weeder was tried on some plots with a degree of success. It was eventually recommended that subsoiling is best done immediately after harvest and in advance of the following season.
Subsoiling + ridging	Subsoiling done as above followed with ripping with ridging wings attached to form ridges. Fertilizer application and planting are done by hand.	Draft requirement as above for subsoiling unless done soon after harvesting. Takes more time to ridge and hand plant.
Manual subsoiling (pick-axing)	A linear, continuous manual ridging operation. Upto 20 cm depth possible followed by manual seed placement on manure and fertilizer holes.	Introduced later as a compromise between pitting and animal ridging, for the farmers without animal traction. Argument was it is easier to dig a continuous ridge manually than disjointed pits requiring manual soil removal after each hole is dug. Very labor intensive and costly.
Ripping	Deep ripping with Magoye ripper to depths in excess of 12cm, followed by manual fertilizer application and planting	Can break shallow plough pans with ease. High draft requirement under difficult soils but has good soil loosening characteristics without turning soil over. Where no hardpans exist this is the only operation required.
Ridging	Ridging operation either using a conventional ridger or the Magoye ripper with ridging wings attached. Fertilizer/manure application and seeding is done manually.	Takes more time to ridge, hand plant and to manually apply fertilizer/manure. Also excessive soil movement.
Pitting	A pick-axe operation on hard crusted soil. Digging upto 20 cm holes, 40 to 50cm apart and in them applying manureand fertilizer before placing seeds in indirect contact. A highly labor intensive operations.	Like the Zai system of Burkina Faso, where it is used as a land reclamation method, this technique proved a good rainwater harvesting method, able to help develop a crop during the worst of a drought season. The technique helped maximize nutrient and water use by concentrating the same around the plant.
Contil	Adopted as best practice in Machakos and Laikipia after several trials. It is basically ripper-planting either direct or manual seed & fertilizer placement after ripping. Hardpans must be removed prior to ripping. Weeding is by slash-and-lay or using herbicides or a shallow cultivator.	Cover crops can be incorporated to suppress weeds in addition to fixing nitrogen and providing soil cover.

Basic procedure

As a matter of consistency and procedure, regulations were set out for field-staff to assist farmers in laying out the experiment and monitoring crop and other performances. Several forms to guide in the reporting were developed and revised over time to help generate as much information with and from the farmers. The derived protocol helped develop consistency and a comparative basis of information coming from the various trial sites. The forms were divided into three protocol groups:

- Tillage operations information sheet (completed on the day tillage was conducted).
- Field visit and performance monitoring sheet (completed when officers visited the farms on a regular basis).
- Harvesting period information sheet: plot specific and locality specific (completed with information directly from the farmer and the site scientist or harvesting crew with the farmer playing the lead role).

During the crop growing period:

- Farmers were allowed to handle tillage equipment as much as possible and eventually left on their own as training turned to common practice in terms of equipment adjustments and animal handling.
- Records included a mapping of which treatments were where and these were eventually physically labeled for ease of identification and monitoring. Slowly farmers took over this responsibility.
- Records included details of soil and operation conditions (wet, dry, with or without mulch, weed or other infestation level, rocky etc) time taken, fertilizer rates, labor requirement, farmer's comments and other relevant or general observations.
- Farmers were taught to mark out a 10 m x 10 m section (or equivalent size plot, relative to the overall plot size) away from the plot boundaries. Farmers were trained on how to protect the marked out section and how, within the marked section, to count seedling emergence rates, weeds (with absolute minimal soil disturbance), the number of plants dropped by pest etc, and eventually harvest and weigh total biomass, cobs and grain.

On-station trials

Two sites, one at Katumani Dryland Research Station and the other at National Agricultural Research Laboratories (NARL) both of Kenya Agricultural Research Institute (KARI) were selected to formally conduct, in a controllable manner, what had proven difficult to sustain in the farmers' fields. NARL, situated at Kabete, is an upland experimental station with high potential soil characteristics.

For Kabete the trial plots were meant to evaluate pure no-till practices. Bush clearing was done by slashing followed by chemical weeding and direct mulch seeding using a jab planter.

The test crop was maize (*Zea mays*) but cover crop (here, *Dolichos lab lab*) was included in one of the treatments. Chart 2 shows the nature of the on-station treatments at both sites. Appropriate labor (area and man-hours) and cost information were recorded as was crop performance (including diseases and pests), soil chemical analysis (eg to capture the N build-up from leguminous nitrogen-fixing cover-crop), yield and other socio-economic information.

Soils were tested to decide which fertilizer was needed for both on-farm and on-station sites. On-station treatments were replicated at least twice. For on-farm trials each farmer was a replicate. Fertilizer was used evenly on all plots, including the conventional ones. All reporting was done according to prepared protocol, including occasional field visit forms.

Chart 2. On-station trials for NARL - Kabete and NDLFRS – Katumani for Long Rains 2002 season.

Treatment	Description
Conventional tillage without mulch	Mouldboard plough tillage and planting followed by plough weeding. No mulch.
Conventional tillage with mulch	Mouldboard plough tillage and planting followed by heavy application of grass mulch. Weeds removed by hand.
Subsoiling + direct ripper planting + cover crop	Subsoiling done with Magoye subsoiler to about 20cm depth followed by direct planting using Magoye ripper planter attachment. Two rows of cover crop (*D. lab lab*) planted between maize rows.
Subsoiling + direct ripper planting + herbicides	Same as above but without the cover crop. Weed control is by herbicides.
Conventional hand hoeing	Whole plot dug by hand hoe including fertilizer and seed holes. Weeding also by hand hoe.
Mulch (maize stover) + hand planting	Treatment as above up to planting. Maize stover applied as soil cover. Weeds removed by hand.
Zero tillage + cover crop + Jab planting	No till. Bush initially cleared by slashing. Direct seeding into trash done using Jab planter. Two rows of cover crop planted between maize rows. Subsequent weeding by slashing and uprooting.
Zero tillage + herbicide + Jab planting	No till. Large bushes initially cleared by slashing followed by chemical weeding leaving all trash on the surface. Direct seeding into trash done using Jab planter. Subsequent weeding by spot treatment.

Results and discussions

Rachuonyo

Rachuonyo District occupies 930 sq km of land. Three quarters of this land is under Agroecological Zone Lower Midland three (AEZ ML3) with semi-arid climatic conditions. Most of the soils are a combination of regosols and lithosols. Soil erosion is rampant resulting in loss of water and nutrients. Due to this, crop yields are low.

Rainfall is bimodal and erratic. The annual average is 1133 mm. The average for the Long Rains (LR) is 750 mm - 1020 mm while the Short Rains (SR) averages 383 mm. It is therefore necessary to conserve soil, water and nutrients in order to get good yields.

The treatments tested were as shown in chart 1. The test crop was maize. Planting was done at a spacing of 75 cm inter-row and 60 cm within the row on plots approximately 10 m x 10 m. Two seeds were placed in each planting hole. Fertilizers applied were 60 kg ha^{-1} N, 60 kg ha^{-1} K, and Farm Yard Manure (FYM) at the rate of 10 t ha^{-1}. The FYM and K were applied during planting while N was applied when the maize crop was 30-40 cm high. Weeding was carried out at least twice during the crop growing period. Crop germination rates were evaluated soon after emergency.

Figure 1 shows ripping to have had consistently higher yields and lower production costs. Pitting also produced good results but had production costs comparable to those of conventional ox ploughing. It is therefore possible to produce more at lower production costs under Contil systems.

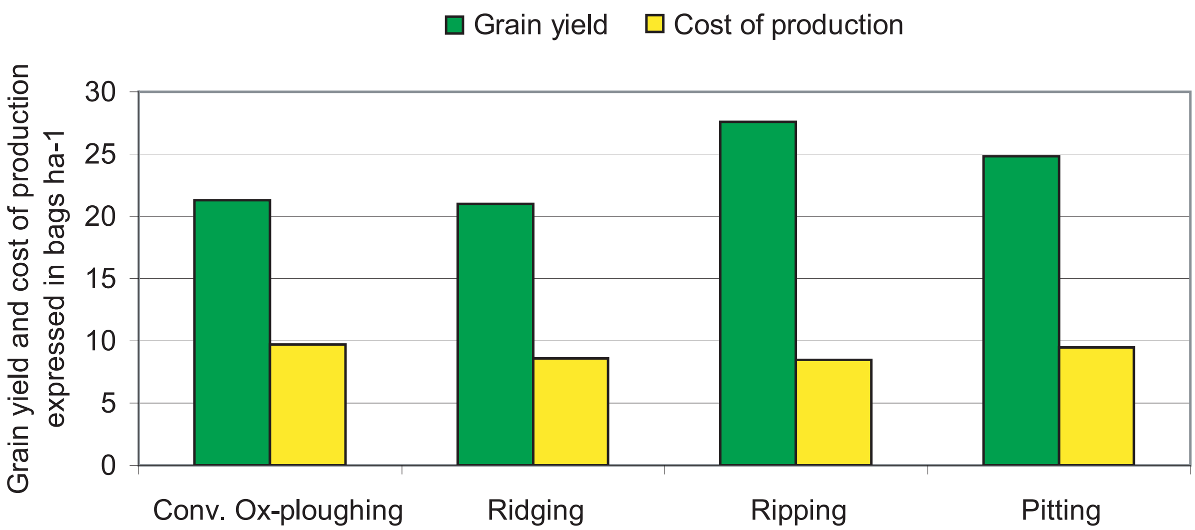

Figure 1. Average grain yield and cost of production (over seven seasons expressed as in bags per hectare) for maize under different tillage systems in Rachuonyo.

Machakos

The trials in Machakos were carried out in two sites - Iuyini and Kola both of Kalama Division. Soil types in the two locations range from sandy loam to clay loam. The soils are generally highly susceptible to surface sealing and crusting resulting in low infiltration rates and high surface runoff. Soil erosion is high. The soils are also generally highly abrasive on tillage tools. They have a natural hardening tendency in the subsoil necessitating frequent sub soiling.

Rainfall is bimodal, relatively low (below 800 mm annually), erratic and poorly distributed. Moisture losses due to evaporation are high. Moisture and soil conservation is therefore of paramount importance. The long rains start early to mid March. Short rains start in October.

The treatments tried out are detailed in Chart 1. Maize was the test crop throughout the four seasons. The choice of seed was farmer's own which was a local variety selected from the previous crop. Spacing of the crop was approximately 1 m inter-row and 25-30 cm within the rows. FYM and chemical fertilizers (DAP) were applied equally on all treatments during planting at recommended rates. Top dressing was done with either Urea or CAN also at recommended rates.

SR 2000 – LR 2001 seasons

The results shown in Figure 2 are the averages for the two seasons. Evidently direct planting on previously subsoiled plot had the highest grain yields at much lower production costs. Although manual subsoiling (pick axing) gave yields comparable to those from direct planting, it had very high costs of production. Conventional ploughing was the least favorable. The higher yields from the contil systems can be attributed to the breaking of the hardpan thus maximizing on available moisture.

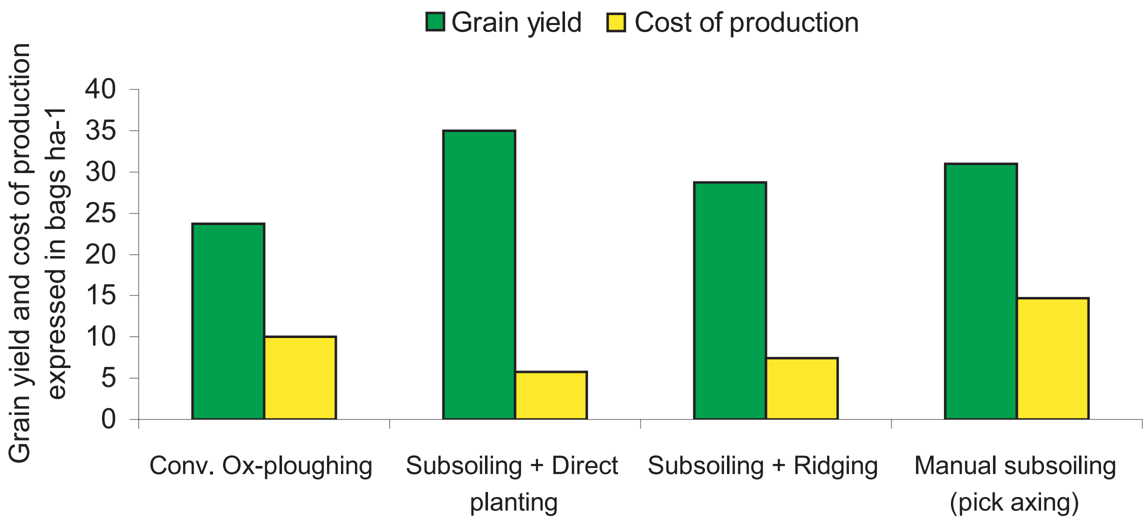

Figure 2. Average grain yield and cost of production during SR 200 – LR 2001seasons (expressed as in bags per hectare) for maize under four different tillage systems in Machakos.

SR 2001 – SR 2002 seasons

Due to the consistently good results from Subsoiling+Direct planting, all other treatments were dropped in favor of this system and the trials from SR 2001 onward were aimed at simple comparative demonstrations without confusing farmers with too many options.

Results for the average grain yields and costs of production are shown in Figure 3. It is clear from these results that farmers can expect better yields with fewer inputs under contil systems.

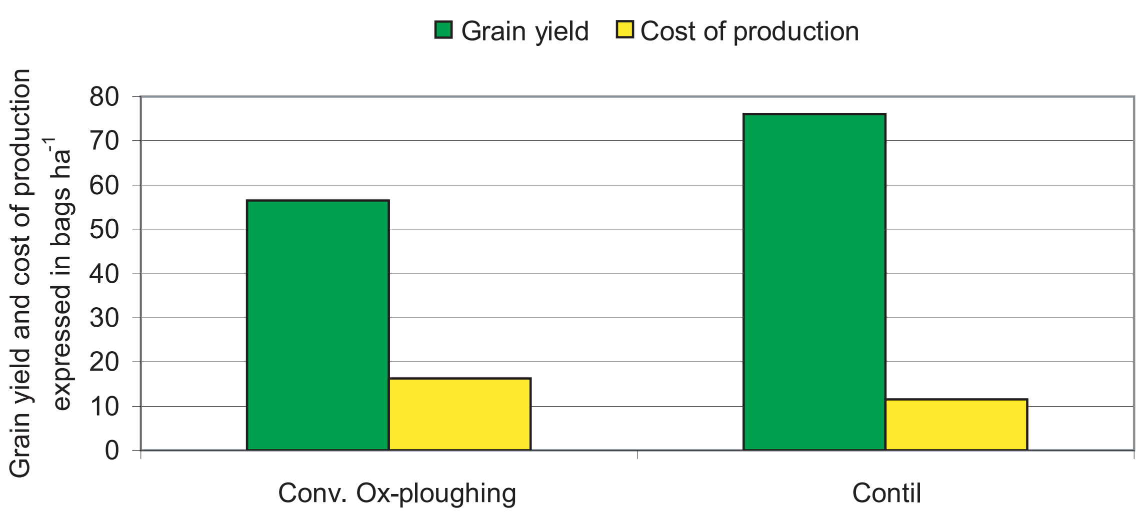

Figure 3. Direct comparison between conventional ox ploughing and a contil system during SR 2001 and SR 2002 seasons in Machakos.

On an average, contil treatments performed better than conventional treatments. Differences in grain yields were not significantly different but returns from contil treatments were significantly higher due to lower operational costs. Contil systems were therefore highly recommended, especially if one took into account other perceived contil benefits not measured in the on-farm trials.

On-station Results

The on-station trials were effectively run for only one season – LR 2002 - in both Katumani and Kabete. The results are shown in Tables 1 and 2.

General comments and observations regarding the trial results

In seasons with adequate rainfall contil benefits may not be obvious in terms of grain yields until production costs are taken into account. The short-term benefits of contil lie in savings in labor costs and timeliness of operations as well as reduced environmental degradation. In the long term, rehabilitation of severely degraded lands through contil systems can result in sustainably higher yields.

Impacts of the pilot trials

The response to the trials has been overwhelming. In Machakos, farmers have reported significant increase in maize yields, solely attributed to the method of tillage. In Laikipia, where rainfall is unpredictable, CA farmers have been able to raise a crop in seasons when their neighbors got nothing. More significant are sentiments expressed by farmers regarding the systems ability to reduce labor demand. Labor is one of the major bottlenecks in crop production in smallholder farming in Kenya. Due to the time saved through the CA system, women farmers who are at the center of farming activities said they were able to engage in other social and income generating activities.

Farmers also reported less erosion from CA plots compared to conventional plots. After three to four seasons of continuous cultivation under the CA system, farmers said the soil under the CA system felt softer, was easier to work with and had an increase in microbial activity.

As a result of the pilot trials, an estimated 2,000 farmers have been exposed to the CA system and over 200 farmers are believed to have tried the system from the original 36 participating farmers supported by the pilot trials. Twelve artisans have been trained in the production of the Magoye ripper and are ready to start production of the units. More than 80 units of rippers and subsoilers have been produced locally through the Department of Agriculture Engineering, University of Nairobi.

Contil clubs are well established especially in Machakos and are already doing business in subsoiling and ripping for others. As the gains of crop selection, mix and rotation are exploited, coupled with soil cover for reduced soil temperatures, moisture preservation and soil fauna development, the prospects of sustainable farming are looking very good. The challenge now lies in creating appropriate uptake pathways for rapid adoption of the technology. This is being realized through field days and demonstrations, in-field training of frontline extension workers, farmers and other key stakeholders, establishing a dependable equipment manufacturer and

Table 1. Mean grain and biomass yields and economic data from Katumani on-station contil trials for LR 2002.

Treatment	Germination count Plants ha^{-1}		Mean grain yield Kg ha^{-1}		Mean biomass yield (maize only) Kg ha^{-1}		Gross revenue Kshs ha^{-1}	Marginal costs Kshs ha^{-1}	Gross margins Kshs ha^{-1}	Benefit cost ratio
	Maize	Dolichos	Maize	Dolichos	Stover	Cob				
Conventional tillage (No mulch)	29,333		528		2,778	778	10,560	17,575	-7,015	0.6
Conventional tillage (With mulch)	27,444		639		3,556	779	12,780	19,260	-6,480	0.7
Sub-soiling + direct ripper planting + cover crops	32,000	26,000	583	185.4	4,222	837	22,984*	11,450	11,534	2.0
Sub-soiling + direct ripper planting + herbicides	30,222		500		3,667	833	10,000	12,350	-2,350	0.8

Note: *Includes revenue from Dolichos grain

Table 2. Mean grain and biomass yields and economic data from KARI-Kabete (NARL) contil trials sites for LR 2002

Treatment	Mean grain yield Kg ha^{-1}	Mean cob weight Kg ha^{-1}	Mean biomass Kg ha^{-1}	Gross revenue Kshs ha^{-1}	Marginal costs Kshs ha^{-1}	Gross margins Kshs ha^{-1}	Benefit cost ratio
Conventional tillage	1,750	2,380	14,990	35,000	19,640	15,360	1.8
Mulch (maize stover)	1,440	1,800	15,910	28,800	21,190	7,610	1.4
Zero tillage (Jab planting + cover crop)	3,000	2,860	27,560	60,000	12,830	47,170	4.7
Zero tillage (Jab planting + herbicides)	2,750	2,900	26,350	55,000	10,320	44,680	5.3

repair services by training local artisans and helping farmers commercialize farming activities with CA as the entry point.

Limitations to adoption of CA

In spite of the great deal of enthusiasm expressed by farmers, adoption rates are still low. One of the main reasons often cited for this scenario is lack of appropriate equipment. However, a closer look at the scenario indicates there is much more to it than non-availability of equipment. Artisans trained to support the initiative have reported lack of orders from the farmers. Farmers on the other hand say the equipment is expensive and beyond their resources. When this is viewed against the environment of risk management under which the smallholder farmer operates, it is easy to understand why some farmers shy away from investing in the CA equipment.

Furthermore, the CA information reaching the farmers is still inadequate and incoherent. Issues on weed management, cover crop options and their management, choice of herbicides, safe use and application rates remain unclear to most of the interested farmers thus curtailing adoption of the system.

