Soil Management Practices to Improve Nutrient-use Efficiencies and Reduce Risk in Millet-based Cropping Systems in the Sahel

C.F. Yamoah[1*], A. Bationo[2], B. Shapiro[3] & S. Koala[4]

Keywords: Diversification - Cropping systems - Nutrient-use efficiency - Risk - Soil management

Summary

Low soil fertility and moisture deficit are among the main constraints to sustainable crop yields in the Sahel. A study therefore, was conducted at the ICRISAT Sahelian Center, Sadore in Niger to test the hypothesis that integrated soil husbandry practices consisting of manure, fertilizer and crop residues in rotational cropping systems use organic and mineral fertilizes efficiently, thereby resulting in higher yields and reduced risk. Results from an analysis of variance showed that choice of cropping systems explained more than 50% of overall variability in millet and cowpea grain yields. Among the cropping systems, rotation gave higher yields than sole crop and intercropping systems and increased millet yield by 46% without fertilizer. Rainfall-use efficiency and partial factor productivity of fertilizer were similarly higher in rotations than in millet monoculture system. Returns from cowpea grown in cowpea-millet rotation without fertilizer and the medium rates of fertilizers (4 kg P.ha^{-1} + 15 kg N.ha^{-1}) were found to be most profitable in terms of high returns and low risk, principally because of a higher price of cowpea than millet. The study recommends crop diversification, either in the form of rotations or relay intercropping systems for the Sahel as an insurance against total crop failure.

Résumé

Pratiques de gestion de sols pour améliorer l'efficacité de l'utilisation des éléments nutritifs et réduire les risques liés aux systèmes agricoles à base du mil

La pauvreté des sols et le déficit d'humidité font partie des contraintes majeures au rendement durable au Sahel. Une étude a été menée au centre ICRISAT du Sahel, Sadore au Niger en vue de tester les hypothèses selon lesquelles des pratiques de gestion intégrée des sols consistant en l'utilisation du fumier, de l'engrais et des résidus culturaux dans des systèmes d'assolement, utilisant efficacement les engrais minéraux et organiques, et de cette façon augmentant les rendements et réduisant les risques. Les résultats de diverses analyses indiquent que le choix de systèmes agricoles explique plus de 50% de la variabilité globale des rendements du mil et du niébé. Parmi les systèmes de culture, l'assolement a donné de plus forts rendements que la monoculture et la culture intercalaire. Il a également augmenté de 46% le rendement du mil sans engrais. De même, l'efficacité de l'utilisation des pluies et la productivité partielle des engrais étaient aussi plus fortes dans le système assolement que dans le système de monoculture du mil. Les rendements de la culture du niébé dans un système de rotation mil-niébé sans engrais et les doses moyennes d'engrais (4 kg P.ha^{-1} + 15 kg N.ha^{-1}) étaient jugés plus rentables en termes de revenus élevés et de faibles risques, en particulier à cause du prix du niébé qui est plus élevé que celui du mil. L'étude préconise la diversification culturale sous forme d'assolement ou de système de culture intercalaire de relais, pour le Sahel, comme garantie contre la faillite totale des cultures.

Introduction

Crop rotations and intercropping systems are practiced in both the tropical and temperate regions. The two common reasons farmers give for practicing mixed cropping systems are I) high and stable yields and income (3, 4) in Niger and Burkina Faso, (8) in Niger, (1, 5, 16) in the USA (16) and II) to reduce the levels of diseases and pests infestation (6, 18). Rotation of soybean and with maize improved maize yields and fertilizer-use efficiency in USA (34). Others have ascribed benefits of rotations to improved soil physical properties (19, 20) and to the ability of leguminous crops (e.g. pigeon pea) to increase P availability through secretion of enzymes or acids in the rhizosphere to solubilize P bounded to sesquioxides.

[1] International Crop Research Institute for the Semiarid Tropics (ICRISAT), Niamey Niger. Present address and author for correspondence: C/o P.O. Box KA 30740 Airport, Accra Ghana. Email:yamoahcf@yahoo.com.
[2] Tropical Soil Biology and Fertility, Nairobi, Kenya.
[3] ICRISAT, India.
[4] Desert Margins Program, ICRISAT Niamey, Niger.
Received on 17.10.01. and accepted for publication on 13.12.02.