Arguably, though, the gains made are significant. Together with lessons learned, the prospects to higher adoption rates seem promising. It is important to bear in mind that breaking old traditions takes time and only patience and persistence and hard work will bear fruits.

Options for scaling up

Building up on successes of the last four years, the time is ripe for scaling up.
Scaling up will be realized through:

- Additional on-farm trials with more farmer groups built around the concept of Farmer Field Schools (FFS).
- Additional field days and demonstrations countrywide.
- Sensitization of frontline extension staff, local leadership and policy makers.
- Production of training manual based on our experiences and well packaged CA messages.
- Training and support of local manufacturers and artisans.
- Increase technical support and presence in the field, especially on weed control strategies and cover crop management.
- Selection of appropriate cover crops for the different areas and their management.
- Empowerment of farmers through: information and skills transfer, training in group dynamics and entrepreneurial skills, support in market oriented production and information.
- Improved access to credit by linking farmers to micro-finance and training in credit management.
- Increased farmer exchange visits.

Conclusions

Short-term gains in yield increase and reductions in labor demand have generated a great deal of enthusiasm but these must be supported with long-term benefits of sustainability, profitability and reduction in land and environmental degradation. This is only possible if the process of transition to truly CA system is followed through.

Due to the complex nature of CA, a multi-sectoral and multi-disciplinary approach is required in CA technology transfer.

With the availability of animal drawn and tractor powered CA equipment from Brazil and other countries for smallholder farmers, coupled with the enthusiasm expressed by farmers, the prospects for scaling up and eventual transition to CA look very good. However, local equipment solutions must evolve to ensure adequate distribution and support.

Participatory adaptive research and development need to go hand in hand with the scaling up process to incorporate farmer ideas/innovations in the process

Support at policy level is required to enhance and consolidate the adoption process at national level.

La valorisation de l'agrobiodiversité pour assurer une production agricole durable: Le cas du sorgho dans la zone cotonnière de Koutiala au Mali

D Bazile[1] et M Soumare[2]

Résumé

Dans la zone cotonnière du Mali, la culture des céréales s'intensifie rapidement. En raison de la faible productivité des variétés locales, les agriculteurs se tournent vers le maïs qui valorise mieux les intrants. Cette culture est devenue récemment la céréale dominante au sud de la zone cotonnière. Son développement concurrence fortement les céréales traditionnelles. Pour enrayer la disparition des céréales locales, le défi à relever consiste à remonter leur productivité pour en faire une alternative plausible dans un système de culture intensifié.

Notre étude se situe dans la zone de Koutiala à la limite nord de l'aire d'extension du maïs (900 mm de pluviométrie annuelle). Pour limiter le risque hydrique important sur maïs, la stratégie adoptée par les paysans consiste à semer celui-ci sur les terres les plus profondes du bas glacis (meilleure fertilité et meilleure réserve hydrique). De plus, la saturation de l'espace agricole limite les nouvelles défriches aux zones difficiles à mettre en valeur par l'agriculture et où seuls le mil et le sorgho offrent une espérance de rendement. Le sorgho est alors marginalisé sur les moins bonnes terres du fait de sa rusticité.

Le recherche d'une rente immédiate via le maïs et le coton fait oublier la rentabilité incertaine de ces cultures. Il faut donc repenser à la parcelle l'opportunité de chaque culture pour concevoir un système de production agricole optimisé et durable. Cela revient à se poser la question suivante : faut-il opter pour une faible productivité mais stable dans le temps (avec les céréales traditionnelles) ou pour une forte productivité avec un risque non géré par toutes les exploitations agricoles (pour le maïs)?

Notre discussion est centrée sur le lien entre la dégradation des terres (baisse de fertilité) et la baisse de productivité agricole. L'analyse spatiale montre que cette dernière peut simplement être le reflet d'une mise en valeur de terres de plus en plus impropres à l'agriculture. La dispersion/stabilité des rendements, pour le maïs et pour le sorgho, est analysée en termes de coût d'opportunité des céréales. La diversité des écotypes de sorgho présente alors un avantage comparatif sur le maïs pour mettre en valeur les différents écosystèmes de l'exploitation agricole.

Abstract

In the south of Mali, the percentage of farms cultivating maize as well as area cultivated has been increasing with a net acceleration since 5 to 10 years. This penetration of maize has a detrimental effect on the culture of sorghum, which is being reduced or marginalized on the poorest lands. The disappearance of sorghum presents a stake on the ecological plan (loss of biodiversity) as well as on the food security plans: sorghum is a rural cereal which adapts itself better to difficult ecological conditions (weak water reserves or acidity of soils). The genetic erosion of sorghum is strongly correlated to the penetration of maize in the farms. The use of the genetic diversity of the sorghum landraces is then perceived as a factor of rustic character of the agroecosystem. Climate is the major risk that presses on the production and consequently on the stability of supply. The uses of these local

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varieties is above all a strategy to assure self sufficiency of food but effects of which are multiple: minimization of the costs of exploitation, optimization of water resources and protection against the degradation of soils.

When land use is so important, farming system must be more intensive to contribute to food security. In natural conditions, Koutiala is a representative of the maximal north area of extension for maize in Mali. Importance of cotton and maize in the agricultural system provides an economical opportunity to farmers but masks the intrinsic risk of each speculation.

On the way of saturation of agricultural land cover, farmers occupy marginal soils with important constraints for agriculture. If maize and cotton provide maximal yields in better conditions, sorghum and millet, with a panel of folk varieties, are more adapted through wide environments and provide more stability in yields. Economical benefits in low input system could be double than in intensive system. The question that arises is the opportunity of a new farming system conceptualized between crops and ecosystem for best results to provide a sustainable agroecosystem.

A long-term approach with a globally spatial use of the ecosystem shows the dispersion/stability of crop yields. There is a sorghum opportunity, with Malian landraces, to improve agricultural system along with conservation of biodiversity.

Introduction

Le Mali est un pays largement agricole (80% de sa population). L'agriculture s'exerce dans des conditions climatiques aléatoires avec des risques de sécheresse importants et parfois catastrophiques (1972–1973 et 1983–1984). La pluviométrie diminue du sud vers le nord si bien que l'agriculture pluviale comporte un risque qui est intégré dans les stratégies agricoles. La production agricole malienne subit en conséquence des fluctuations importantes de sa production vivrière principalement liée au démarrage de la saison des pluies (Traore et al. 2000). La production céréalière est principalement constituée par des cultures pluviales dans la zone agricole ayant une pluviométrie annuelle supérieure à 600 mm: le mil et le sorgho sont présents dans toute cette zone; le maïs est surtout présent dans les régions à plus de 900 mm de pluie par an.

Depuis plusieurs décennies, on assiste au développement très important de la culture du coton sous l'impulsion de la CMDT. En zone Mali-sud, l'augmentation de la fertilité des sols, conséquence de la fertilisation apportée sur le cotonnier entraîne, une demande importante pour l'intensification des cultures. Comme les performances des céréales locales sont faibles, le paysan se tourne vers le maïs considéré comme la céréale qui valorise le mieux l'arrière-effet de la fertilisation apportée sur cotonnier. La culture du sorgho diminue et se marginalise sur les sols les plus pauvres. L'érosion variétale qui en découle est importante (Kouressy et al. 2003).

Le présent article montre comment le potentiel de production du maïs est rarement atteint à la limite nord de son aire d'extension. Cette espérance de rendement fait encourir un risque élevé au paysan. L'analyse comparée des résultats techniques de cette culture avec le sorgho nécessite de bien préciser la position de la parcelle sur la toposéquence pour s'assurer de la faisabilité d'une telle comparaison (Criado 2002; Dembele et Kone 2003). Pour s'adapter à la fois aux contraintes climatiques et de disponibilité de main d'œuvre agricole, la gestion d'une palette de variétés de sorghos offre une souplesse de dates de semis (photopériodisme), et une souplesse d'adaptation aux différents environnements de l'exploitation agricole (rusticité) (Altieri 1999; Cleveland et al. 1994; Collins and Qualset 1999; Garcia-Barrios and Gonzales-

Espinosa 2002; Gollin and Small 1999; Savita et al. 2001; Schulze and Mooney 1994; Staveren and Stoop 1986). Cette écologie du sorgho répond bien à l'objectif premier du paysan qui est d'assurer un minimum de production quelle que soit l'année.(Bazile et al. 2003)

Matériels et méthodes

Dans le Mali-sud, on peut identifier quatre zones agroécologiques selon le niveau de concurrence qui existe entre les céréales traditionnelles (mil-sorgho) et le maïs (Kouressy et al. 2003). Dans le sud-ouest du pays (Bougouni), la culture du maïs est ancienne et domine celle du sorgho car les précipitations moyennes annuelles sont plus élevées que dans le reste de la zone cotonnière (1100 à 1400 mm). De même à Sikasso où la pluviométrie moyenne est voisine celle de Bougouni, on note une diversité des systèmes de culture avec la présence de tubercules (igname, patate douce, pomme de terre, etc.). Malgré une culture traditionnelle du sorgho dans cette région, la pénétration du maïs est très visible (Figure 1) dans les assolements depuis 5 ans et il est désormais plus cultivé que le sorgho et le mil. Dans les régions de Fana et de Koutiala, au centre et à l'est du pays, la pluviométrie est en moyenne de 800 à 1000 mm par an. Dans ces régions, la culture intensive de maïs présente un risque hydrique élevé. L'engouement des paysans pour l'intensification est tel que le maïs se développe malgré l'incertitude de rendement et une rentabilité non avérée.

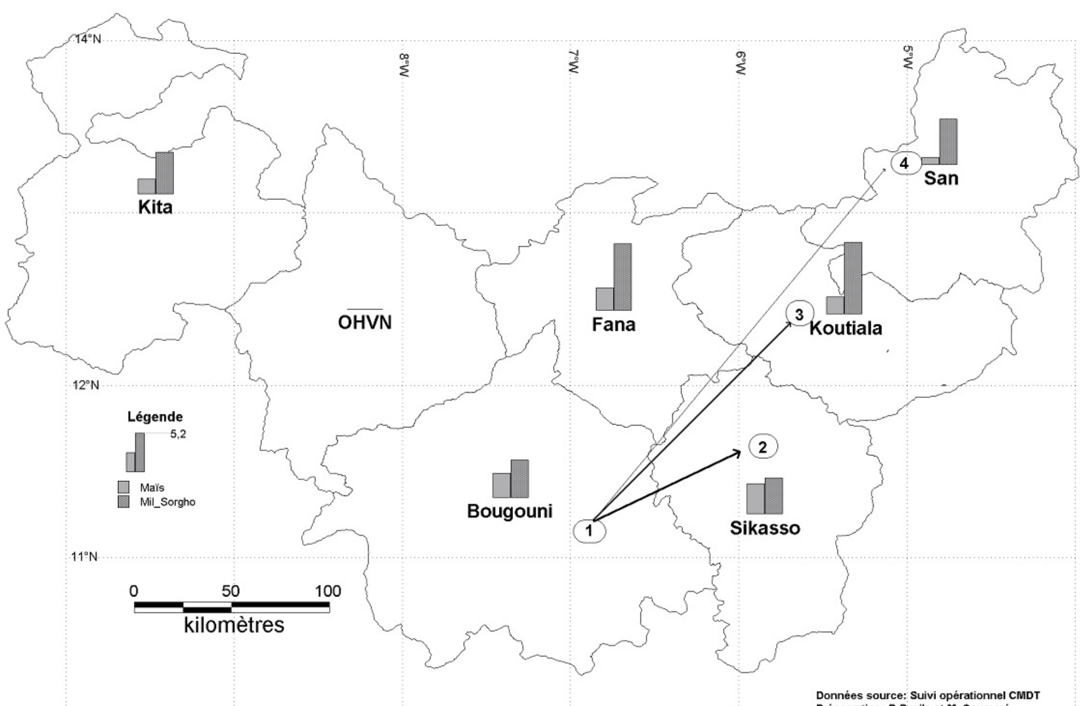


Figure 1. Extension de la culture du maïs depuis sa zone traditionnelle de culture.

Dans le cadre du projet « Agrobiodiversité du sorgho au Mali » (FFEM), un village représentatif de chacune des trois zones d'extension du maïs a été étudié mais nous ne présenterons ici que les résultats du village de Kaniko (15 km à l'est de Koutiala) qui marque bien la limite climatique nord pour la culture du maïs.

Une enquête exhaustive sur la structure des exploitations (N=91) a été menée en mai 2002. Une analyse factorielle des correspondances (AFC) a permis de caractériser les systèmes de production (Benoit-Cattin and Faye 1982) pour construire une typologie fortement orientée sur la place du sorgho dans les systèmes de culture (Giraudy et al. 1997; Perrot 1993). Trente-cinq exploitations choisies de façon raisonnée à partir de la typologie constituent notre sous-échantillon d'étude. Le parcellaire a été levé sur le terrain avec un GPS afin de déterminer précisement la surface cultivée et pouvoir localiser les parcelles dans le terroir. A cette occasion, la culture, la variété et la surface estimée de la parcelle par le paysan[3] ont été recueillies pour décrire l'assolement 2002. Un suivi détaillé de l'itinéraire technique [en cours de campagne agricole] de 92 parcelles de sorgho (77ha) et de maïs (78ha) a été conduit en retenant par exploitation toutes les combinaisons de variétés par type de sol (Tableau I, Figure 2).

Tableau I. Plan d'échantillonnage.

	Exploit-ations	Echantillon d'exploitations	Maïs		Sorgho	
			Variétés	Parcelles suivies	Variétés	Parcelles suivies
Kaniko	91	35	5	50	5	42

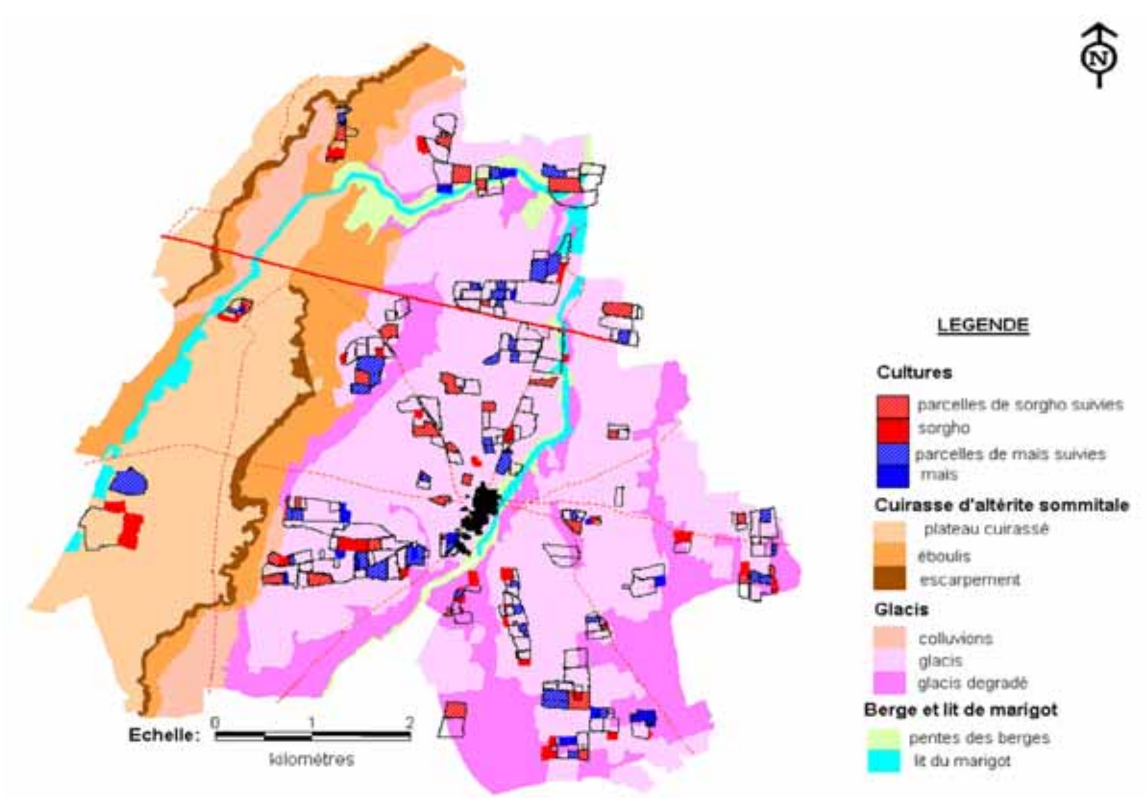


Figure 2. Village de Kaniko : Localisation des parcelles suivies en fonction des types de sol.

Résultats et Discussions

Le maïs dans les exploitations agricoles, un bon indicateur d'intensification

Le village de Kaniko est situé au cœur du vieux bassin cotonnier du Mali. 90% des exploitations sont équipées pour la culture attelée et ont accès aux intrants avec la culture du coton. L'analyse du système de culture montre que la surface en coton est bien corrélée à la surface totale (R^2 = 0,92). Cela signifie que la part du coton dans l'assolement est relativement constante pour Kaniko (30%). Même si le maïs reste très lié au coton dans la rotation suivant les recommandations de la C.M.D.T., il est intéressant de noter que le sorgho est semé à part égale avec le maïs derrière le coton. Les variables d'intensification (équipement et accès aux intrants) permettent de discriminer les 91 exploitations agricoles du village. Il apparaît qu'au sein des 3 classes de surface du maïs, on note une relation inverse entre l'âge du chef d'exploitation et la surface consacrée aux céréales traditionnelles (mil-sorgho) (Figure 3). L'accumulation de capital avec l'âge permet d'intensifier les pratiques agricoles.

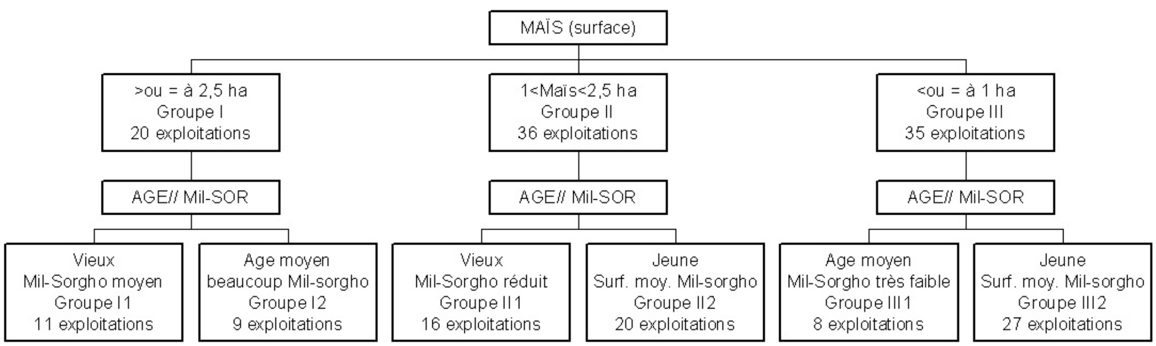


Figure 3. Typologie des exploitations de Kaniko .

Saturation de l'espace agricole et marginalisation du sorgho sur les versants

Les deux exploitations agricoles présentées à la figure 4 reflètent bien la stratégie générale d'assolement du village de Kaniko. Le maïs est cultivé sur les sols les plus profonds avec une richesse minérale élevée (présence d'argile et de limons). Le risque hydrique est toujours évité tant pour la sécheresse (sols drainants à fort taux d'éléments grossiers, pente marquée) que pour l'excès d'eau (sols à hydromorphie temporaire en bordure de marigot). Ces sols sont alors valorisés par les céréales traditionnelles (sorgho et mil) qui sont moins exigeantes et permettent du fait de leur rusticité d'avoir une espérance de rendement, certes limitée, mais quasi-certaine quelles que soient les conditions climatiques de l'année.

Cas de l'exploitation de Fousseyni A. SANOGO

L'exploitation agricole est morcelée en deux parties : cuirasse et glacis. Sur le glacis, les sols limono-argileux permettent la culture du coton et des céréales. Sur la partie de cuirasse, le fort pourcentage d'éléments grossiers des sols est défavorable aux cultures exigeantes en eau (maïs et coton). On note alors l'importance accordée à la culture du sorgho sur cette partie de l'exploitation. Le maïs y est malgré tout cultivé sur de petites parcelles avec des formes irrégulières qui doivent se superposer à des sols plus profonds (désagrégation de la cuirasse).