The traditional millet-cowpea rotations in the Sahelian ecozone of West Africa do not usually increase millet yields unless inorganic N and P fertilizers and/or manure are added (2, 7, 10). It was noted that millet-cowpea rotational systems at Sadore did not increase soil organic matter but did increase mineral N in the top 20 cm soil (7). Yield increase in rotations is commonly attributed to N supply through fixation by the associated legumes. However, other scientists contend that, the N credit in rotations is the difference between mineralized N of the non-legume and the legume components. Thus, mineralized N from highly fertilized maize residues i.e. high N and low lignin (high quality crop residue) is about equal to the fixed N from soybean crop (15). Considering that annual grain N removal from soybean field yielding 2000 $kg.ha^{-1}$ is 100 kg $N.ha^{-1}$, the explanation of N credit in legume-cereal rotations by Green and Blackmer (15) seems logical.

Low cowpea yield in the Sahel is a reflection of poor N fixation due to acid infertile soils and the frequent drought spells. It is necessary therefore, to amend the soil through addition of crop residues, animal manure and fertilizer together with cereal-legume rotations. Application of animal manure and retention of crop residues in the field are nutrient recycling processes that culminate in increased soil organic matter, pH, exchangeable bases, improved soil structure, and a reduced capacity of soils to fix P (2, 29). The objective of this study is to test the hypothesis that integrated soil husbandry practices consisting of fertilizers and organic manure in rotations are more profitable and less risky than continuous monoculture.

Material and methods

From 1998 to 1999, field studies were conducted at Sadore (13^o 15 N' latitude, 2^o 18 E' longitude), a key benchmark site of the ICRISAT Sahelian Center in Niger, West Africa. Mean annual rainfall of the site is 560 mm/yr and mean annual temperature is 29 ^oC (33). With respect to soil, sand fraction is 94%, organic matter content is 0.22%, and Bray 1 phosphorus is 2.3 mg/kg (11).

The study tested an integration of four soil management options, namely, inorganic fertilizer application, use of crop residues, manure application and cropping systems. The treatment combinations presented in table 1, were purposely designed to give a range of options to farmers with variable resources. As well, the choice of treatments was meant to address P deficiency and low organic matter levels in the sandy soils of the Sahel through a mixture of organic and inorganic fertilizers. We also recognize that the kaolinitic sandy soils are not capable of retaining N and therefore, it should be routinely applied in order to make nutrients like P more efficient (9, 23).

Thus, the first factor in this study was N and P inorganic fertilizers at three levels: I) no fertilizer, (F_0) II) 15 kg $N.ha^{-1}$ + 4 kg $P.ha^{-1}$, (medium rate, F_1) and III) 45 kg $N.ha^{-1}$ + 13.1 kg $P.ha^{-1}$ (high rate, F_2). The second factor was farm manure at three levels: I) 300 kg manure/ha, (M_0), II) 900 kg manure/ha (M_1), and III) 2700 kg manure/ha (M_2). The third factor was crop residues at also at three levels: I) 300 kg residue/ha, (R_0), II) 900 kg residue/ha (R_1), and III) 2700 kg residue/ha (R_2). The fourth factor was cropping systems at four levels, that is, I) millet grown as sole crop in 1998 and 1999, II) millet in 1998 alternated with cowpea in 1999, III) millet intercropped with cowpea both years, and IV) cowpea in 1998 alternated with millet in 1999. The design was a complete 4 x 3 x 3 x 3 factorial with four replications. Plot size was 50 m^2. Test crops were millet cultivar CIVT 110 and cowpea variety TN5-78. Millet was planted at a density of 10000 hills/ha in sole and rotation and 6660 hills/ha in intercropping systems. Cowpea was planted 40000 plants/ha in rotation and 24000 plants/ha in intercropping systems. Fertilizers and manure were broadcast on the surface followed by incorporation by hand rake. Residues were surface applied as mulch two weeks before planting as reported by Bationo *et al.* (8).