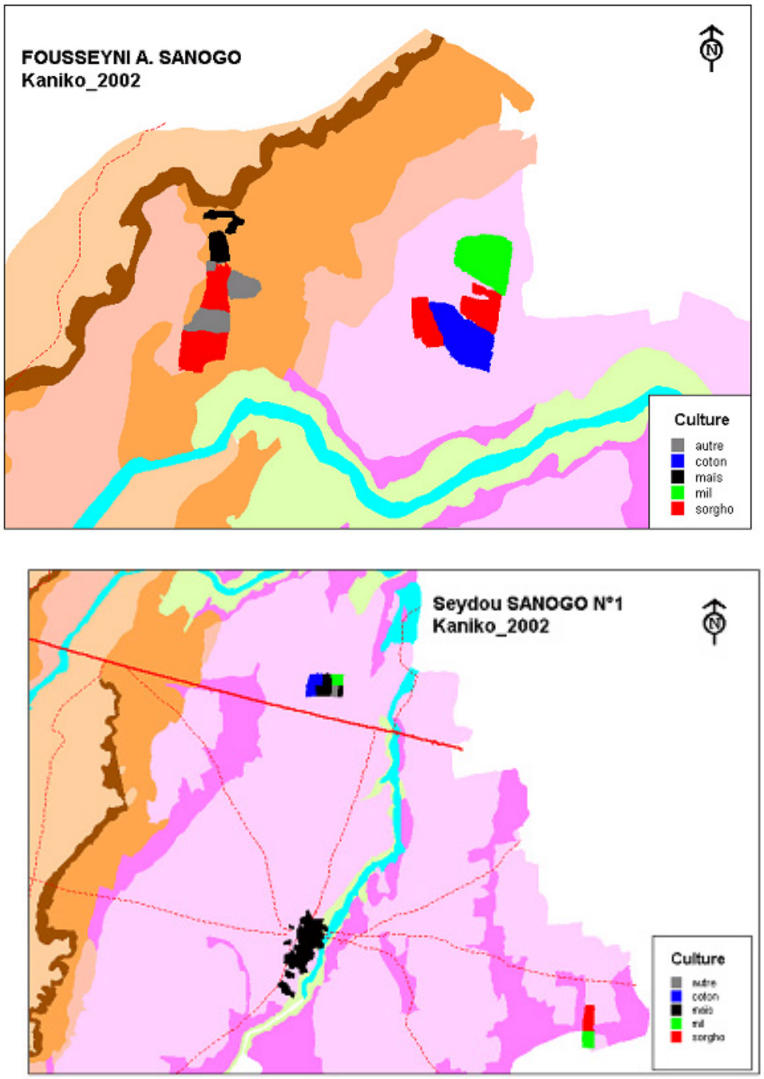


Figure 4. Stratégies d'assolement des exploitations de Kaniko.

Cas de l'exploitation de Seydou SANOGO n°1

Les meilleurs sols de l'exploitation sont réservés au maïs et au coton alors que mil et sorgho sont marginalisés sur les sols plus sableux avec une réserve hydrique et une richesse minérale moindre.

L'évolution de la productivité des céréales sur 20 ans donne un avantage très net au maïs dont les cultivars modernes rentabilisent bien les charges liées à l'intensification dès lors qu'il est semé sur les sols fertiles. Néanmoins, il y a lieu de s'interroger sur l'avenir avec la mise en valeur de moins bonnes terres pour l'agriculture lié à une saturation progressive de l'espace. En effet, même si le sorgho est marginalisé sur les versants et les plateaux cuirassés, la stagnation des rendements doit être considéré comme un critère de réussite en conditions difficiles.

Le maïs peut produire plus que le sorgho, mais à quel prix ?

L'analyse de variance ne permet pas de mettre en évidence de différence significative entre les rendements des parcelles de sorgho (k = 589 kg ha^{-1}) et de maïs (k = 780 kg ha^{-1}). Cela s'explique par une dispersion plus importante des rendements sur maïs (Figure 5). En effet, le nombre d'échecs sur maïs est considérable (20%). Cela tient à la fois au risque hydrique élevé mais aussi à la sensibilité du maïs à l'acidité (sur versants) et à l'exigence d'une bonne fertilité du sol. C'est pourquoi, il est couramment admis et conseillé de placer le maïs derrière le coton dans la rotation pour qu'il valorise l'arrière effet de la fertilisation apportée sur le cotonnier.

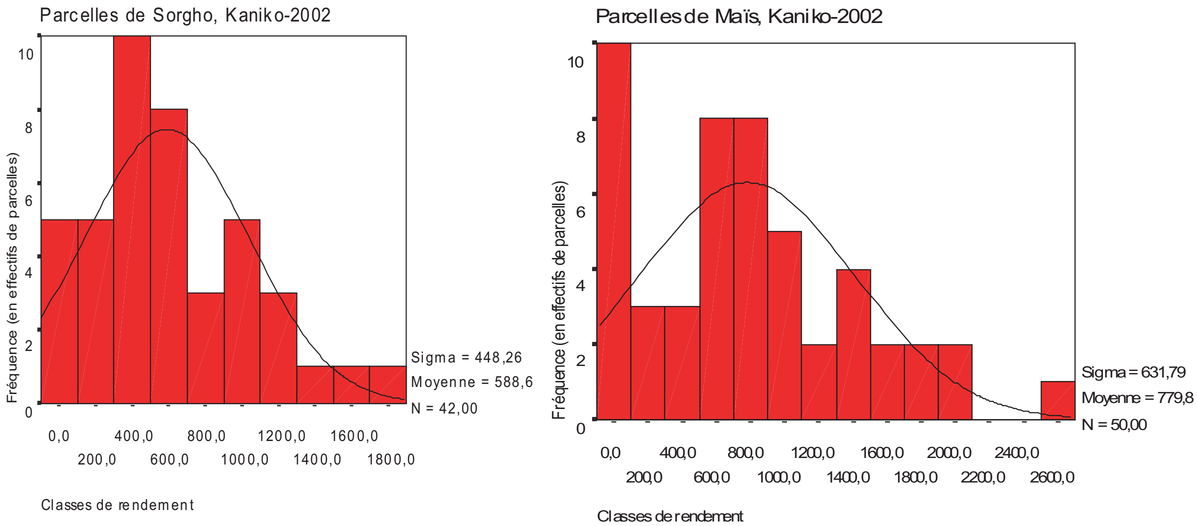
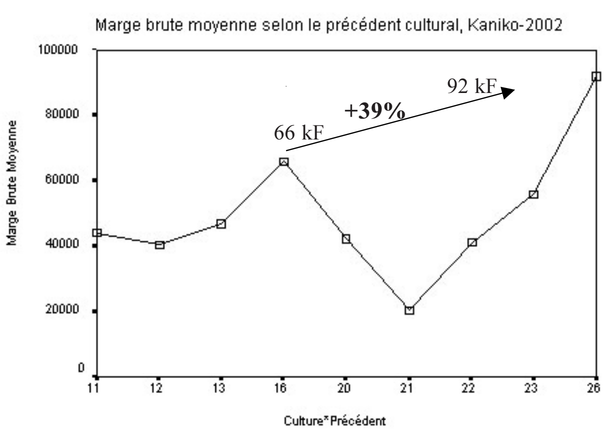


Figure 5. Distribution des rendements de maïs et de sorgho à Kaniko en 2002.

La rusticité du sorgho se caractérise par un regroupement autour de la moyenne alors que pour le maïs l'applanissement de la courbe de Gauss vers les forts rendements offre une probabilité de fort rendement [rarement atteint] que les paysans se fixent comme objectif de production. Cette courbe schématise bien le risque encouru par le paysan avec le maïs.

La production à l'hectare masque la rentabilité des différentes spéculations dans un système en voie d'intensification. En effet, 98% des parcelles de maïs bénéficient d'une fertilisation alors qu'une seule parcelle de sorgho (2,4%) reçoit de l'engrais. Le paysan doit donc raisonner à partir de la marge brute à l'hectare pour prendre en compte les charges en engrais et pesticides sur la parcelle (Figure 6).

Notre analyse montre que le maïs est le plus mauvais précédent quelle que soit la culture. Cela laisse supposer que la fertilisation apportée ne compense pas les exportations puisqu'elle



Code	Culture (N)	Précédent
11	Maïs	Maïs
12	Maïs	Sorgho
13	Maïs	Mil
16	Maïs	Coton
20	Sorgho	Autre
21	Sorgho	Maïs
22	Sorgho	Sorgho
23	Sorgho	Mil

Figure 6. Comparaison des marges brutes à l'hectare selon le précédent cultural.

laisse le sol à un niveau de fertilité plus bas que celui obtenu avec un précédent mil ou sorgho sans aucune fertilisation. Est-ce que la valorisation des pailles des céréales traditionnelles (très forte biomasse à l'hectare) permet d'assurer une production agricole plus durable qu'une agriculture intensive mal maîtrisée dont les intrants ne compensent pas les exportations ? La question mérite d'être posée surtout quand le rendement du sorgho avec un précédent coton est significativement différent du sorgho derrière une céréale alors que la différence de rendement n'est pas significative pour le maïs selon les différents précédents (céréales/coton) (Tableau 2).

Tableau 2. Analyse de variance sur les rendement (kg ha^{-1}).

	Culture (N)	Précédent (N^{-1})	N	Sous-ensemble pour alpha = .05	
REGPREC				1	2
211	Sorgho	Céréale	35	511,71	
111	Maïs	Céréale	8	547,50	547,50
16	Maïs	Coton	39	794,36	794,36
26	Sorgho	Coton	10		1044,00
Signification				,074	,156

Les moyennes des groupes des sous-ensembles homogènes sont affichées. F de Ryan-Einot-Gabriel-Welsch

Les moyennes des groupes des sous-ensembles homogènes sont affichées. F de Ryan-Einot-Gabriel-Welsch

On peut ainsi conclure que la rotation coton-sorgho est la stratégie qui valorise la mieux l'arrière effet de la fertilisation apportée sur coton puisque la Marge Brute à l'hectare est significativement différente du maïs et du sorgho avec un précédent céréale (Tableau 3). L'analyse des fréquences sur les parcelles avec un précédent coton (N=49) montre que dans le cas du Maïs, 60% des parcelles ont un rendement inférieur à 1 tonne à l'hectare alors que c'est l'inverse pour le Sorgho avec 60% des parcelles dont le rendement qui dépasse 1 t ha^{-1}.

Tableau 3. Analyse de variance sur la Marge Brute (Francs CFA ha^{-1}).

	Culture (N)	Précédent (N-1)	N	Sous-ensemble pour alpha = .05	
REGPREC				1	2
111	Sorgho	Céréale	8	44511,42	
211	Maïs	Céréale	35	45401,25	
16	Maïs	Coton	39	65908,57	65908,57
26	Sorgho	Coton	10	91937,68	
Signification				,154	,240

Conclusions

L'activité humaine, et en particulier agricole, est souvent perçue comme un facteur de dégradation de l'environnement. Pourtant, la diversité variétale entretenue par des générations de paysans offre l'opportunité d'exploiter différents faciès du milieu. Le potentiel des variétés traditionnelles est sous-exploité et il est important de bien évaluer cette diversité génétique pour qu'elle soit mieux prise en compte dans les schémas de sélection. Malgré des efforts croissants lors des prospections pour recueillir une information *in situ* sur les variétés, rarement celle-ci est analysée au même titre que les recherches menées sur les cultivars améliorés dans les stations agronomiques.

Les variétés traditionnelles de sorgho poussent dans une grande diversité d'environnements où elles sont stables et souvent plus productives que beaucoup de variétés modernes. La stabilité de la production du sorgho montre que le choix du maïs n'est pas toujours rentable, y compris après une culture de coton. Le paysan doit donc réfléchir sur le coût d'opportunité de ses céréales à la parcelle en s'appuyant sur la marge brute générée à l'hectare et non pas seulement sur un rendement potentiel.

Les centres de recherche agronomique essaient de répondre au problème de l'accroissement de la population mondiale en proposant des variétés à fort rendement. L'analyse de la richesse variétale des sorghos maliens montre qu'il est possible de s'appuyer sur les variétés locales pour proposer une alternative plausible dans un système céréalier en cours d'intensification.

Remerciements

Je tiens à remercier M. Cheick Tidiane DOUCOURE, service Suivi-Evaluation de la CMDT, pour l'accès aux données d'archives de 1974 à nos jours, les paysans de Kaniko pour leur disponibilité et, l'ensemble de mes collègues de l'IER pour leurs commentaires tout au long de ce travail.

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Enhancing the productivity and sustainability of integrated crop-livestock systems in the dry savannahs of West Africa

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Abstract

Traditional farming systems are breaking down as evidenced by shortened fallow periods and expansion of agriculture onto marginal lands. These changes result in lowered productivity and the emergence of unsustainable farming practices with potentially disastrous consequences for poor people, their food security and their environment. Although some technologies are available, they are not adopted by farmers due to high costs and unavailability of inputs. Alternative technologies involving cereals, grain legumes, ruminant livestock and improved agronomic practices in an integrated and holistic manner could be an appropriate response to ameliorating soil fertility, crop yields, feed quantity and quality for livestock. A multi-center, multi-disciplinary approach was implemented using farmer participatory research to understand and address the constraints faced by smallholder crop-livestock farmers in the dry savannas of West and Central Africa. The benefits of working together are at least additive, but synergistic effects are also anticipated. A pilot project was implemented in Kano State, northern Nigeria in 1998 and in 1999 this was expanded to include another site in northern Nigeria as well as sites in Mali and Niger. This paper describes the implementation, evolution and progress of a new approach to improving crop-livestock farming in the dry savannahs whereby best bet packages involving elements of crop varieties, crop geometry, soil fertility, residue and livestock management are assessed on-farm using a holistic strategy including biophysical and socioeconomic monitoring.

Introduction

Dry savannahs consist of the drier part of the Northern Guinea Savannah, plus the Sudan Savannah, and are defined as regions where rainfall is between 400 and 1200 mm per annum with a growing period of 90 to 150 days. The region represents more than 50% of the total land area of sub-Saharan Africa, with a significant proportion located in West and Central Africa (Figure 1). Given the length of growing period, the region experiences a long harsh dry season of

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7 to 9 months, which lengthens on a south-north axis. Soils are generally poor with low organic carbon, cation exchange capacity, and nutrients, especially nitrogen and phosphorus.

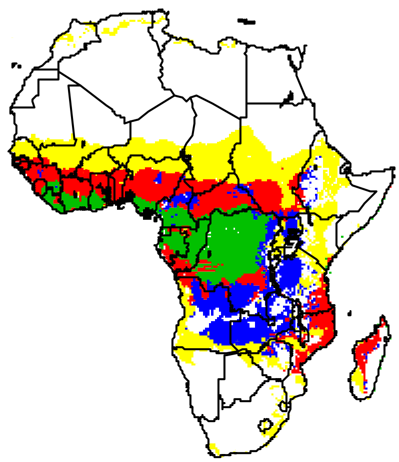

Figure 1. Map of Africa showing agroecological zones according to length of growing period. The yellow area shows the dry savannas (LGP 30 to 150 days).

Cropping is cereal-based, dominated by sorghum and millet, with the former decreasing in prominence towards the north. Intercropping cereals with grain legumes (cowpea or groundnut) is common in over 90% of fields and as well as grain, the residues from cropping, are important components of the farming systems. Ruminant livestock are also an integral part of the farming systems, with over 50% of the total ruminants of West and Central Africa found in this region (Winrock 1992; Grandi 1996). Cattle, sheep, goats and to a lesser extent camels provide milk, meat, traction, manure, and cash.

As with much of sub-Saharan Africa, in the dry savannahs, both human and livestock populations are high and increasing (Delgado et al. 1999) and are among the forces driving agricultural intensification resulting in reduced or absent fallow periods, and cropping on marginal lands. Such trends could, if unchecked, have potentially disastrous consequences for the food security of poor, small-scale farm families and the environment in which they live. Inputs such as chemical fertilizers, and pesticides, which may increase productivity in such systems, have limited use, mainly due to reasons of cost and availability. In this respect, technologies that maximize the benefits from these limited inputs, without detriment to the natural resource base, are very desirable. Simultaneously, it is recognized that crop-livestock systems, such as those operating in the dry savannahs, have among the highest potentials for increasing productivity in a sustainable manner. The development of alternative technologies involving cereals, grain legumes and ruminant livestock could be an appropriate response to ameliorating binding constraints to sustainable farming in the zone which include soil fertility and feed quantity and quality for livestock.

In the context of the pressures imposed by increasing population on evolving crop-livestock systems in the dry savannahs of West and Central Africa, there is a need to exploit and combine the comparative advantages of earlier component research carried out by international and national research institutions in the region to promote sustainable agricultural intensification. Complementarities between research on cereal and legume breeding and selection, animal traction, improved nutrient capture, socio-economics and livestock husbandry will enable positive synergistic impacts to be realized. This is a multi-institutional, inter-disciplinary approach implemented using farmer participatory research to understand and address constraints faced by smallholder farmers in the dry savannahs.

International and national research institutions that are working in the dry savannahs of West and Central Africa have developed improved crop varieties and management options for crops, soils, and animals. National research institutes in the participating countries have on-going component research that includes aspects of crop variety improvement, crop residue and manure management, development of fodder resources for ruminant livestock and livestock health. These institutions also have strong links to development and extension services, thereby facilitating dissemination to farmers. Within the international research institutions, there are very specific and complementary strengths. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has comparative advantages in the areas of crop improvement (pearl millet, sorghum and groundnut), cropping systems, farmer participatory research, and modeling; International Institute of Tropical Agriculture (IITA) has strength in socioeconomics, natural resource management and has active breeding programs for cowpea, maize, cassava and soybean. International Livestock Research Institute (ILRI) contributes to research on livestock production, including the role of livestock in income generation, nutrient cycling, crop residue quality and management as well as policy and institutional issues. Tropical Soil Biology and Fertility Institute of International Centre for Tropical Agriculture (TSBF-CIAT) and IFDC, an International Centre for Soil Fertility and Agricultural Development, have on- going research on integrated nutrient management, especially soil fertility improvement as well as related policy and input accessibility issues. Whilst all these international and national institutions have carried out research on these various components of the dry savannah farming systems, as related to their own area of expertise, a combined "whole system" approach has been lacking. It is this holistic strategy, combining the strengths of the various research components from all institutions, combined with the farmers' expertise that had been implemented. The benefit of working together will be at least additive, but synergistic effects are also anticipated.

The demand driven nature of this work is at least twofold, at the farming systems level and at the institutional level. Although in many parts of the dry savannahs, crop-livestock systems are already operating, agricultural intensification means that the pressure on these has increased, and ways need to be found to increase the output in a sustainable manner, without damaging the environment. Farmers themselves are the managers of complex whole farm crop-livestock systems and there is a need for research aimed at improving the productivity of such systems to be considered in the same, interactive environment, taking cognizance of biophysical and socioeconomic issues. Institutionally, the international and national research institutions with mandates in the dry savannahs have realized that unless their component interventions are directed towards whole systems, they are unlikely to have major impacts. Crop varieties with superior grain yield, but little fodder are unlikely to be acceptable; crop residue management that precludes its use for livestock fodder, fuel or building materials would not be a popular option with many farmers; likewise livestock management that does not optimize the benefits of traction or manure utilization. In this context, this multi-center collaboration targeting whole farm improvements, meets the demands of farmers, the evolving farming systems in which they operate, and the institutions concerned with the sustainable improvement of agricultural productivity.

The objective of this study is to enhance the integration of crop-livestock systems to increase farm productivity and livelihoods while conserving the natural resource base in the dry savannah of West and Central Africa. In this context, "best bet technologies" seek to address the needs of whole farm systems by combining components of crop varieties, crop geometry, integrated nutrient management, and livestock husbandry.