Fertilizer-use efficiency (FUE) of applied fertilizer was defined as total yield ($kg.ha^{-1}$), that is, yield due to native fertility plus yield due to fertilization ($kg.ha^{-1}$) divided by total amount of fertilizer ($kg.ha^{-1}$) applied (12). The FUE is a measure of nutrient-use efficiency. Rainfall-use efficiency (RUE) was the ratio of yield to the amount of rainfall in the year that normally occurs from June to September. Returns above variable cost of fertilizer were the difference between the revenues (yield*price) of crops (including cowpea fodder) and the cost of fertilizer inputs. Millet grain, cowpea grain and cowpea fodder prices were 100, 260, and 50 CFA/kg respectively. Total costs of fertilizers were 13755 for the low and CFA 41049/ha for the high rate.

Since our main interest was in finding the different soil management options that give high yields and exhibits low variability, we created 108 production environments by combining the various treatments for 1998 and 1999. Riskiness of the cropping systems in the various fertilizer categories was then appraised by plotting the returns averaged across manure and crop residue treatments (y-axis) with the standard deviations (x-axis). In the present study, risk is a measure of spatial variability of yield in both low (1999) and high (1998) rainfall. Statistical analyses using Statview (30) included analysis of variance, regression, correlation and t-test for comparison of treatment means between years.

Results and discussion

Yields and sustainability

The results of millet and cowpea yields in table 1 validate the hypothesis that integrated soil husbandry practices in rotations yield higher than their counterparts in monoculture. In this study, rotation with cowpea increased millet yield by 46% in plots without inorganic fertilizer in 1998.

Table 1
Fertilizer effects on yields (kg.ha^{-1}) of millet and cowpea in cropping systems averaged across crop residue and manure treatments

Crop systems	Fertilizer (kg.ha^{-1})	1998				1999			
		Millet		Cowpea		Millet		Cowpea	
		Grain yield	Stover yield	Grain yield	Fodder yield	Grain yield	Stover yield	Grain yield	Fodder yield
Sole millet	0	552	1133			790	1526		
	15N + 4.4P	1055	1870			1230	2315		
	45N + 13.1P	1260	2185			1421	2915		
Millet in rotation	0	805	1855			880	1722		
	15N + 4.4P	1370	2896			1360	2730		
	45N + 13.1P	1900	3488			1734	3260		
Millet in intercop	0	250	547			415	1120		
	15N + 4.4P	535	982			605	1573		
	45N + 13.1P	745	1351			770	2153		
Cowpea rotation	0			885	840			360	842
	15N + 4.4P			1050	1487			415	1300
	45N + 13.1P			1150	1900			275	1652
Cowpea intercrop	0			700	587			180	390
	15N + 4.4P			840	1053			120	508
	45N + 13.1P			925	1526			80	687
S.E.		49	76	43	93	43	90	15	45

Probability levels of the difference in grain yields between years according to t-test: p= 0.08 for millet; p= 0.002 for cowpea.

The increase was slightly less and was about 30% with the low rate (4 P + 15 N kg.ha^{-1}) of fertilizer. Similar trends were observed in 1999 in both grain and stover yields. Also from figure 1, it was clear that grain yield of millet is significantly and positively correlated with stover yield (r= 0.84, P< 0.0001). It was evident from figure 1, that rotations produced the highest grain and biomass yields. Since organic matter is crucial to the productivity of soils of the Sahel, it is safe to argue that rotations may lead to sustainable yields if portions of the crop residues remain in the fields.

plants/ha in intercrops versus 40000 plants in rotations. Possible yield reduction resulting from competition for light, moisture and nutrients cannot be eliminated as well. Millet yields in intercropping were equally low, as the legume component could not make up for the reduced plant population from 10000 in sole crop and rotations to about 6660 hills/ha. Cowpea yields were much lower in 1999 compared to 1998 due to poor and late rains in 1999, however, millet yields were unaffected (Table 1 and figure 2).

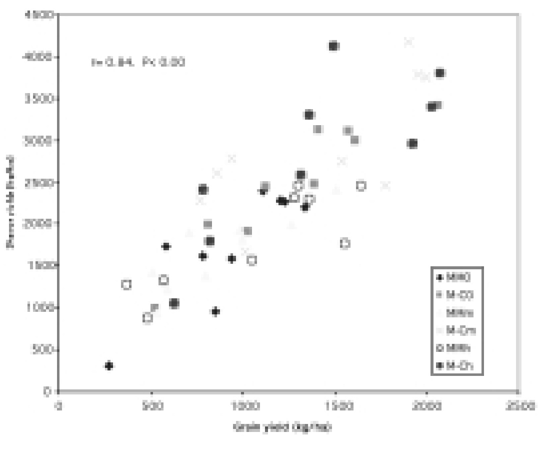

Figure 1: Correlation of millet grain with stover yields (see table 1 for explanation).

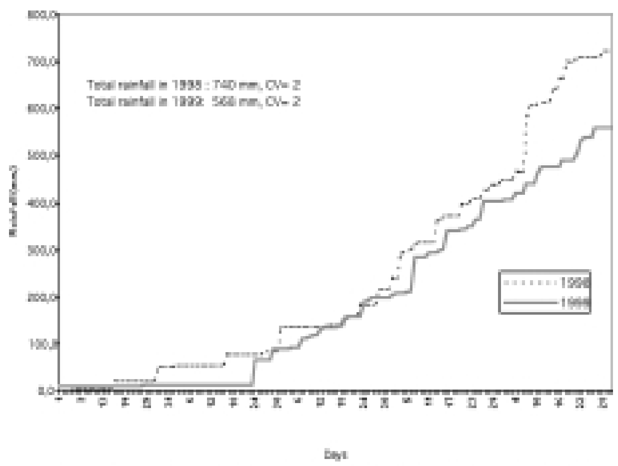

Figure 2: Cumulative growing season rainfall at Sadore in 1998 and 1999.

As expected, cowpea yielded higher in rotations than in intercrop because of low plant population; 24000

In the Sahel, onset of rainfall is inversely related to the length and reliability of the growing season (32, 33) and it is likely that such variability might have hurt cowpea more than drought-tolerant crops like millet and sorghum (14, 21).

Sequential cropping of cereals and legumes has been found generally to improve crop yields and soil organic matter through an increase in production of crop residues. Using regression analysis (31), we estimated N equivalency value of the cowpea component as <1.0 kg $N.ha^{-1}$. Therefore, the high yield of millet in rotation under this circumstances may not necessarily be due to N fixation by cowpea but to other factors embedded in the rotational effect such as pests reduction or moisture conservation (6, 15).

Contribution of soil management options

Among the soil management options, cropping systems emerged as a major contributor to grain and stover yields (Table 2).

Rainfall-use efficiency (RUE)

Rainfall-use efficiency in 1998 was higher in rotations than in sole and intercropped millet. Relative 1998, RUE increased 57% in 1999 in sole millet plots (Table 3), implying that millet used rainfall in 1999 efficiently to produce more grain.

Fertilizer also improved RUE of millet in both years. The relatively high RUE of millet in 1999 is not atypical, as millet is known to adapt well to moisture and nutrient-stressed environments (21). Estimated rainfall for good growth of dryland crops, e.g. millet, averages 5 mm/day (13). The total rainfall in 1999 was 568 mm and that could be said to be adequate for millet, assuming runoff and evaporative losses are minimal. Obviously, crops' moisture demands increase with growth as the season progresses up to physiological maturity. Intercropping with cowpea introduced an

Table 2
Percentage contribution of each source of variation to total variation of yields

Source	1998				1999			
	Millet		Cowpea		Millet		Cowpea	
	Grain	Stover	Grain	Fodder	Grain	Stover	Grain	Fodder
Crop systems (CS)	50.0	63.0	52.0	20.0	54.0	30.0	82.0	68.0
Crop redidue (R)	0.0	0.0	2.0	1.0	0.0	2.0	0.0	3.0
Fertilizer (F)	33.0	27.0	25.0	53.0	36.0	56.0	6.0	13.0
Manure	2.0	5.0	5.0	18.0	2.0	8.0	0.0	8.0
CS*R	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
F*M	0.0	0.0	6.0	2.0	0.0	0.0	1.0	0.0
R*F	0.0	1.0	1.0	2.0	0.0	0.0	0.0	0.0
R*F*M	0.0	0.0	4.0	1.0	0.0	1.0	1.0	0.0

Cropping systems alone explained more than 50% of overall variability in millet and cowpea grain yields and over 20% in stover yields. As stated earlier, systems involving millet and cowpea in rotation were more productive than the other systems tested with respect to yields (Table 1). A mixture of N and P fertilizers was next in importance to yield, followed by manure. Crop residue was the least contributor to yields according to the present study that lasted only two years.