In the late 1980s, cowpea breeding research by IITA focused on developing high grain yielding varieties for the dry savannahs using pesticide sprays on sole cowpea fields (Singh and N'tare 1995). However, after several years, whilst this approach produced high grain yielding varieties, it was recognized that cowpea is rarely grown in isolation by farmers in the region. The crop is almost always intercropped with sorghum or millet and the farmers value the residue as livestock fodder as well as the grain for household use and income generation. As a result, scientists from ILRI began to work together with IITA scientists to consider the fodder value of the cowpea varieties (Singh and Tarawali 1997; Tarawali et al. 1997a), and researchers from ICRISAT provided input on the cereal components of the farming systems. The 'best bet' concept was developed by this consortium of scientists.

Materials and Methods

Trial establishment in Bichi, Nigeria

In 1998 the trial was established at just one location in northern Nigeria, in Bichi Local Government (8°19' E; 12°12' N) consisting of three adjacent villages Badume, Yakasai and Gangere. This site is about 50 km from Kano city, on a good road and classified as system 2 (Figure 2). It was selected because there was good information on village characterization (Ogungbile et al. 1999) resulting from a survey carried out by ICRISAT and Institute of Agricultural Research (IAR) scientists. Originally the intention was to use this survey dataset to define various groups of farmers so that representatives of each group could be selected to participate in the trial. However, after describing the aims of the trial to farmers from the village, just 11 volunteered to participate and provided land; it was therefore decided to work with these 11 for the first year. In 1999, an additional 13 farmers participated.

Three treatments were used:

- BB+: Cowpea variety: IT90K-277-2; sorghum variety: ICSV 400. Fertilizer: 100 kg ha^{-1} compound 15:15:15 (NPK) applied to the whole area at planting with an additional 60 kg N ha^{-1} split application of urea to the sorghum rows only 4 and 8 weeks after planting (total 75 kg inorganic N ha^{-1} to sorghum). Insecticide: Sherpa Plus (1 l ha^{-1}) sprayed twice on the cowpea rows only, at the time of cowpea flowering and again two weeks later. Sorghum and cowpea rows were planted in a 2:4 row arrangement.

- BB: Cowpea and sorghum as above, no fertilizer or insecticide.
- L: The farmers' own practice, using local varieties of cowpea and sorghum, with their row arrangement (usually widely spaced rows 1.0 to 1.5 m apart with a 1:1 cereal:legume row arrangement).

In 1999 the BB treatment was modified in response to observations and the farmers' reactions in 1998. Farmers were not happy with the "no input" treatment and in general the local sorghum performed similar to the improved variety. As a result, the BB treatment in 1999 included the same inputs as the BB+ treatment, but used local rather than improved sorghum.

All treatment plots received 3 t ha^{-1} of manure (1.6% N and 0.7% P) at the start of the growing season. Row spacing was 75 cm between rows with sorghum hills spaced at 25 cm and cowpea at 20 cm within rows. All operations, land preparation, planting, weeding, application of inputs, harvesting, etc were carried out by the farmers themselves with some technical guidance from technicians and scientists. In 1998 the inputs (fertilizer and insecticide) were provided at the onset of the experiment, and the costs of these recovered as grain equivalents at harvest time. In 1999, farmers paid for the inputs before the trial commenced.

Data collection

Prior to planting, bulked soil samples were collected from the top 20 cm of soil and analyzed for C, N and P. Plots were sampled at maturity; at the same time they were harvested by the farmers. Strings were used to mark out quadrats of approximately 5 m x 10 m randomly placed within each plot. Irrespective of the plot size, three of these quadrats were located in each plot. Within the quadrat, all cowpea pods were harvested, dried and threshed to get dry grain yield.

Sorghum panicles were cut, dried, threshed and the grain weighed. Sub samples of grain weighing approximately 100 g were ground and analyzed for N and P. In 1998, from the grain harvested within the quadrats, sufficient quantities of grain were retained to compensate for the cost of inputs. Biomass of both sorghum and cowpea were harvested by cutting and drying the remaining herbage after panicles and pods were harvested for grain yield determination. Sub samples (about 200 g) of the harvested biomass were oven dried to constant weight to estimate dry matter content and the dry samples ground and analyzed for N and P, the remaining biomass was returned to the field for complete drying. When the sorghum and cowpea residues were dry in the field, they were weighed, collected and stored in treetops or on house roofs prior to use in the feeding trial. Residues from different treatments were kept separately. Yields and quality estimates were compared using the MIXED procedure of SAS with farmers as random variables.

On farm livestock feeding

During the first part of the dry season, farmers usually release their small ruminants into the fields once the grain harvest is completed to enable them to graze any remaining crop residues as well as weeds. Once these resources are used up, usually by the middle of the dry season, the animals are tethered within the homestead and fed with the stored crop residues. The initial intention was to tether animals on the respective treatment plots early in the dry season, but farmers indicated that there would be no way to prevent other animals from grazing the plots also, as livestock roam freely once the crop harvest is complete. It was therefore decided to follow the farmers' usual practice and allow free grazing until the weeds and crop residue remains in-situ were used up. Harris (1998) reported that manure from free grazing animals is fairly insignificant at an estimated 17 kg ha^{-1}. Accordingly, the period for feeding the crop residues harvested from the present experiment began in early February in 1999 and early March in 2000, when the animals were confined to the compounds. By using estimates of 10 kg dry matter per TLU (TLU = Tropical Livestock Unit = 250 kg animal liveweight) per day for a period of 180 days the recommended liveweight of animals to be fed using the available residue was estimated. The 10 kg daily allowance was made up of a mixture of sorghum and cowpea residue in proportion to the available total weight of biomass of each component on a plot-by-plot basis. To assist farmers in providing the appropriate weights of fodder, a length of rope was provided according to the appropriate size of the fodder bundle. After weighing, the farmers' own animals were then allocated to treatment groups to give, as near as possible, the total required weight. At their suggestion, the farmers provided areas within their compounds where the animals were tethered. In those cases where one farmer had more than one treatment, the area was divided to separate different treatment groups. Animals were tagged, and tags, bowls for feed and ropes to tie the fodder were color coded according to treatment. It was recognized that for the L treatment, the fodder was unlikely to be sufficient and farmers were not prevented from providing their own inputs to animals on these treatments, once the material from the experimental plots had been used up. In these instances, the material provided, amounts and costs were monitored. Even for the animals on BB+ and BB treatments, some farmers opted to provide additional feed resources in the form of *dussa*, from millet or sorghum grain. *Dussa* consists of the testa of the sorghum or millet grain which is separated from the endosperm by soaking and then pounding and winnowing. In these instances, the quantities fed were estimated, and samples taken for analysis of N and P. The animals were weighed at the start of the feeding period and thereafter every two weeks. A hanging scale with a sling was used for weighing operations. Liveweight changes were compared using the REPEATED MEASURES procedure of SAS.

In order to keep the manure and residue refusals from different treatments separate during the feeding trial the intention was to collect the material in color coded sacks. However farmers discouraged this practice, indicating that the quality would be poor if the material was not allowed to accumulate in-situ, thereby encouraging capture of some nutrients from urine as well as trampling by the animals to ensure good mixing. Accordingly, manure and urine produced during the course of the feeding trial were allowed to accumulate in-situ, and kept in the treatment compartment, together with any feed refusals. At the end of the feeding period, in late May, samples of this manure/compost were collected for analysis of N and P. The manure/compost was applied to the same treatment plots shortly before planting in 1999.

Unguwan Zangi, Nigeria

Research at Unguwan Zangi began in 1999. Unguwan Zangi (8° 05' E, 11°15' N) was selected as a village in the Northern Guinea Savannah (NGS) and classified as system 2 (Figure 2); it had been surveyed as part of the characterization of the NGS benchmark area for the Ecoregional Program for the Humid and Sub-humid Tropics of Africa (EPHTA) for which IITA is the convening center. The survey implemented had provided village level information on characteristics relating to resource use intensity, and had been used to delineate four domains ranging from very intense with no fallow period (domain 4) through low intensity areas where fallow periods of up to 5 years are still present (Manyong et al. 1998). Unguwan Zangi was classified as medium to high resource use intensity, domain 3. Again, it was anticipated that subsequent information available at household level could be used to identify groups of farmers

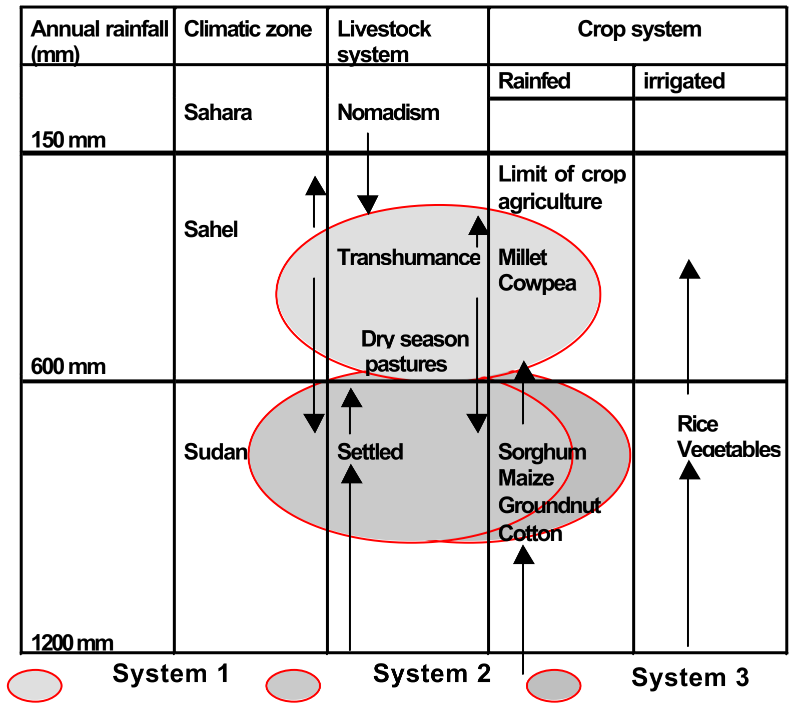

Figure 2. Schematic representation of major farming systems in the drysavannas, and the three systems identified for the present project. Note that systems 2 and 3 are overlapping. Figure adapted from Grandi (1996).

to participate in the trial but with 23 farmers volunteering to participate, it was decided to work with all of them.

Three treatments were used:

- BB+: Cowpea variety: IT86D-719; sorghum variety: KSV 8. Fertilizer: 100 kg ha^{-1} compound 15:15:15 (NPK) applied to the whole area at planting with an additional 60 kg N ha^{-1} split application of urea to the sorghum rows only 4 and 8 weeks after planting (total 75 kg inorganic N ha^{-1} to sorghum). Insecticide: Sherpa Plus (1 l ha^{-1}) sprayed twice on the cowpea rows only, at the time of cowpea flowering and again two weeks later. Sorghum and cowpea rows were planted in a 2:4 row arrangement.
- BB: Cowpea, fertilizer and insecticide as for BB+; local sorghum.
- L: The farmers' own practice, using local varieties of cowpea and sorghum.

Row spacing was 75 cm between rows with sorghum hills spaced at 25 cm and cowpea at 20 cm within rows. All operations, land preparation, planting, weeding, application of inputs, harvesting, etc were carried out by the farmers themselves. Inputs (fertilizer and insecticide) were provided at the onset of the experiment, and the costs of these recovered as grain equivalents at harvest time. Sampling, data collection, and on farm livestock feeding studies were carried out as described above for Bichi.

Characterization studies in Mali

In Mali, in the absence of previous characterization data on which to base the selection of research sites and participating farmers, it was necessary to develop and implement characterization studies in three regions identified as typifying the crop-livestock production systems. The three regions selected were Koulikoro, Fana and Ségou. Koulikoro (villages: Doumba and Djeni) has largely subsistence agriculture (mainly sorghum-based) with some settled and transhumant livestock; it could be classified as system 2 (Figure 2). Fana (villages: Zanguena and Wolodo) is more typical of system 3 (Figure 2) where cotton is present as a cash crop, in addition to both sedentary and transhumant livestock. Ségou (villages: Bakawere and Welenguana) has subsistence agriculture (mostly millet-based) although there is a tendency towards more commercial production of cereals and cowpea in particular. Livestock rearing is semi-intensive with some being extensive. Ségou could be classified as system 1, possibly evolving towards system 2 (Figure 2).

In each region, five villages were initially selected, and from these, two were chosen for detailed characterization and soil profile analyses with an average of about 30 Agricultural Production Units (APU) per village. Nine criteria were used for village selection, some of which were quite qualitative, and included aspects such as accessibility (infrastructure/roads), peace/social harmony within the village, population density, crop-livestock integration practices (such as, number of bullocks used for animal traction, etc), number of APU, number of bullocks per APU, willingness of farmers to participate in the project/study, geographical factors such as proximity to Bamako city and access to markets. Detailed questionnaires were administered in these villages and included discussions with groups of farmers, in the case of the characterization of the five villages; and with individual farmers or head of households in the case of the characterization of the APUs in the two villages in each region. These studies were carried out in close collaboration with extension agents operating in the respective regions.

The analysis of soil profiles was linked to the village characterization, and a GIS used to generate maps of each of the villages. Each soil profile was described, and soil samples were taken to a depth of about 100 cm and analyzed for N, P, pH, and organic carbon. The APUs were then linked to the identified/described soil profile.

Livestock feeding in Niger

Improved cowpea varieties (IITA – IT89KD-349 and INRAN – IN92E-3) were compared with local cowpea intercropped with local millet using the 2:4 (cereal:legume) row planting for BB treatments. The two cowpea varieties were used in two separate trials, with nine farmers participating in each.

Results and discussions

Bichi, Nigeria

Analysis of the soil samples from the farmers' plots before planting in 1998 indicated there were no significant differences between plots allocated to the different treatments in terms of pH, nitrogen, carbon or phosphorus contents (Table 1).

Table 1. Average soil parameters before planting. Bichi, 1998.

Plots allocated to treatment	pH	Nitrogen%	Organic carbon%	Phosporus Mg/kg Bray 1
BB+	5.2	0.029	0.23	5.21
BB	5.3	0.028	0.20	3.81
L	5.4	0.031	0.23	4.21
Probability	0.74	0.11	0.28	0.60

In 1998, all 11 farmers participated actively, and the trials were well established and maintained. One farmer had a plot on land that was severely eroded and another on an area of extremely low fertility; yields on these plots were as a result, reduced. Grain and fodder yields estimated from the marked quadrats are shown in Figure 3. Dry matter yields of sorghum fodder, cowpea grain and fodder were all highest in the BB+ treatment, although the improved sorghum fodder yield was not significantly different from the yield of local sorghum fodder. This was mainly because the local sorghum is very tall and has thick stems; it was estimated that only about 30% of the dry matter of the local sorghum was edible as compared to 60% of the improved variety, which has much thinner stalks. Farmers appreciated this difference and commented that the animals preferred the improved sorghum fodder. Sorghum grain yield was highest for the local treatment. For both sorghum fodder and grain, the yields of BB were less than those for BB+ or L. The most dramatic difference was in cowpea grain yield, where the BB+ treatment yielded more than double of BB and 16 times more than L. BB+ cowpea fodder yields were also more than BB or L (1.5 and 5 times, respectively). Actual fodder yields of both

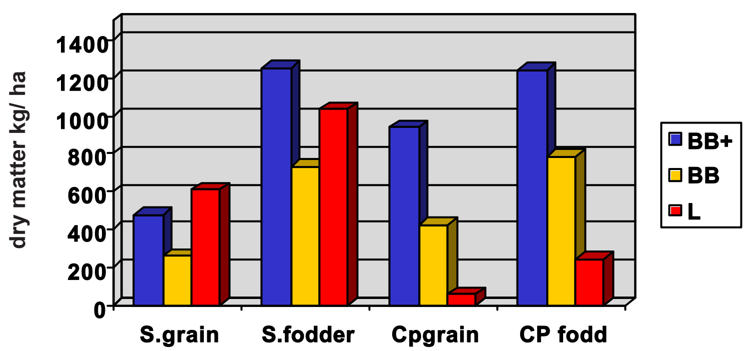

Figure 3. Estimated grain and fodder yields at Bichi, 1998.

sorghum and cowpea were considerably less (in some cases as low as 20%) than the estimated yields, when converted to kg ha^{-1} and these reductions were attributed to losses during transportation and storage of the fodder. This suggests that there may be opportunities for improving the best bet package if such fodder losses could be reduced.

One of the original intentions included within the BB treatments was to plant a second crop of cowpea after the first was harvested ("double cropping"). Previous experiments in the region had shown that if the first cowpea crop was harvested before the end of September and a second crop planted which received one or two rains, it was possible to harvest some grain and substantial amounts of fodder from this second crop (Singh and Tarawali 1997). Farmers' reactions and actions in response to this suggestion at Bichi varied and one of the factors that influenced this in 1998 was the weather. The rains, atypically, continued well into October. This meant that the farmers were reluctant to harvest fodder from the first cowpea crop because it would be spoiled by the damp conditions, furthermore, the first cowpea crop continued to produce pods and farmers were able to continue picking grain. One other factor was the farmers' need to use their family labor for pepper and tomato harvest around the same time as the field would need to be prepared and planted with the second cowpea crop. Nevertheless, a few farmers did plant a second crop, and obtained some fodder and grain (estimates of average 47 kg ha^{-1} grain and 260 kg ha^{-1} fodder of good quality). One farmer used some of the seed harvested from the first cowpea crop to plant almost 1 hectare of his farmland with a second crop of cowpea from which he obtained substantial yields (estimates of 600 kg ha^{-1} grain and 485 kg ha^{-1} fodder). In view of these varied reactions, when discussing the 1999 trial with farmers, the option of planting a second crop of cowpea was left open; in fact just one of the farmers opted for this and had a reasonable yield of high quality fodder (370 kg ha^{-1}). Farmers acknowledge at least three types of cowpea fodder quality with criteria of leafiness and greenness being the most important criteria for assessment. Such observations are in accord with quantitative measurements that indicate that late flowering varieties, which retain leaves late into the season and have better fodder quality (Tarawali et al. 1997b). Fodder from local sorghum (L) had plenty of biomass, but only 30% was edible by small ruminants, in contrast to the fodder from improved sorghum (BB+ and BB) where 60% was edible.

In 1999, average yields were slightly less than in 1998 (Figure 4), possibly due to the lower (but more typical) rainfall. Sorghum fodder yields did not differ between the three treatments, but grain yield for BB, where the local sorghum was used with fertilizer, was more than BB+ or L.

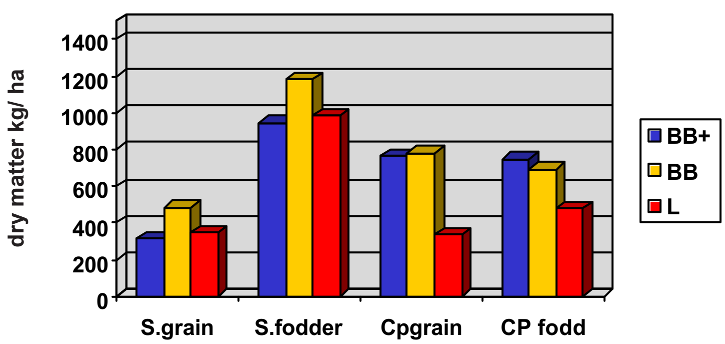

Figure 4. Estimated grain and fodder yields, Bichi, 1999.

Cowpea yields for BB and BB+, which did not differ in terms of variety or input, were not significantly different, but grain yield was more than twice L and fodder yield over 1.5 times.