Traditionally, crop residues are removed from fields after harvest for other domestic purposes, therefore, soil organic matter levels tend to be low, usually < 0.25% (8). The potential value of crop residues for soil improvement is adequately established (25). Studies have shown that organic materials stabilize soil macroaggregate between one to five years (11, 27). Thus, the weak contribution of crop residues to yields in this instance may arise from the poor quality (high lignin and low N) of the millet residues (26) or from the fact low quantities of residues were used in view of the low carbon status of the soil. Manure and fertilizer could mask the effect of crop residue as well. It is expected, however, that the high-lignin millet residues will decompose gradually over time to contribute to the improvement of soil organic and other physical properties (26).

additional stress on soil moisture in the system. Consequently, RUE was similar for cowpea in rotations and intercrops in 1998 but reduced five-fold in 1999 ($p= 0.005$). Rainfall was not only less in 1999 than 1998 but also started late. Besides, there was a short dry spell from July 25 to August 10, 1999 (Figure 2). Thus, competition for moisture and possibly light might have occurred and intensified in the course of the growing season since millet seemed to be more resilient to low moisture conditions than cowpea.

Fertilizer-use efficiency

Nutrient-use efficiency of both applied and native soil nutrients measured by the partial factor productivity (PFP) is shown in table 4.

Again, partial factor productivity of fertilizer was higher in rotations than in sole millet crop. As expected, FUE decreased with an increased in fertilizer rate. In rotations, it is possible to obtain 70.6 kg for every kilogram of N and P fertilizer applied as opposed to 54.4 kg in sole millet. Partial factor productivity of fertilizer was almost the same for millet in 1998 and 1999, emphasizing the resilient nature of millet (21). Fertilizer-use efficiency was higher in 1998 than 1999 for cowpea,

Table 3
Analysis of variance of rainfall-use efficiency, RUE, ($kg.mm^{-1}$) of millet and cowpea in cropping systems averaged across crop residue and manure treatments

Crop systems	Fertilizer	1998		1999	
		Millet	Cowpea	Millet	Cowpea
Sole millet	0	0.74		1.40	
	15N + 4.4P	1.42		2.16	
	45N + 13.1P	1.70		2.50	
Millet in rotation	0	1.08		1.55	
	15N + 4.4P	1.85		2.39	
	45N + 13.1P	2.57		3.05	
Millet in intercop	0	0.33		0.72	
	15N + 4.4P	0.72		1.06	
	45N + 13.1P	1.01		1.36	
Cowpea rotation	0		0.94		0.62
	15N + 4.4P		1.13		0.73
	45N + 13.1P		1.25		0.48
Cowpea intercrop	0		1.19		0.31
	15N + 4.4P		1.42		0.21
	45N + 3.1P		1.55		0.14
S.E.		0.08	0.08	0.06	0.03

Probability levels of the difference in RUE between years according to t-test:
$p < 0.0001$ for millet; $p = 0.005$ for cowpea.

Table 4
Partial factor productivity (PFP) of cropping systems averaged across crop residue and manure treatments

Crop systems	Fertilizer	1998		1999	
		Millet	Cowpea	Millet	Cowpea
Sole millet	15N + 4.4P	54.4		69.6	
	45N + 13.1P	21.7		24.5	
Millet in rotation	15N + 4.4P	70.6		70.1	
	45N + 13.1P	32.7		29.8	
Millet intercop	15N + 4.4P	27.6		31.2	
	45N + 13.1P	12.9		13.2	
Cowpea rotation	15N + 4.4P		54.1		21.4
	45N + 13.1P		19.8		4.7
Cowpea intercrop	15N + 4.4P		43.3		6.2
	45N + 13.1P		15.9		1.4
S.E.		1.3	1.1	1.1	0.4

Probability levels of the difference in PFP between years according to t-test:
$p = 0.28$ for millet; $p = 0.02$ for cowpea.

suggesting that cowpea is a poor competitor with millet to applied fertilizer and native soil nutrients under moisture-limited conditions.

Risk

Diversification, be it in investment portfolios or agriculture settings generally yield high economic returns with low risk (3, 16, 24). Information in figures 3 and 4 presents the relative risk associated with the proposed diversified soil management options.