Eight of the 11 farmers participated in the livestock feeding part of the trial. Assessment of animal liveweights indicated that animals receiving fodder from the BB+ treatment gained significantly more weight than the BB or L treatments during the last six weeks of the trial. Overall, the liveweight weight gain (averaged over all farmers) was 3.54 kg for BB+, 0.91 kg for BB and 2.19 kg for L (Figure 5). Manure quantities produced by the three treatments in terms of kg/TLU/day were not significantly different, and in terms of quality, N and P content for manure from BB+ treatments were slightly higher, but the differences were not significant. For BB+, BB and L, N

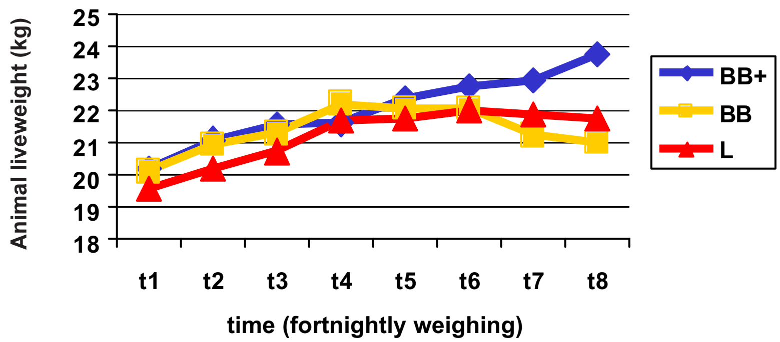

Figure 5. Average liveweight of small ruminants, Bichi, 1998

contents were estimated as 1.35, 1.09 and 0.80% respectively and P contents were 0.28, 0.27 and 0.25% respectively. Given the small number of farmers participating in 1998, and the plot-to-plot variation, these results should be viewed with some caution at this stage.

In terms of nutrient dynamics, whilst it must be stressed that the information available so far is very preliminary, and based on information taking mean values of just a few plots (n= 8 for BB+; n=8 for BB and 5 for L), Figure 6 indicates nitrogen and phosphorus inputs, outputs and balances for the first growing season at Bichi. Inputs were taken as the soil status at the onset of the trials (therefore including inputs during the previous dry season from, for example, grazing animals), the manure applied and the inorganic fertilizer. In the case of phosphorus, the Harmattan dust also contributes a small amount (Harris 1998). These figures are within the ranges found by Harris (1998,1999) for similar farmers fields in the Kano region and indicate that both nitrogen and phosphorus balances were positive at the end of the growing season, but

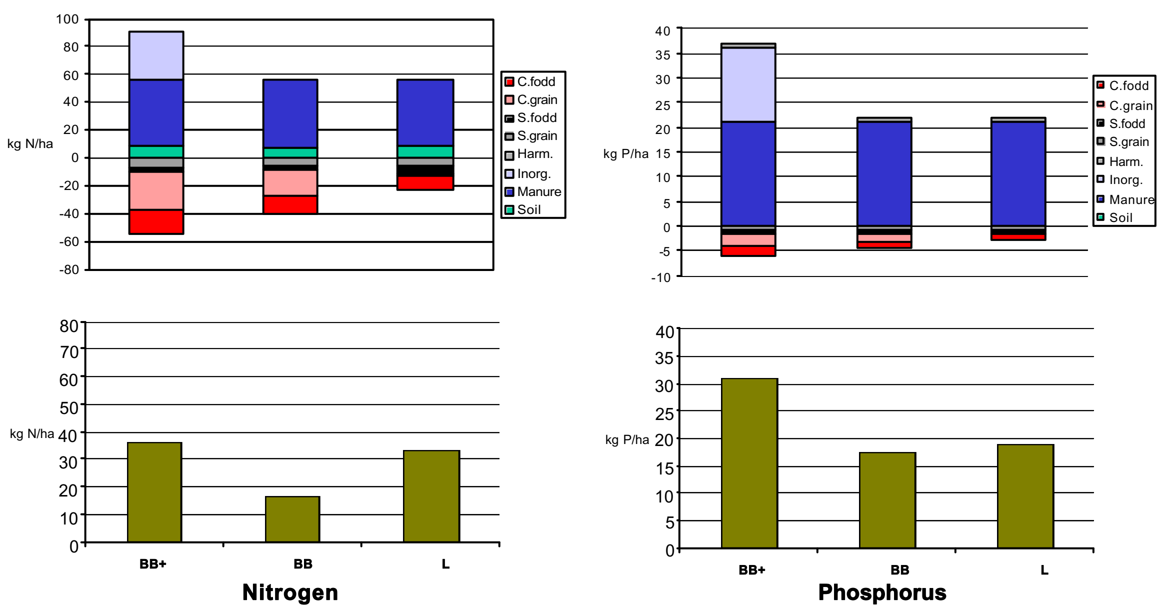

Figure 6. Estimated nitrogen and phosphorous inputs and outputs (upper graphs) and balances (lower graphs) for Bichi, 1998.

that the cowpea removed more nutrients – or used the applied nutrients more effectively, than the sorghum. Continuation of nutrient monitoring for several more cycles, including the returns to the system from the manure and crop residue refusals, removals from the subsequent crop harvests etc, are required to further elucidate these balances.

Unguwan Zangi, Nigeria

At Unguwan Zangi for cowpea grain yields, the BB and BB+ treatments (670 and 608 kg ha^{-1} respectively) were significantly higher than those of the L treatment (343 kg ha^{-1}). Despite this, farmers expressed some disappointment in the cowpea grain yields. This was related to their anticipation of a bumper harvest when the pods were immature on the plants in the field, but yields were subsequently reduced due to damage by pod insects (Murdock et al. 1997). The strategy to alleviate this in future years is to plant earlier and ensure the two sprays are timely; an approach that has been welcomed by the farmers who are excited by the potential they have observed. Planting earlier in this Northern Guinea Savannah environment will also enable the double cropping to be implemented to ensure good quantity and quality of cowpea fodder. In this particular region, this concept is not unfamiliar as farmers often plant an early millet variety between sorghum rows and then introduce a local fodder type cowpea after the millet harvest. Sorghum grain yields were also significantly higher for BB plots (1221 and 981 kg ha^{-1} for BB+ and BB respectively) than the local (560 kg ha^{-1}). BB plots also had considerably greater fodder yields than the L treatment, for both cowpea and sorghum (Figure 7). The farmers were all very pleased with the sorghum performance, and many indicated that they would begin using this on adjacent fields also.

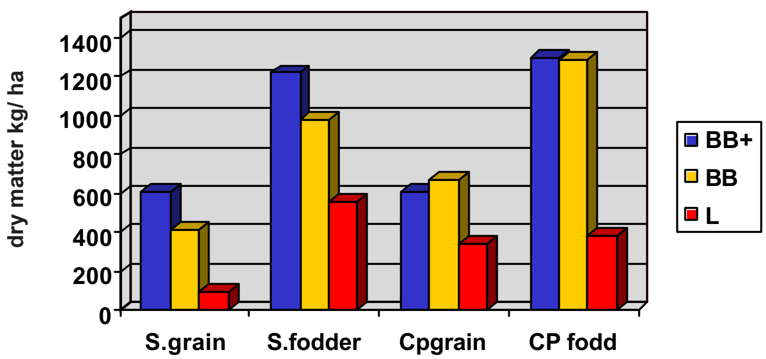

Figure 7. Estimated grain and fodder yields, Unguwan Zangi, 1999.

Mali

Dominant crops in the villages are shown in Table 2. Sorghum dominates in all except the Ségou region, where it is replaced by millet. Grain legumes, cowpea and groundnut, appear to be fairly insignificant in terms of land area, again, with the exception of the Ségou region, but this may be related to the fact that these crops are usually grown as intercrops, and therefore this classification on the basis of area may be, to some extent, misleading. The importance of cotton in the Fana region is clear, although it is also noted as 13% of the area in Doumba in the Koulikoro region. In Zanguena, it is apparent that maize is increasing in importance. Village level discussions with project scientists in the villages of Djeni and Doumba (Koulikoro region) and Zanguena (Fana region) largely confirmed the patterns of Table 2.

Table 2. Area (%) of total farmland occupied by various crops

	Koulikoro		Fana		Segou	
	Doumba	Djani	Zanguena	Wolodo	Bakawere	Welenguana
Millet	28	20	20	6	34	66
Sorghum	48	59	27	44	6	10
Maize	1	2	20	8	-	2
Rice	2	5	1	-	4	-
Cotton	13	5	20	30	-	-
Groundnut	4	7	7	2	5	4
Sesame	2	-	-	-	-	-
Forio	2	2	-	-	6	7
Cowpea	-	-	5	11	35	4
Woandzou**	-	-	-	-	10	7

Four types of farming systems (*type d'exploitation*) were identified, forming a gradient based on the degree of utilization of animal traction, as follows:

- Type A: Farms well equipped for animal traction, with at least one cart and a herd of 10 or more cattle, including a minimum of two pairs of traction animals.
- Type B: Farms with at least one pair of traction animals, but with a total of less than 10 cattle (including the traction animals).
- Type C: Farms not equipped for animal traction (often having incomplete equipment), but with awareness of the utilization (often through hiring from better equipped neighbors) of animal traction.
- Type D: Farms where only manual cultivation is practiced. Lack of awareness of animal traction.

An example of the distribution of soil profiles and the GIS maps generated for each region are presented for the Fana region in Figure 8. In general soils in the regions of Koulikoro and Fana are low in organic carbon and P; they are also acidic.

Niger

In general, the cowpea yields were extremely low with respect to both grain and fodder, and the local was better than the two improved varieties. Feeding trials have just been completed (on farm, using rams) using only the local cowpea fodder as a supplement at various levels. Interestingly, whilst supplementing with 300 g day^{-1} dry cowpea fodder had a significant effect on liveweight gains, no further increase in liveweight gain was noted with daily cowpea supplements over this amount, up to 900 g day^{-1}.

Conclusion

Institutionally, scientists from different disciplines have gained an increased awareness of the relationship of their research areas to other aspects of production systems. No longer is it

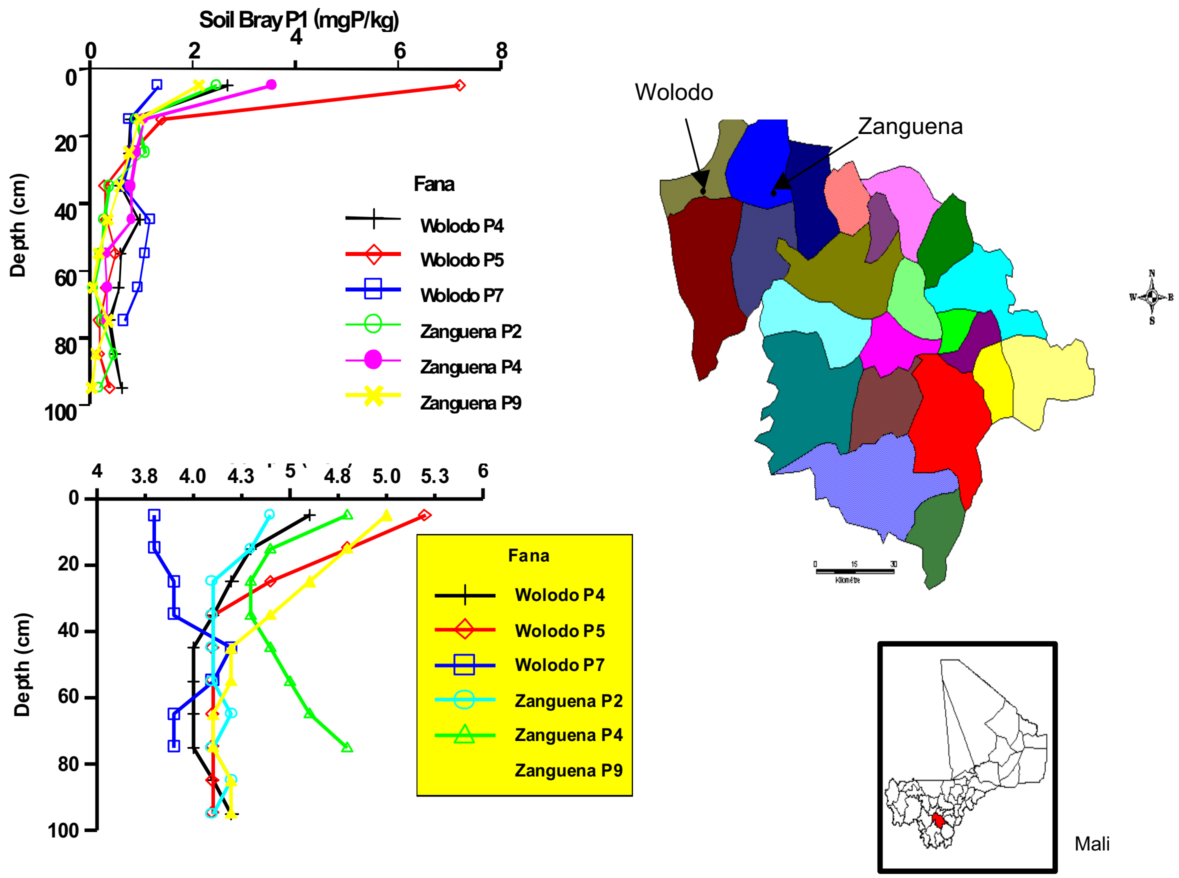

Figure 8. Map of the region of Fana showing the two villages of Wolodo and Zanguena and the communes (districts). The graphs on the left show information on the soil profiles from the two villages relating to phosphorus content (upper graph) and pH in KCl (lower graph).

possible to work on component research – crop breeding, livestock feeding, nutrient management, etc in isolation. In Niger, the crop varieties in the best bet package were in fact, not superior to the farmers' local, resulting in the potential of a best bet package with farmers' varieties combined with other elements and emphasizing the need to consider fodder as well as grain yield as part of variety selection. At Bichi, whilst the local sorghum yielded as much as the improved variety in terms of quantity, farmers clearly indicated a preference for the improved variety in relation to the fodder quality. It is also necessary to stress that the aim is to evaluate a best bet package, not only in terms of yields of crops or livestock production, but economic value, feasibility for the farmer to implement and implications for nutrient management. A best bet package that produces very high yields of grain and fodder in the first year, but is uneconomical, places unrealistic demands on farm labor, or results in nutrient mining in the long term, would not be appropriate.

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The sahelian eco-farm

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Abstract

The Sahelian Eco-Farm (SEF) is an integrated agriculture production system that provides simultaneous solutions to the main constraints of Africa's rain-fed agriculture. These are: soil erosion, low soil fertility, low water use efficiency, droughts, insufficient supply of animal feed, low income, and inefficient distribution of the labor force.

The SEF is an alley cropping system in which trees and/or shrubs are intercropped with annual crops. The first SEF model under development is composed of Acacia colei *trees, domesticated* Ziziphus mauritiana *called* Pomme du Sahel *(PDS) and three annual crops (millet, cowpeas and Roselle).*

Soil erosion by water is prevented by the construction of earth bunds combined with micro-catchments every thirty meters down the slope. PDS trees are planted inside each micro-catchment. Erosion by wind is prevented by the wind breaking effect of the Acacia colei *trees and by mulch produced from the Acacia branches and phyllodes.*

Acacia colei trees play a major role in soil fertility enhancement. The trees are pruned once a year and their branches are spread over the field adding organic matter to the soil. Tree roots add organic matter and fix atmospheric nitrogen. Soil fertility is also enhanced by crop rotation.

Water use efficiency (WUE) is increased due to the reduction of water run-off resulting from higher rates of water infiltration induced by mulching, the improved soil porosity, and through the reduction run-off water by the combined earth bunds and micro-catchments structures. Trees that utilize residual moisture and water from depths beyond the reach of annual crops roots, and the higher biomass production by the annuals and perennials further improves WUE.

The SEF provides a greater amount of animal feed, than the conventional systems, deriving from the greater biomass produced by the annual crops, the incorporation of dual purpose (grain/forage) cowpeas varieties, the Roselle leaves, PDS leaves and A. colei *seeds.*

The incorporation of fruit and edible seeds-producing drought tolerant trees mitigate the effect of droughts. Trees are less sensitive to the advent of dry spells and lower water availability than annual crops.

It is estimated that the combined profit per ha from all the SEF components is ten times higher than the profit derived from a millet field.

The SEF model under study utilizes farm-labor eleven months of the year as compared with traditional systems that provide labor for only four months of the year.

The SEF is still at an experimental stage. This paper presents the rationale for the development of the SEF and reports the results of a few diverse studies that were carried out to support the SEF system.

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Introduction

The Sudano-Sahelian zone is a strip of land about 600 km wide and more then 6,000 km in length stretching south of the Sahara desert from the Atlantic to the Indian Ocean (Le Houerou 1989). The borders of the Sudano-Sahelian zone are defined by the 300 mm rain isohyets in the north and the 800 mm rain isohyets in the south. The climate of this region is typified by a monomodal precipitation pattern with a short rainy season of 3-5 months and a dry season of 7-9 months (Bationo and Buekert 2001).

The agropastoral system of this region is based on two main coarse grains; millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) intercropped many times with cowpeas (*Vigna unguiculata* L. Walp). Ruminants are raised on pasturelands (normally degraded agricultural lands) and on crop residues.

The Sudano-Sahelian agropastoral system is characterized by a very low level of productivity that results from an inherent poor soil and from a severe, human induced land degradation process. Frequent droughts also contribute to low productivity. Average grain yields are very low. For example average sorghum yield in Niger is 300 kg ha^{-1} compared with 4,000 kg ha^{-1} in the USA (Lal 1988).

Soil erosion is the main reason for land degradation. Land clearing for agricultural use combined with overgrazing and utilization of all crop residues leave the land bare and susceptible to erosion inducing elements. Water erosion is more common in the Sudano region where alfisols dominate the landscape whereas wind erosion is the dominant factor in the Sahelian region where entisols are more common. The very strong monsoonal storms, typical to the region, result in considerable run off and soil erosion (Kowal and Kassam 1978). The strong impact of the rain drops on the soil results in soil surface crusting, reducing infiltration rates and further accelerating run off and soil erosion (Morin 1993). Soil loss ranging between 10 - 40 t ha^{-1} $year^{-1}$ due to water erosion is common on cropped lands of the Sudano region (Lal 1988; Bationo et al. 1996).

Soil erosion by wind can be even greater than soil erosion by water. Buerkert et al. (1996a) measured absolute soil loss of 190 t ha^{-1} in one year on bare plots as opposed to soil deposition of 270 t ha^{-1} on plots with 2 t ha^{-1} millet stover mulch. Sterk et al. (1996) calculated that 45.9 t ha^{-1} of soil was lost at Sadore, Niger during four storms in 1993. The corresponding loss of N was 18.3 kg ha^{-1}, of P it was 6.1 kg ha^{-1} and 57.1 kg ha^{-1} for K. Reduction of soil erosion can be more effective in reducing nutrient losses than additions of costly fertilizers, compost or manure.

Africa's soils are derived from old, highly weathered landscapes that are inherently poor in nutrients which is expressed in low levels of organic carbon (generally less than 0.3%), low total and available phosphorus and nitrogen, and low effective cation exchange capacity (Bationo and Mokwunye 1991). In the Sudano-Sahelian region farmers do not fertilize the soil and the result is soil "nutrient mining" at a serious scale. Stoorvogel and Smaling (1990) reported average negative annual budgets of 22 kg ha^{-1} of N, 7 kg ha^{-1} of P and 18 kg ha^{-1} of K in Burkina Faso. Sandy soils lose their carbon and nitrogen contents within the first two years after beginning of cultivation. Thus a continuous supply of nitrogen and carbon to these soils is a prerequisite for the maintenance of soil fertility.

A major constraint for crop production in the Sudano-Sahel is inadequate water supply. In many instances however, rains provide adequate quantity of water for optimal crop production but this water is lost through runoff, evaporation from bare soils, and deep percolation beyond the rooting zone of the annual crops (Fox and Rockträm 2003). The low dry matter yields resulting from poor soil fertility and water insufficiency markedly reduce crop water use efficiency.

Droughts are a permanent feature of the Sudano Sahelian climate (Sivakumar 1991). The coefficient of variation of monthly rainfall is very high in the beginning of the rainy season, in May – June, and at the end of the season, in September and October. Crop failures due to dry spells can be as severe as crop failures from lower total annual rainfall.

Livestock population in Africa increased from 295 animal units in 1950 to 515 million in 1983 (Brown and Wolf 1985). In the Sahel, animal feed is available during seven months of the year but it is severely limited between the months of February and July (Abouda 2001). The lack of animal feed results in significant animal weight loss towards the end of the dry season negating all the gains during the July-February period.