Technologies below the efficient frontier curves have relatively low returns and carry high risk and therefore may be less attractive than technologies on the curve. Specifically, risk analysis for soil management alternatives in 1998 (Figure 3) indicated that rotation of cowpea and millet with no fertilizer was the most efficient choice since it combined high returns of about CFA 350000 with a downside risk of CFA 58000.

Risk analysis of the same treatments in 1999 is shown in figure 4. Again, rotation of cowpea and millet with no

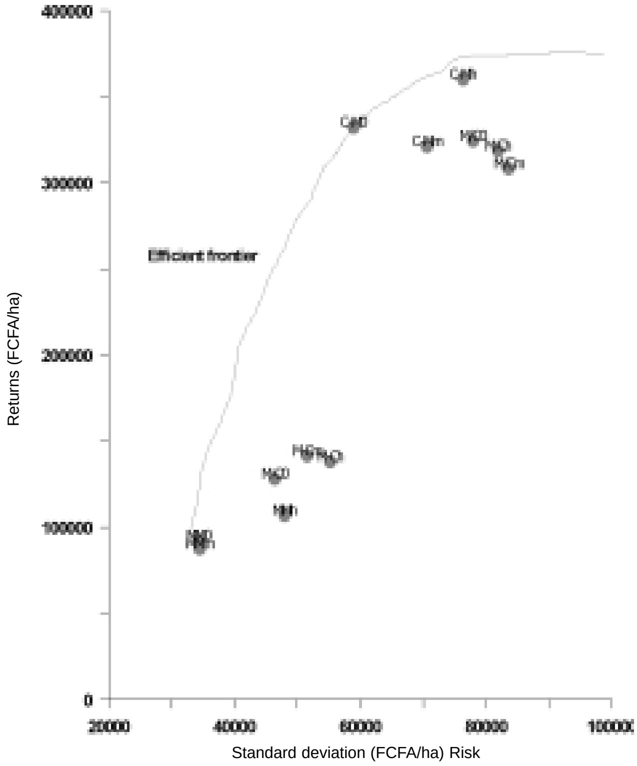

Figure 3: Risk analysis for high rainfall.

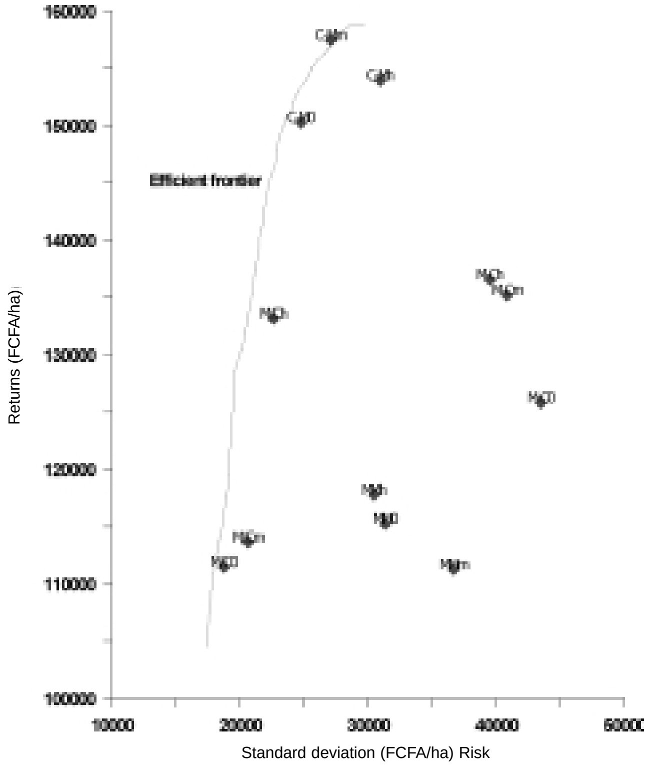

Figure 4: Risk analysis for low rainfall.

and the medium rates of fertilizers were most efficient. Therefore, it may be concluded from this study that cowpea-millet rotation with no and medium fertilizers (4 kg $P.ha^{-1}$ + 15 kg $N.ha^{-1}$) are appropriate for the Sadore area of Niger. Higher returns of the cowpea-millet rotations is largely attributed to the differential prices of cowpea (CFA 260/kg for grain + CFA 50/kg for fodder) and that of millet grain (CFA 100/kg). This underscores the economic benefit of including cowpea in the millet-based cropping systems in the Sahel (32).