The price of grains, the main product of present day systems, is about US$0.1 kg^{-1}. An average farmer can cultivate a maximum of 4 hectares giving a gross income worth US$120. According to an IFPRI report (Pinstrap-Andersen et al. 1999), these low international prices for grains will persist until the year 2020 and beyond. The prices of cowpea grains are higher than the prices of cereal grains; however in general, cowpea yields are only 10% of potential due to the fact that farmers do not spray against cowpeas insects (Franks et al. 1987).

In the Sahel, human labor is the most underutilized resource. Farm work is available only during the 100-120 days of sorghum and millet production and even during this short period of activity, the return per work is very low because of the low current prices of grains. In many places farmers migrate to cities during the dry season in search of seasonal labor. Others just wait idly until the advent of the following rainy season.

The problems of the rain-fed Sahelian systems can be solved only through an integrated approach in which all the limiting factors are simultaneously addressed. Solutions of single problems without addressing other existing constraints are doomed to fail. For example, farmers will be able to purchase farm inputs such as chemical sprays and fertilizers or to address soil erosion problems only after the net income from the land will increase significantly. The use of high yielding varieties cannot be materialized under low soil fertility conditions. The use of chemical fertilizers without addressing the problem of soil erosion will eventually result in total soil degradation.

Description of the Sahelian Eco-Farm

The Sahelian Eco-Farm is a rain-fed production system that provides simultaneous solutions to the major constraints of the rain-fed system.

The model under investigation is comprised of the following components (Plate1),

- A hedge of *Acacia colei*, planted at 2 meters spacing surrounding the field.
- Trees are planted down the slope in units of three rows; two rows o f *A. colei*, followed by a row of the domesticated *Ziziphus mauritiana* called Pomme du Sahel (PDS). Spacing is 10 m between rows and 5 m between trees in a row.
- Pomme du Sahel (PDS) trees are planted inside 3m wide and 3m long micro-catchments connected by 2m wide earth bunds.

• Three annual crops are planted among the trees. Millet, dual-purpose (grain and forage) cowpeas and Roselle. The annual crops are rotated annually.

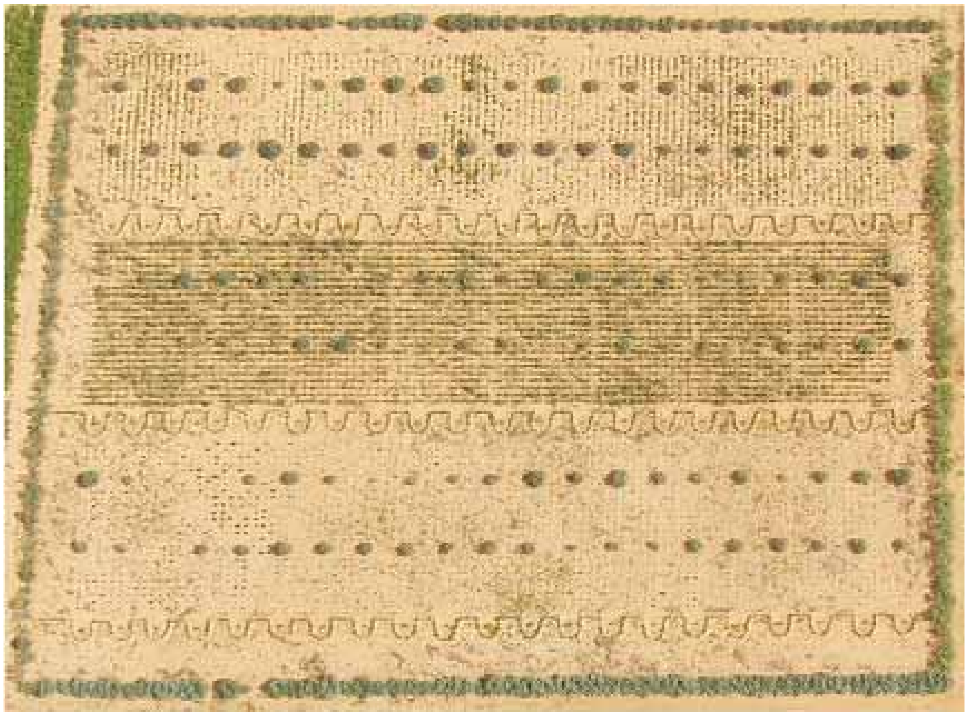

Plate1. An aerial photograph of the SEF.
Note: *A. colei* fence and sets of two rows of *A. colei* followed by a row of *Pomme du Sahel* planted inside micro-catchments. Top one-third planted with cowpeas, center with millet and bottom one-third with Roselle.

Global services of the SEF components

• The *A. colei* hedge can become impermeable to farm animals by reinforcing it with dry spiny branches from PDS.
• *A. colei* trees are pruned once a year (at a height of 1.0m) before the rainy season to produce firewood and mulch (phyllodes and small branches). Mulch provides the following services, (a) Prevention of crust formation thus increasing rainwater infiltration, (b) Impediment of soil erosion by wind and water, (c) Addition of organic matter to the soil and (d) Prevention of soil surface heating during annual crops germination and establishment. Large *A. colei* branches can be later collected to provide firewood. Pruning of Acacia trees just before the rainy season eliminates potential competition for water and light between the trees and the annuals, which are planted between the trees. Top pruning results in root death thus providing organic matter to the soil. Acacia phyllodes are not palatable to animals and are therefore not collected by farmers or eaten by animals (as is the case of crop residues) during the dry season. Labor requirement for carrying the mulch is minimized by the fact that the mulch is spread in a 5-10 m circle around each tree. *A. colei* seeds are rich in crude protein (24%) and are therefore a valuable feed source for chicken and other fowl. *A. colei* roots fix atmospheric nitrogen.
• The micro-catchments reduce water and soil loss from the field while harvesting water for the PDS trees.

- The PDS trees provide nourishing fruit, forage, spiny branches for fencing and firewood.
- Roselle provides income from the sale of dry calices and seeds, forage from its leaves, and raw material for ropes, firewood, and mulch from the dry branches.
- Double purpose cowpeas provide valuable protein for the farmer's family, forage for his animals, and income from sales. Cowpeas also fix atmospheric nitrogen.
- Millet provides carbohydrate, protein and animal forage.

Rotation among the three annual components ensures maintenance of high soil fertility and reduction in the population of parasites such as striga and of soil nematodes and pathogens.

Economic and socioeconomic services

- Simultaneous planting of five income-generating crops in a single field mitigates risks of crop failures as compared with mono-cropping systems.
- Mitigation of drought effects - Perennial crops (trees and shrubs) are less sensitive to droughts (imposed by dry spells or by a general low rainfall year) as compared with annual crops.
- The higher yields that result from improved soil fertility and higher water use efficiency result in higher income as compared with the conventional systems.
- The incorporation of income generating crops increases profits (Figure 1).
- A higher biomass production coupled with the addition of feed crops results in higher animal feed production.
- Labor and income distribution - The SEF provides employment for 11 months and income during 8 months of the year. The SEF yearly work calendar is as follows: Annuals are sown in June and weeding and spraying are carried out till September. Millet is harvested in September, cowpeas in October, Roselle in November, PDS from December to March, *A. colei* seeds are harvested in March and pruning of *A. colei* and PDS is carried out in May.

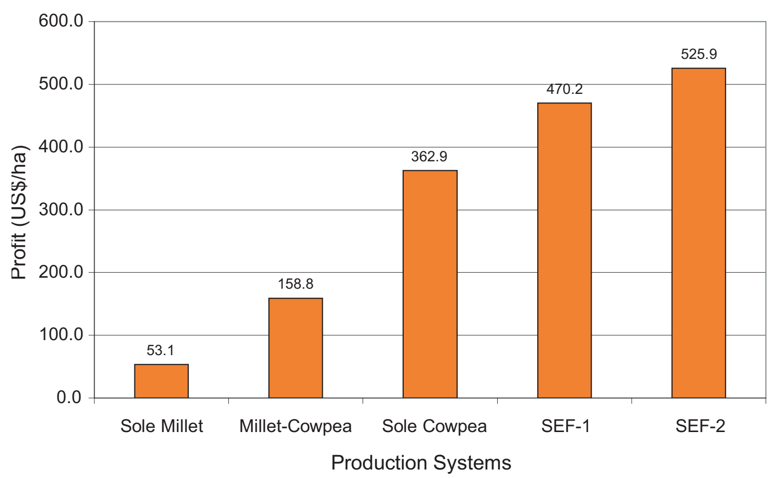

Figure 1. Profits per ha of three production systems in the Sahel. Millet only, cowpeas only and the SEF.

Data obtained from on-station research.

Environmental services

- Arresting soil erosion.
- Build up of soil fertility.

- Provision of firewood thus reducing pressure on natural resources.
- Diversification of micro-fauna due to increased number of trees and enriched soil organic material.
- Reduced use of chemical fertilizers and chemical sprays.

Results and discussions

First research results

On station research of the SEF started in the 2002 rainy season. On farm research with eight pilot farmers started in 2003. This is a long-term study that will require a minimum of five years to complete.

The development of integrated systems starts with the study and the perfection of each of the subsystems involved and continues with their integration into the SEF.

We are reporting here the first results of four studies of individual subsystems of the SEF. They are as follows,

1. Substitution of conventional protein sources by *A. colei* seeds in the diet of broilers.
2. Jatropha oil - an effective insecticide against cowpea pests.
3. Agro-management of Roselle.
4. Effect of termites on the rate of disappearance of *A. colei* mulch.

1. Substitution of conventional protein sources by Acacia colei *seeds in the diet of broilers.*

Sahelian countries normally use two sources of protein in chicken rations: groundnut cake (10%) and fish meal (10%). A broiler feeding trial was conducted to verify whether *A. colei* seeds that contain about 24% crude protein could substitute part of the protein sources in the diet of broilers. Treatments were:

- Control-commercial broiler feed.
- Substitution of 50% of fish meal by *A. colei* seeds.
- Substitution of 75% of fish meal with *A. colei* seeds.
- Substitution of 50% of groundnut cake by *A. colei* seeds.
- Substitution of 75% of groundnut cake by *A. colei* seeds.

Broilers weight gains over a 70-day period are given in Figure 2. *A. colei* seeds could substitute 50% of either fish meal or groundnut cake without affecting broiler weight gain. The price of fish meal in Niger is about US$2.0 /kg. *A. colei* seeds can be sold at 10% of this price. Sale of *A. colei* seeds to chicken feed producers can introduce a new source of income for farmers practicing the SEF.

2. Jatropha oil - an effective insecticide against cowpea pests.

In West Africa cowpea grain yield is around 300 kg ha^{-1}. This is in marked contrast to yields over 2000 kg ha^{-1} that are obtained on research stations (Ntare 1989; Reddy et al. 1992). A major reason for these low yields lies in the fact that farmers normally do not spray the cowpeas against insect pests that attack this species. The damaging effects of insects during grain storage are no

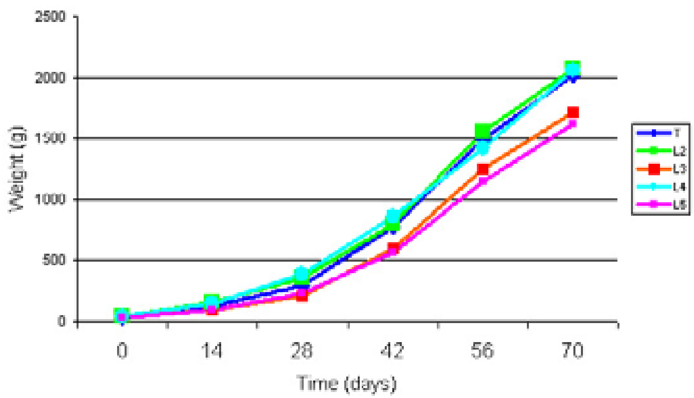

Figure 2. Weight gain with time of broilers fed with various rations containing different sources of protein.

T= Control: 10% groundnut cake + 10% fish meal

L2: 5% groundnut cake + 5% *A. colei* seeds

L3: 3% groundnut cake + 7% *A. colei* seeds

L4: 5% fish meal + 5% *A. colei* seeds

L5: 3% fish meal + 7% *A. colei* seeds

less severe than insect damage caused during plant growth. Caswell (1984) demonstrated that under traditional grain storage practices and after eight months of storage the proportion of grains with one or more holes was as high as 82%.

Jatropha curcas Linnaeus is a shrub belonging to the Euphorbiaceae family. It has its origins is Central America. It is cultivated in the tropics of most continents (Gübitz et al. 1999). *J. curcas* is a succulent drought tolerant species that sheds its leaves in the dry season. Solsoloy and Solsoloy (1997) have conducted the most comprehensive study on the action of *J. curcas* oil as a multi-purpose insecticide. The formulated crude oil had contact toxicity to corn weevil and bean weevil and deterred their oviposition on corn and sprayed mungbean seeds. The oil extract was able to effectively control cotton bollworm and the cotton flower weevil.

Figure 3 shows the effect of Jatropha oil concentration on grain yield of cowpeas. A 7.5% concentration of *Jatropha* oil was as effective against cowpea pests as a commercial insecticide.

The results of the above study indicate that the incorporation of *Jatropha curcas* shrubs in the SEF could provide low cost, effective and affordable insecticide for the control of cowpea pests.

3. Agro-management of Roselle.

Roselle (*Hibiscus sabdariffa*) is an annual herbaceous plant widely grown in the Sahel. Farmers normally plant Roselle in small plots in the periphery of their millet fields. The dried succulent calices of this plant are used to produce a drink called *Bissap*. In many countries Roselle calices are used in herbal teas and as a natural food colorant. A recent USAID-Mali market survey showed that the international market for dried Roselle calices is worth more then US$120 million per year. Roselle calices produced in the Sudano-Sahelian country receive double the prices than Roselle produced in tropical countries. Seeds are used to make sauces. Roselle leaves are highly nutritious for ruminants. Stems are used for production of ropes and as firewood.

A series of trials were conducted in order to evaluate yield potential of Roselle under good management conditions. In this study we compared the effect of planting density on the

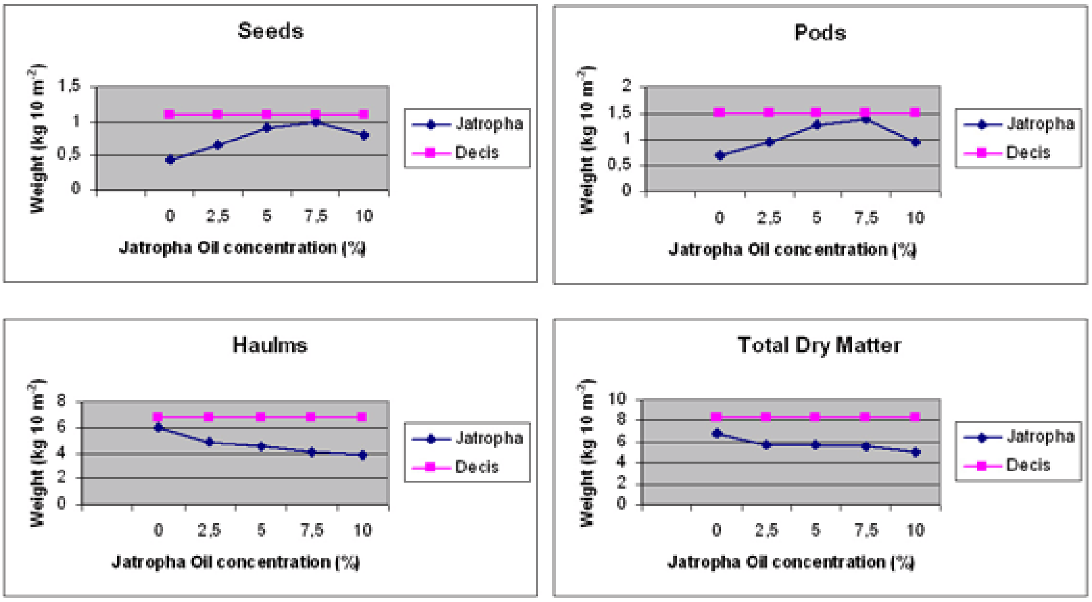

Figure 3. Effect of six concentrations of Jatropha oil spray on cowpeas grain yield. Horizontal line gives yields of cowpeas sprayed with a commercial chemical insecticide (Decis).

performance of three varieties. Results are given in Table1. Dry calices yields were as high as 500 kg ha^{-1}. There were no significant differences in calyx yield between the three tested varieties but the Tanout variety, an early maturing variety, produced higher grain yields as compared with the two other varieties.

Table1. Yield Parameters (in kg ha^{-1}). and Days to Harvest for Three Roselle Varieties. Means of 3 densities (0.5x0.5; 0.5x1.0;1.0x1.0m).

Yield parameters	Roselle Variety		
	Niamey	Senegal	Tanout
Days to harvest	118	124	103
Calices	451	499	487
Grain	444	343	614
Significance (p = 0.05)	S	NS	S

NS =Not Significant, S = Significant

4. Effect of termites on the rate of disappearance of Acacia colei *mulch.*

Termites are effective decomposers of dry organic matter (Mando and Stroosnijder 1999).

A trial was conducted to appraise the effect of termites on the decomposition of *A. colei* mulch. The following treatments were imposed,

1. *Acacia colei* mulch. No pesticide.
2. Millet mulch. No pesticide.
3. *Acacia colei* mulch with furadan pesticide.
4. Millet mulch with furadan pesticide.

Results are expressed in Figure 4 as the rate of mulch disappearance. The effect of the pesticide furadan lasted about 100 days. During this period the difference in mulch disappearance between the plots with and without pesticide was attributed to the action of termites. It can be seen that termites acted on both *A. colei* and on millet mulch but the rate of decomposition by termites of millet mulch was much higher than the rate of *A. colei* decomposition. The relatively slower rate of decomposition of *A. colei* mulch might be an advantage because it allows covering of the ground for a longer period of time as compared with millet mulch and the production of stable humic acids.

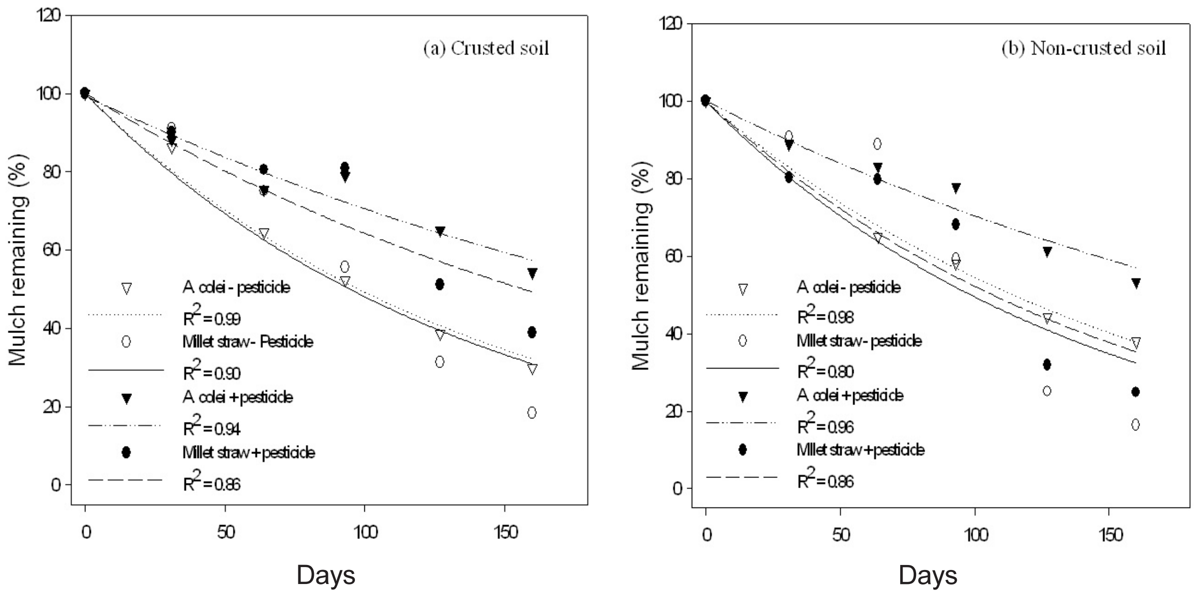

Figure 4. Rate of disappearance of insecticide treated and untreated Acacia colei and millet mulch with time.

Conclusions

Results of the four diverse studies reported in this paper should markedly contribute to the performance of the SEF system. The finding that seeds of *A. colei* can replace 50% of the protein source of chicken rations should produce a market for the seeds, adding to the farmer's revenue from the SEF, thus encouraging tree maintenance by farmers. The finding that *J.curcas* oil is an effective insecticide against both plant pests and grain storage pests should result in marked increases in cowpea yields planted in the SEF once farmers start using this low cost and readily available bio-pesticide. The Roselle trial shows that high calyx and seed yields can be obtained with 550 mm of rain under proper agronomic management and the results of the fourth study demonstrate that *A. colei* phyllodes are consumed by termites that decompose the lignin rich phyllodes making the nutrients stored in them available for the plants and enriching the soil with organic carbon.

The Sahelian Eco-Farm is a new integrated approach to rain-fed agriculture in the semi arid tropics of Africa. The development of the SEF is being carried out with the help of a series of long-term studies during which the performance of the whole system is evaluated using both on-station and on-farm studies.

So far the results of research of the individual sub-systems and their integrated performances indicate that a solution for the many constraints of present day Sahelian rain-fed systems is in the making.

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Systemes integres de production/domaine prioritaire pour action interdisciplinaire (PRODS/PAIA)

Célestin Belem[1]

Introduction

Le Burkina Faso est un pays de l'Afrique de l'Ouest de 274 000 km^2 situé entre les parallèles 9°3' et 15° Nord et les méridiens 2°30' et 5°30'.

Sa population est d'environ 12.000.000 d'habitants inégalement répartie. Elle est essentiellement rurale (>84,6%). Sa densité moyenne de population est de l'ordre de 38 hab km^{-2}. Elle présente de fortes disparités (25 hab km^{-2} dans les provinces de l'Ouest du pays et plus de 100 hab km^{-2} sur le plateau central).

Il a un climat qui n'est pas favorable à l'agriculture dans son ensemble à cause:

- de la concentration des précipitations sur 3 à 5 mois de l'année, de leur violence (intensité trés élevée) favorisant la dégradation des sols et de leur irrégularité d'une année à l'autre ou à l'intérieur d'une même saison ;
- des températures élevées favorisant l'évaporation et l'assèchement des sols.

Bien que de fertilité très inégale, les sols sont dans leur ensemble assez médiocres. Les plus fertiles sont les sols bruns euthrophes relativement fréquents sur les collines birrimiennes, les vertisols et les sols hydromorphes plus difficiles à travailler mais de richesse minérale élevée.

Le système de production est de type extensif peu performant et dépendant des aléas climatiques, malgré des efforts de maîtrise de l'eau faits ces dernières années. Il est dominé par les productions vivrières céréalières souvent cultivées en association avec le niébé.

Dans l'Ouest du pays, le système de production est dominé par le coton , très souvent cultivé en rotation avec le maïs.

C'est dans ce contexte que «l'Activité Systèmes Intégrés de Production / Domaine Prioritaire pour Action Interdisciplinaire » ou « Integrated Production Systems / Priority Area for Interdisciplinary Action » (PRODS/PAIA) en Afrique de l'Ouest, a été mis en œuvre dans l'Ouest du Burkina Faso.

Justification et objectifs de PRODS/PAIA au Burkina-Faso

Le rôle de PRODS/PAIA est d'améliorer la collaboration entre les différents départements et disciplines impliqués dans la mise en œuvre des actions d'intensification de la production et du transfert de technologies.

Il appuie l'adoption de technologies appropriées permettant une intensification des systèmes de production en étroite collaboration entre la FAO, les Institutions nationales, régionales et la société civile pour le développement, la mise en œuvre de stratégies, programmes et de pratiques de production appropriées.

1. Chargé de Recherches, Responsable des Opérations du PSSA du Burkina Faso

Dans le cadre de l'Activité PRODS/PAIA au Burkina Faso, un dispositif de démonstration est mis en place en milieu paysan. Il vise à améliorer la collaboration entre les différents départements et disciplines impliqués dans la mise en œuvre des actions d'intensification et de diversification de la production agricole ainsi que le transfert de technologies.

Le dispositif du test démonstratif s'appuie sur les sites du Programme Spécial pour la Sécurité Alimentaire (PSSA), impliquant la FAO, le Programme GRN/SP de l'INERA, la Direction Régionale de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques (DRAHRH), des Organisations paysannes et des Producteurs volontaires des villages concernés. Il est convenu que les acquis de l'exécution des activités doivent être partagés avec les autres producteurs des villages retenus.

La question de la durabilité des systèmes de production se conçoit à travers le maintien de la fertilité des sols, supports de la production agricole. Elle passe par leur préservation contre la dégradation physique (causée par le ruissellement, les vents, le tassement, la baisse du taux de matière organique), chimique (appauvrissement en éléments nutritifs) et biologique (baisse de l'activité biologique du sol). Concernant la fertilité organique, les réflexions actuelles portent sur l'intégration agriculture - élevage. Cependant, cette option est confrontée à la difficulté de mobilisation des ressources alimentaires nécessaires à l'entretien des animaux en saison sèche. Elle conditionne le temps de séjour des animaux dans les exploitations, la quantité de fumure produite et la capacité à entreprendre les travaux à l'entrée de la saison pluvieuse. De plus, l'assurance de revenus monétaires aux producteurs est une préoccupation dans les systèmes de production actuels.

L'objectif global assigné à ce travail conduit en collaboration est de démontrer l'utilité des pratiques d'agriculture durable dans la bonne gestion des sols arables fragiles et l'intégration des activités agricoles pour une amélioration des revenus des producteurs.

De manière spécifique, il vise entre autres à :

a) démontrer les effets de l'utilisation des plantes de couvertures (*Mucuna*) sur l'amélioration de la fertilité des sols, la conservation des eaux et des sols, l'alimentation animale en saison sèche chaude et la production agricole ;
b) démontrer les effets de l'utilisation des résidus de récolte sur la conservation des sols et l'amélioration de la productivité des terres agricoles à travers l'établissement rapide des plantes, la résistance aux poches de sécheresse etc. ;
c) démontrer l'utilité du niébé à double usage dans l'amélioration de la fertilité des sols, l'augmentation des rendements et la nutrition animale ;
d) introduire le soja en vue de faciliter sa culture dans les activités de diversification agricole ;
e) introduire le *Brachiaria* en vue de promouvoir les cultures fourragères pour l'amélioration de l'alimentation animale pendant les périodes non favorables (saison sèche par exemple) ;
f) animer les discussions pendant les visites des paysans pour susciter leur intérêt pour les pratiques d'agriculture durable et pour l'intégration des activités agricoles diverses.

Methodologie

Identification et installation des sites pilotes

Pour la conduite des activités de PRODS/PAIA, il a été identifié et installé un nombre limité de sites pilotes pour des actions concertées et coordonnées en faveur des systèmes intégrés de production. Un des objectifs visés des sites pilotes est de créer des opportunités de collaboration entre les différents services de la FAO engagés dans la résolution des problèmes de politiques technologiques et humains associés aux systèmes intégrés de production, de permettre d'améliorer le dialogue et de créer des synergies entre les différents intervenants, et de servir pour les paysans de lieux de démonstration de technologies utilisables dans le cadre de bonnes pratiques agricoles.

Ainsi cinq sites du PSSA, dans la Région des Hauts-Bassins (Bobo Dioulasso), ont été retenus comme sites pilotes. Ce sont :

- Karaba, à 110 km de Bobo-Dioulasso ;
- Klesso (50 km)
- Bama (25 km) ;
- Dandé (75 km);
- Kounséni/Banzon (70 km)

Sur chaque site, il a été retenu un producteur partenaire (sauf à Dandé où deux producteurs ont été retenus) pour conduire les démonstrations.

Choix et test des technologies en milieu paysan

En milieu paysan un certain nombre de technologies disponibles en station sur les plantes de couverture, les légumineuses cultivées à double usage et la production fourragère sont testées.

Description

Il est testé trois types d'associations Légumineuses - Céréales et 6 séries de rotations Légumineuses/Céréales avec différents types de fumure (organique et minérale) et mode de gestion des résidus de récolte (Figure 1). Le maïs, principale culture céréalière de la zone ouest est utilisée en priorité. Le sorgho, une des principales cultures céréalières de la zone, peut être utilisée si certains producteurs le souhaitent.

Le niébé local, le niébé à double usage (alimentaire et fourrager) et le Mucuna sont les trois légumineuses utilisées en association ou en rotation avec le maïs.

Les déférents traitements et successions de cultures sont (Tableau 1):

Tableau 1. Liste des traitements et successions des cultures.

Traitements	Année 2002	Année 2003
1 Monoculture	Maïs	Maïs
2 Association	Maïs + Mucuna	Maïs + Mucuna
3 Association	Maïs + Niébé	Maïs + Niébé
4 Association	Maïs + Niébé fourrager	Maïs + Niébé fourrager
5 Rotation	Mucuna	Maïs

continué

Tableau 1. *continué*

Traitements	Année 2002	Année 2003
6 Rotation	Maïs	Mucuna
7 Rotation	Niébé	Maïs
8 Rotation	Maïs	Niébé
9 Rotation	Niébé fourrager	Maïs
10 Rotation	Maïs	Niébé fourrager

Figure 1. Systeme integre de legumineuses – cereals.

Liste des traitements fumures:

F1: Engrais minéral NPK
F2: Engrais minéral NPK + Résidus de récolte
F3: Engrais minéral NPK +Fumier
Les doses d'engrais minéraux sont appliquées selon les cultures :
Maïs: 200 kg NPK ha^{-1} au semis et 150 kg d'urée au 40^{e} jour après le semis ; Niébé : 100 kg NPK ha^{-1} au semis
Le fumier est appliqué à la dose de 3 t ha^{-1}.

L'application des résidus de récolte est basée sur le principe que les résidus de récolte de la saison précédente doivent être recyclés dans la parcelle. Dans les champs protégés par du grillage, chaque producteur doit garder les résidus sur le sol pendant toute la saison sèche.

Les associations de cultures

Dans l'association Maïs/Mucuna, le Mucuna est semé 45 jours après le semis du maïs. Ce décalage dans le semis permet au maïs d'atteindre la période de la montaison avant que le *Mucuna* n'envahisse les parcelles. Cela permet d'éviter la compétition entre les deux (2) cultures.

Dans les associations Niébé/Maïs, on sème deux lignes de maïs pour trois lignes de niébé. Le maïs est semé aux écartements de 0.8 m x 0.4 m. Le niébé (local et à double usage) est semé aux écartements de 0.4 m x 0.4 m.

Dispositif expérimental

Un dispositif factoriel 10 x 3 en split splot a été utilisé:

- le facteur principal (parcelle principale) comporte 10 traitements correspondant à 3 associations culturales, 6 séries de rotations et une monoculture de mais ;
- le facteur secondaire (sous parcelle) correspond aux trois types de fumures (engrais minéral NPK, engrais NPK + fumier, engrais NPK + résidus de récolte).

La liste des traitements est présenté au tableau 1 ci dessus.

Resultats

Ils portent essentiellement sur **la production de biomasse** et sur l'introduction de plantes pour les besoins de diversification.

L'intérêt de la production de biomasse dans le cadre du développement des systèmes intégrés de production est double:

- la biomasse de résidus de récolte peut être intégrée dans le plan de gestion de la fertilité des terres, en formant du paillage ou mulch sur place ;
- cette biomasse est à la base de la stratégie de gestion des animaux de l'exploitation dans le but d'augmenter les quantités de fumure organique d'origine animale.

Dans le cadre des tests, cette biomasse comporte les tiges de maïs, les fanes de niébé et de Mucuna ainsi que le foin de *Brachiaria ruzuziensis*. Les valeurs observées sont présentées dans le chapitre suivant.

On observe une variation important des rendements en grains de maïs en fonction des producteurs, des fertilisations et des modes de cultures.

Production de biomasse

Le résidus de maïs

Les tiges de maïs présentent un intérêt à la fois pour l'alimentation des animaux et pour le recyclage des matières minérales et organiques dans les parcelles. Dans le cadre de ce test, le tableau 2 présente les rendements en biomasse.

Les rendements en résidus de biomasse de tiges de maïs observés sont très variables. Les valeurs sont élevées en particulier dans le cas des parcelles ayant reçu un apport en fumier. Le rapport grains/pailles laisse présager d'un mauvais niveau de valorisation du potentiel de production en grains, lié à la mauvaise pluviométrie observée sur l'ensemble des sites.

Niébé à double usage

Cette variété sélectionnée a été retenue à cause de ses aptitudes à produire à la fois du grain et de la biomasse pour l'alimentation animale. Le tableau 3 donne la production de biomasse évaluée sur les parcelles du test.

Tableau 2. Rendement en biomasse de résidus de maïs (kg ha^{-1} MS).

Village	Nom et prénoms	F1			
		Maïs_IAR7	Maïs_Mucuna	Maïs_NL	Pure
Bama	Bologo Amidou	5 000	3 000	4 000	2 675
Dandé	Kiemdé Abdoulaye	2 800	4 900	3 800	3 400
Dandé	Sawadogo Salam	3 400	5 600	3 700	3 825
Karba	Fankani Tini	1 733	1 667	1 933	2 258
Klesso	Ouattara Moumouni	5 600	4 000	6 200	4 800
Kounséni	Traoré Mamadou	2 200	1 900	3 500	2 225
Total		**3 183**	**3 400**	**3 683**	**3 163**
Village	Nom et prénoms	F2			
		Maïs_IAR7	Maïs_Mucuna	Maïs_NL	Pure
Bama	Bologo Amidou	4 000	3 000	3 000	1 875
Dandé	Kiemdé Abdoulaye				
Dandé	Sawadogo Salam				
Karba	Fankani Tini				
Klesso	Ouattara Moumouni				
Kounséni	Traoré Mamadou				
Total		**4 000**	**3 000**	**3 000**	**1 875**
Village	Nom et prénoms	F3			
		Maïs_IAR7	Maïs_Mucuna	Maïs_NL	Pure
Bama	Bologo Amidou	7 000	2 000	6 000	2 350
Dandé	Kiemdé Abdoulaye	4 000	2 000	2 000	3 600
Dandé	Sawadogo Salam	2 600	6 000	3 000	3 700
Karba	Fankani Tini				
Klesso	Ouattara Moumouni	7 200	7 200	6 600	5 100
Kounséni	Traoré Mamadou	2 400	1 400	2 600	2 150
Total		**4 640**	**3 720**	**5 360**	**3 380**

Tableau 3. Rendement en biomasse de résidus de niébé à double usage (kg ha^{-1} MS).

Village	Nom et prénoms	F1		F2		F3	
		Maïs_IAR7	Pure	Maïs_IAR7	Pure	Maïs_IAR7	Pure
Bama	Bologo Amidou	2.000	4.000	2.000	4.000	2.000	4.000
Dandé	Kiemdé Abdoulaye	4.500	3.400			4.000	3.200
Dandé	Sawadogo Salam	3.700	3.100			3.000	4.400
Karba	Fankani Tini	1.733	4.000				
Klesso	Ouattara Moumouni	6.400	3.130			7.200	3.460
Kounséni	Traoré Mamadou	2.600	3.400			2.800	3.200
Total		**3.467**	**3.505**	**2.000**	**4.000**	**3.800**	**3.652**

La production de biomasse de résidus de niébé à double usage a varié de 1,5 et 7 tonnes/ha MS. Les plus fortes valeurs ont été observées dans les parcelles en association avec le maïs. Cela pourra s'expliquer par l'apport d'engrais sur le maïs. En moyenne, elle varie entre 2 et 4 tonnes/ha, confirmant son intérêt de spéculation à double usage dans les systèmes intégrés de production.

Le niébé local

Une variété locale de niébé a été introduite dans le test, en comparaison avec le niébé à double usage, afin de donner plus de possibilités de choix aux producteurs. Chaque producteur a mis en place sa variété préférée dont il dispose. Le tableau 4 donne les rendements en biomasse évalués sur les parcelles après la récolte des gousses.

Tableau 4. Rendement en biomasse de résidus de niébé local (kg ha^{-1} MS).

Village	Nom et prénoms	F1		F2		F3	
		Maïs_NL	Pure	Maïs_NL	Pure	Maïs_NL	Pure
Bama	Bologo Amidou	1.000	6.000	1.000	3.000	1.000	3.000
Dandé	Kiemdé Abdoulaye	2.000	1.500			2.000	1.000
Dandé	Sawadogo Salam	1.400	1.400			1.200	2.000
Karba	Fankani Tini	1.933	4.933				
Klesso	Ouattara Moumouni	4.000	1.730			4.000	1.060
Kounséni	Traoré Mamadou	1.400	2.500			1.200	2.000
Total		**2.033**	**2.922**	**1.000**	**3.000**	**1.880**	**1.812**

La biomasse de résidus de niébé local est très variable (1 à 3 tonnes/ha en moyenne). Elle est élevée dans le cas de Klésso, Bama et Karba.

Comparée à la biomasse résiduelle de niébé à double usage, on se rend compte que cette dernière est plus productive, confirmant son intérêt dans les systèmes intégrés de production.

Le Mucuna

Le Mucuna a été introduit dans ce test à cause de ses aptitudes à produire une biomasse élevée, pouvant servir dans l'alimentation des animaux et la conservation des sols. Le Tableau 5 présente la production de biomasse évaluée sur les parcelles.

Tableau 5. Rendement en biomasse de résidus de Mucuna (kg ha^{-1} MS).

Village	Nom et prénoms	F1		F2		F3	
		Maïs_Mucuna	Pure	Maïs_Mucuna	Pure	Maïs_Mucuna	Pure
Bama	Bologo Amidou		3 000		4 000		3 000
Dandé	Kiemdé Abdoulaye	2 000	4 000			2 000	2 000
Dandé	Sawadogo Salam	2 000	2 250			2 000	2 000
Karba	Fankani Tini	2 000	3 167				
Klesso	Ouattara Moumouni	3 000	3 000			3 000	8 000
Kounséni	Traoré Mamadou	915	3 650			970	3 000
Total		**1 985**	**3 192**		**4 000**	**1 993**	**3 600**

Le rendement en biomasse de Mucuna a varié entre 1 à 8 tonnes MS/ha. En culture pure, il varie entre 2 et 4 t ha^{-1} sans fertilisation. Avec l'apport de fumure organique, cette biomasse peut atteindre 8 t ha^{-1} dans le cas de Klesso. La faible production de biomasse dans les cas de Dandé malgré l'apport de fumier pourrait s'expliquer par le type de sol argileux prononcé de ces sites.

L'intérêt du Mucuna dans ce système tient à sa forte capacité de production de biomasse et son intérêt pour l'amélioration de la fertilité des terres cultivées. Elle n'a pas reçu d'apports d'engrais minéraux. F1 dans ce cas correspond à zéro amendement. La fumure organique a été appliquée sur certaines parcelles en F3. C'est seulement pour les besoins des successions culturales que le dispositif a été respecté. Les résultats obtenus sont présentés au Tableau 6

Il ressort de ce tableau:

- Une production en graines de Mucuna qui peut être élevée (400 à 950 kg ha^{-1}) ;
- La culture en pure a influé sur la production de graines. Cela est lié au décalage de la date de semis du Mucuna associé à une pluviométrie insuffisante et brève observée cette année ;
- Une amélioration de la production en graines du Mucuna avec l'application de la fumure organique.

Tableau 6. Rendement en graines de Mucuna en fonction de la fertilisation et du mode de culture (kg ha^{-1}).

Village	Nom et prénoms	F1		F2	F3	
		Maïs_Mucuna	Pure	Pure	Maïs_Mucuna	Pure
Bama	Bologo Amidou		115	115		146
Dandé	Kiemdé Abdoulaye	639	813		752	800
Dandé	Sawadogo Salam		1 034			1 409
Karba	Fankani Tini	525	903			
Klesso	Ouattara Moumouni	86	842		195	1 317
Kounséni	Traoré Mamadou		1 213			1 142
Total		**432**	**885**	**115**	**473**	**963**

Introduction des cultures de diversification

Le Soja

Le soja a été introduit pour les besoins de diversification de la production.

L'évaluation des rendements en graines obtenues dans les parcelles avec le soja (variété noire) est présentée dans le Tableau 7.

On observe:

- des rendements très faibles dans les parcelles de Bama, Dandé et Kounséni;
- un niveau de rendement assez intéressant est obtenu à Klésso.

Le faible niveau de rendement observé dans les trois premiers cas s'explique en partie par le retard de semis et surtout l'arrêt brusque des pluies. On peut aussi remarquer que ces trois cas correspondent à des types de sols assez semblables, à forte teneur d'argile et de limon. Par contre, à Klésso le sol était sableux et sablo - gravillonnaire à Karba.

Tableau 7. Rendement en graines de soja (kg ha^{-1}).

Village	Producteur	Soja
Bama	Bologo Hamidou	16
Dandé	Kiemdé Abdoulaye	26
	Sawadogo Salam	17
Karba	Fankani Tini	147
Klésso	Ouattara Moumini	483
Kounséni	Traoré Mamadou	
Total		**138**

Introduction du Niébé fourrager ou niébé à double usage

En tant que culture de diversification, le niébé est la seconde culture du système proposé.

Le niébé à double usage a été introduit dans le système en comparaison à la variété locale utilisée par les producteurs. Il présente un intérêt particulier compte tenu de sa nouveauté dans le milieu paysan. Le Tableau 8 présente les rendements évalués selon le mode de culture et la fertilisation.

Tableau 8. Rendement en graines de niébé à double usage (IAR7/180) en fonction de la fertilisation et du mode de culture (kg ha^{-1}).

Village	Nom et prénoms	F1		F2		F3	
		Maïs_IAR7	Pure	Maïs_IAR7	Pure	Maïs_IAR7	Pure
Bama	Bologo Amidou	297	182	363	235	347	170
Dandé	Kiemdé Abdoulaye	414	500			526	625
Dandé	Sawadogo Salam	510	648			340	977
Karba	Fankani Tini	865	517				
Klesso	Ouattara Moumouni	788	921			875	925
Kounséni	Traoré Mamadou	388	513			350	467
Total		**591**	**575**	**363**	**235**	**488**	**633**

On observe que :

- les rendements en graines de niébé à double usage sont variables d'un site à l'autre. Des rendements élevés avoisinant la tonne/ha sont observés en culture pure avec la fertilisation minérale simple et fertilisation minérale plus apport de fumure organique à Dandé et Klésso ;
- les rendements obtenus en culture pure, comparés à ceux en culture associée sont contradictoires d'un site à un autre ;
- en moyenne, dans les conditions d'application d'engrais minéral simple, les rendements obtenus en culture pure sont comparables à ceux en culture associée avec le maïs ;
- en moyenne, l'association ne semble pas avoir un impact marqué sur les niveaux de production observés avec cette culture ;
- dans les cas d'apports de fumure organique en plus de la fertilisation minérale, les rendements semblent meilleurs en culture pure comparée à l'association avec le maïs.
- la fumure organique semble améliorée le rendement en graines de cette culture ;
- les rendements en graines observés sont comparables au niébé local.

La variété de niébé à double usage retenue est la IAR7. Cette variété sélectionnée a été retenue à cause de ses aptitudes à produire à la fois du grain et de la biomasse pour l'alimentation animale. Le Tableau 9 donne la production de biomasse évaluée sur les parcelles du test.

La production de biomasse de résidus de niébé à double usage a varié entre 1,5 et 7 t ha^{-1} MS. Les plus fortes valeurs ont été observées dans les parcelles en association avec le maïs. Cela pourra s'expliquer par l'apport d'engrais sur le

Introduction du Brachiaria

L'évaluation de la production de fourrage de *Brachiaria ruzuziensis* a donné les résultats présentés au Tableau 10.

On observe que :

Tableau 9. Rendement en biomasse de fanes de niébé à double usage (kg ha^{-1} MS).

Village	Nom et prénoms	F1		F2		F3	
		Maïs_IAR7	Pure	Maïs_IAR7	Pure	Maïs_IAR7	Pure
Bama	Bologo Amidou	2 000	4 000	2 000	4 000	2 000	4 000
Dandé	Kiemdé Abdoulaye	4 500	3 400			4 000	3 200
Dandé	Sawadogo Salam	3 700	3 100			3 000	4 400
Karba	Fankani Tini	1 733	4 000				
Klesso	Ouattara Moumouni	6 400	3 130			7 200	3 460
Kounséni	Traoré Mamadou	2 600	3 400			2 800	3 200
Total		**3 467**	**3 505**	**2 000**	**4 000**	**3 800**	**3 652**

Tableau 10. Production de biomasse de Brachiaria ruziziensis (kg ha^{-1} MS)

Village	Producteur	Brachiaria
Bama	Bologo Hamidou	1 500
Dandé	Kiemdé Abdoulaye	3 167
	Sawadogo Salam	3 250
Karba	Fankani Tini	4 750
Klésso	Ouattara Moumini	5 555
Kounséni	Traoré Mamadou	-
Total		**3 644**

- la production des différentes parcelles est variable ;
- on obtient de bons niveaux de rendements dans certaines parcelles (Dandé et Karaba) avoisinant 5 tonnes MS/ha ;
- le rendement moyen de 3 tonnes MS/ha est intéressant, vu la haute qualité fourragère de l'espèce.

Les rendements de biomasse fourragère obtenus sont en deçà de la production potentielle de cette espèce dans les conditions normales. Cependant, ils sont acceptables dans le contexte du test, vu le retard dans la mise en place de l'essai et l'arrêt précoce de la saison pluvieuse.

Appui pour la protection des résidus de récolte et plantes de couverture (introduction des haies vives d'*Acacia nilotica* ou de *Ziziphus mucronata*)

Les tests qui sont actuellement menés sont clôturés par du grillage afin d'assurer une bonne protection des résidus, notamment pendant la saison sèche où les animaux sont en divagation et les besoins en fourrage sont très élevés.

Il est évident qu'il est impossible de diffuser ces technologies en utilisant ce type de clôture qui coûte très cher et n'est donc pas à la portée des producteurs.

Il a donc été testé des clôtures sous forme de haies vives d'*Acacia nilotica* ou de *Ziziphus mucronata*. Pour le moment, les plants sont jeunes, mais les résultats attendus sont prometteurs.

Information formation et vulgarisation des techniques
Formation en ensilage utilisant les moyens locaux (sels et plastiques …)

Un des objectifs recherchés étant l'amélioration de l'alimentation des animaux en saison sèche, le Système Intégré de Production (PRODS/PAIA) a organisé des formations deux années de suite en ensilage en utilisant des moyens locaux accessibles (fûts remplis d'eau, sels, plastiques). Ces formations ont été organisées au profit des producteurs/productrices et ont été dispensées par des membres du Groupement Féminin de Zitenga (Région du Plateau Central) qui ont séjourné pendant 3 jours sur chacun des sites concernés.

La participation des producteurs à ces formations est la suivante (Tableau 11)

Tableau 11. Participation des Producteurs / Productrices aux formations sur l'ensilage.

Régions	Centre de formation	Nombre de participants
Hauts-Bassins	Dandé	311
	Banarodougou	32
	Klesso	245
	Karaba	45
Centre-Nord	Korsimoro	16
Nord	Bouro	20
Centre- Ouest	Lâ	16
Total		685

Visite commentée

Les visites commentées se sont déroulées du 20/10/2003 au 24/10/2003 et 905 producteurs provenant de 23 villages aux alentours des sites y ont activement pris part, contre 844 producteurs en 2002. (visites guidées du site par groupe de 20 avec les explications du technicien de l'INERA, puis échanges entre équipe technique et producteurs pour recueillir leurs impressions, mais surtout leurs préoccupations).

Les visites commentées ont permi aux producteurs de mieux appréhender la stratégie du système intégrée de production et d'améliorer leurs connaissances en matière d'intensification de la production, de gestion de la fertilité des sols (utilisation de légumineuses à usages multiples, rotations des cultures), de diversification de la production (production de fourrage pour une alimentation saine des animaux).

Lors des visites de terrain, les producteurs ont pu observer avec satisfaction les résultats suivants :

- le bon comportement des plants de maïs après les légumineuses (Mucuna et niébé) ;
- la bonne protection du sol par le Mucuna ;
- le maintien de l'humidité au niveau des parcelles non labourées.

Suite aux résultats des visites de la 1ère année, les producteurs se sont beaucoup intéressés à la culture de Mucuna. Ainsi, 14,07 ha ont pu être emblavés en milieu paysan (agriculteurs + éleveurs) en 2003.

Les préoccupations des producteurs lors des visites commentées ont été les suivantes :

- l'approvisionnement en semences de Mucuna, niébé à double usage, soja, brachiaria, manioc et espèces forestières ;

- La transformation des graines de Mucuna et de soja ;
- La protection des plantules de haies vives.

Partenariat et mis en œuvre
Activités de terrain : partenariat étroit FAO, PSSA, INERA, DRAHRH,OP, GIPD, DVRD, ….

Les activités de terrain sont conduites dans le cadre d'un partenariat comme suit :

INERA

- conception, mise en place, suivi des essais et interprétation des résultats.

PSSA

- mise en place, suivi des essais par les moniteurs PSSA des différents sites, organisation des visites commentées.
- coordination des interventions entre les partenaires.
- appui technique.

DRAHRH

- mise à disposition du personnel d'encadrement des producteurs
- organisation des visites commentées.

FAO

- financement des activités menées par la DRAHRH, l'INERA et les Organisations paysannes (formation dispensée par le groupement des femmes de Zitenga) à travers des protocoles d'accord :

(en 2003 : DRAHRH des Hauts-Bassins : 7800 dollars US)
INERA / GRN-SP: 9000 dollars US

- **Appuis réguliers des services techniques du bureau régional (Accra) et du siège (ROME) en collaboration avec d'autres institutions telles que le CIRAD et IITA.**

Organisations Paysannes

- formation dispensée aux producteurs des différents sites de PRODS/PAIA par le Groupement Féminin de Zitenga (thème : fabrication de l'ensilage à partir de matériaux locaux.)
- choix des producteurs pilotes et des producteurs chargés de multiplier les semences de Mucuna et autres espèces qu'ils ont pu apprécier.

DVRD (Direction de la vulgarisation et de la Recherche Développement)

- missions conjointes avec le PSSA sur les différents sites pour s'imprégner des activités conduites par le PRODS/PAIA et voir leur impact sur le terrain.

GIPD (Gestion Intégrée des Productions et Déprédateurs)

- appui en lutte intégrée sur le coton à travers les champs écoles. Ainsi, 15 producteurs ont été régulièrement formés sur les techniques de la GIPD.

Conclusion

- Le projet a déjà démontré que les plantes retenues (maïs, niébé, mucuna, niébé fourrager) en rotation ou en association peuvent contribuer à la régularisation des sols (couverture, résidus de récolte…) ;
- Les légumineuses (niébé…) et la graminée niébé peuvent jouer un rôle important dans l'alimentation des animaux ;
- La plupart de ces plantes sont également des plantes permettant la diversification de la production (contribution à la sécurité alimentaire et à l'augmentation des revenus) ;
- Le plus grand problème rencontré dans la diffusion de ces technologies est la conservation des plantes de couverture et des résidus de récolte pendant la saison sèche. La diffusion des haies vives semble être une technologie acceptée par les producteurs.

Recommendations of the Symposium

Moderator: I Butare

Rapporteurs: G Omanya and A Nikiema

Recommendations of the symposium

Summary

The Symposium aimed to share experiences and research findings and propose strategies that address the problems of declining crop and livestock productivity and land degradation in the drylands. Deliberations and recommendations were made under four themes namely Crop Diversification in Agriculture systems, Soil and Water Management, Crop and Tree Improvement and Productivity, and Building Sustainable Agriculture Production Systems.

The participants agreed that sustainable and profitable farming is possible in the semi-arid tropics. They expressed that a long-term vision is needed to build a sustainable production system in addition to short-term solutions, and the need to be proactive in this.

The participants stated that crop and tree diversification has the potential to increase farmers incomes, food security and to minimise risks. Nonetheless monoculture plays a role in the diversified system, for example, in crop rotation, as trap crops and high potential areas. The tree component is essential for the economic and environmental sustainability of the production system. The crop and livestock component is integral in semi arid tropics and should be optimized.

The participants' concern was on the need to positively impact wider farming communities on an increasing scale, with sound technologies in the semi arid tropics. They advised that technologies need to be sufficiently elaborated to incorporate the dimensions of socio-economics, agronomy, crop and tree improvement, crop–livestock interactions, soil and water management and ecology. These technologies should lead to marketable products that contribute to increased incomes for farmers. To this end legal, policy and macro economic issues need to be understood and addressed at both local and international levels. The participation of stakeholders was seen as key in addressing this concern. Thus applying participatory approaches, conducting dialogue both upstream, down stream and across institutions, and being gender sensitive are important components that should be used in this process. Lastly, building capacities of farmers, farmer organizations, researchers and government and policy makers was considered imperative for informed decision making.

Symposium participants highlighted that after the conference, there was need to take an extra step towards realization of the recommendations.

Recommendations

General comments

- Participants acknowledged that farmers are producing in the context of a complex system in terms of biophysical factors, markets, social and cultural background
- A long term vision is needed to build a sustainable production system and the need to be proactive, in addition to short-term solutions to food security
- The decline of prices of traditional crops and risks of crop failure due to drought calls for crop diversification

- Crop diversification has the potential to increase farmer's income, food security and minimize risks for example through introduction of high value crops like fruits, vegetables, spices
- Nonetheless, monoculture has its role under certain circumstances such as the high potential areas where cash crops are grown or where legumes and cereals are rotated or as trap crops

Technology development, testing and upscaling

- Crop and livestock system should be integrated and optimally developed for sustainability of the drylands
- Technology packages for the crop diversification systems need to be sufficiently elaborated and time-tested
- Low cost technologies with high outputs should be developed
- Ecological dynamics need to include the effects of water use at landscape level, pest and diseases among others
- Attention must be paid to input and output balances, and optimum use of natural resources such as legumes for soil health and perennial components to provide economic benefits
- The needs of farmers, size of farmers' holdings, livestock needs, the climate of the area should also be considered
- Ex-ante and cost benefit analysis should be conducted to provide information on profitability and adoption possibilities of available technologies
- Human intervention that influences application of these technologies should be taken into account
- Projects should invest in participatory transfer of technologies to farmers and not only concentrate on development of technologies
- Existing soil and water management technologies have a low adoption rate due to physical, social, economic (profitability etc) and political constraints and lack of extension advice
- There is a need to promote an integrated genetic and natural resource management approach that addresses gaps in soil fertility, hence improving soil health
- Water harvesting by farmers is paramount for sustainability; and knowledge on infiltration and retention is required
- Use of both inorganic and organic fertilizers at affordable rates contribute to a sustainable system and should be promoted
- Hill application of small amounts of fertiliser (micro dose) has been found to be a cost-effective in pearl millet and sorghum production in the Sahel
- A multidisciplinary approach is required to build a sustainable production system that addresses all components in crop improvement activities namely breeding, pathology, agronomy and socio-economics
- Selection and breeding of indigenous and exotic crop and tree varieties, should be conducted and include spices and vegetables
- In crop improvement activities, preservation of local agro biodiversity is necessary for a sustainable agricultural system
- There is need to promote new promising tree species that contribute to raising farmer's income, decreasing risks and improving the ecological resilience.

- To improve the system, it is important to develop sound domestication techniques for valued local species (*Vitellaria paradoxa*, *Parkia biglobosa*, *Adansonia digitata etc)*

Income generation and market development

- Income generation for farmers needs to form a basis for sustainable agriculture
- Market opportunities need to be studied, local and international market outlets developed, and farmers linked to them. For example, diversification for farmers near urban areas should incorporate cash crops like vegetables, which takes advantage of the proximity of the market
- In addition to breeding for yield, disease, pest resistance, drought, nutrient use efficiency etc, a market oriented breeding approach should be encouraged
- In the semi-arid zones, the tree component is essential for the economic, environmental sustainability of the production system. Trees need to be recognized to bear the same function as livestock capital in rural farming systems, and be accordingly promoted
- In addition to wood products, non-wood products from trees are increasingly being commercialized in local and urban markets thus signifying their importance in income generation. Research should therefore provide reliable data and information to guide management and promotion actions
- Past experiences in processing and marketing of traditional tree crops such as *Vitellaria sp* and *Parkia* should be collected and assessed

Legal and policy issues

- An enabling policy and government support is necessary for development and transfer of technologies, and this includes enhancement of infrastructure, to promote availability and access to agricultural inputs
- Policy matters concerning land and tree tenure, labor issues and political climate should be considered when planning for crop diversification and other components of sustainable farming
- Researchers should work upstream with policy and decision makers
- Local/community natural resources management should be implemented to protect trees from grazing animals and uncontrolled 'free' harvesting
- There is need for better understanding and integration of macro-economic policies (national and international) impact on agricultural sustainability

Participation of stakeholders

- Collaboration with partners is essential in building a sustainable farming system and development and diffusion of technologies
- Dialogue among farmers, researchers, extension and decision makers should be improved
- Farmers' participation is essential while planning and executing the system approach farming
- A gender sensitive approach and dialogue between all actors is important in development and implementation of crop diversification
- A participatory plant breeding approach is required to incorporate farmers' and other stakeholders' preferences, needs and knowledge to facilitate development, adaptation and adoption of technologies

Capacity building and inputs support

- Training and social mobilization of farmers and other stakeholders are important in technology transfer and for sustainability
- Adequate technical and financial (credit) support should be made available to farmers e.g. development of seed production systems
- Farmers and farmers' organizations need to be strengthened (education/training, information, communication, mobilization) to enable them drive research priorities, influence the decision making, and improve production and marketing

Follow-up activities

- Participants indicated that a symposium follow-up committee be formed to draw an action plan towards realization of the recommendations

Poster papers

1. Les apports de la Spatialisation à l'étude de la biodiversité

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2. Gestion des Ressources Génétiques dans les Sociétés Traditionnelles

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3. Les Coupes de Bois en Milieu Rural : une activité à double tranchant.

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4. Diversité des Systèmes de Production et Viabilité de l'Exploitation Agricole en Zone Cotonnière – le cas de Koutiala au Mali

* Contact : Didier Bazile, CIRAD – TERA, B.P. 1813, Bamako (Mali)
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5. Application Stratégique d'engrais pour la Prospérité des Petits Paysans du Sahel.

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6. Préservation de l'Agrobiodiversité du Sorgho au Mali et au Burkina Faso

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7. Local level Monitoring for Enhanced Decision – making to Combat Desertification in Namibia

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8. Enhancing Capacity Building for Impact: A model for effective partnership in research for development

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9. Catalyzing Village Seed Enterprises in Mali

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10. Promoting Farmer – Friendly Ways to Control Sorghum Head Bug in Mali

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11. Lancer des Entreprises Semencières au Mali

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12. Sustainable Soil Fertility Management in Millet Based Cropping System for Poverty alleviation in Semi – Arid West Africa

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13. Vegetation Restoration Approach for Combating Sand Storms and Desertification in East – NW – China

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14. Conservation Farming: Tillage – with Complete Soil disturbance;

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15. Conservation Farming – Common Conservation Agriculture Implements for Smallholder and Emergent Farmers

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16. Conservation Farming – Common (traditional) Technical Options, some common options....

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17. Conservation Farming – On farm Development and Promotion of Conservation Farming Practices in Africa

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18. Jama'a Jagorarmu

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19. ICRISAT Moving Forward!

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20. The Role of the POO2 in Dryland Degradation

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21. The Livestock Ladder in Southern Africa

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23. Grey to Green Revolution – Turning Adversity into Opportunity

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24. Programme d'Action dans les zones en Marge du Désert

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25. Arresting Land Degradation in Botswana through Improved Conservation and Sustainable Use of Biodiversity

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André Van Rooyen, DMP Sub – Regional Coordinator for South and Easten Africa ICRISAT, P. O. Box 776, Bulawayo, Zimbabwe

29. Amélioration des rendements du Mil et du Sorgho et des revenus des Producteurs avec l'intégration des Technologies issues de la Recherche : Une expérience conduite dans de Maradi au Niger

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About ICRISAT

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