These 'portfolios' assure a high return of CFA 350000/ha in a wet year and a modest return of CFA 160000 in a dry year with risks less than CFA 60000 in all cases. Indeed, the risk analyses in figures 3 and 4 provide farmers with management alternatives from which they can select to suit their resources. The conclusion of this study supports the thesis of diversification by Oades (25) in financial investment, as well as Helmers (17) and Yamoah *et al.* (34) in agribusiness. Recent studies on soybean-maize cropping systems established that diversification increased and stabilized farmers' income in the mid-west USA (17).

Literature

1. Adams J.E., 1974, Residual effects of crop rotations on water intake, soil loss and sorghum yield. Agron. J. 66, 299-304.
2. Bache B.W. & Rogers N.E., 1970, Soil phosphate values in relation to phosphate supply to plants from some Nigerian soils. J. Agric. Sci., Camb. 74, 383-390.
3. Baidu-Forson J., 1995, Determinants of the availability of adequate millet stover for mulching in the Sahel. J Sust Agric. 5, 101-116.
4. Baldock B.O. & Musgrave R.B., 1980, Manure and mineral fertilizer effects in continuous and rotational crop sequences in central New York. Agron. J. 72, 511-518.
5. Baldock B.O., Higgs R.L., Paulson W.H., Jackobs J.A. & Shrader W.D., 1981, Legume and mineral fertilizer effects on crop yields in several crop sequences in the upper Mississipi Valley. Agron. J. 73, 885-890.
6. Bagayoko M., Buerkert A., Lung A., Bationo A. & Romheld V., 2000, Cereal/legume rotation effects on cereal growth in Sudano-Sahelian West Africa: soil mineral nitrogen, mycorrhizae and nematodes. Plant and Soil, 218, 103-116.
7. Bationo A. & Ntare B.R., 2000, Rotation and nitrogen fertilizer effects on pearl millet, cowpea and groundnut yield and soil chemical properties in sandy soil in the semi-arid tropics, West Africa. Journal of Agricultural Science, Cambridge, 134, 277-284.
8. Bationo A., Christianson C.B. & Klaij M.C., 1993, The effect of crop residue and fertilizer on pearl millet yields in Niger. Fertilizer Research, 34, 251-258.
9. Bationo A. & Mokwunye A.U., 1991, Role of manures and crop residues in alleviating soil fertility constraints to crop production with special reference to the Sahelian zones of west Africa. Fert. Res. 29, 125-177.
10. Bationo A., Chien S.H., Henao J., Christianson C.B. & Mokwunye A.U., 1990, Agronomic evaluation of two unacidulated and partially acidulated phosphate rocks indigenous to Niger, *in*: Soil Sci. Soc. Am. J. 54, 1772-1777.
11. Buyanovsk G.A., Aslam M. & Wagner G.H., 1994, Carbon turnover in soil physical fractions. Soil Science Society of America Journal, 58, 1167-1173.
12. Cassman K.G., Gines G.C., Dizon M.A., Samson M.I. & Alcantra J.M., 1996, Nitrogen use efficiency in tropical lowland rice system: contribution from indigenous and applied nitrogen. Field Crop Res. 47, 1-12.
13. Cooper P.J.M., Gregory P.J., Tully D. & Harris H.C., 1987, Improving water use efficiency of annual crops in the rainfall farming systems of west Asia and north Africa. Experimental Agriculture, 23, 113-158.
14. Doggett H., 1970, Sorghum. Longmans Publishers, London. P. 187.

15. Green C.J. & Blackmer A.M., 1995, Residue decomposition effects on nitrogen availability to corn following corn or soybean. Soil Science Society of America Journal, 59, 1065-1070.

16. Helmers G.A., Langemeier M.R. & Atwood J. 1986, An economic analysis of alternative cropping systems for east-central Nebraska. Am. J. Altern. Agric. 1, 153-158.

17. Helmers G.A., Yamoah C.F. & Varvel G.E., 2001, Separating crop diversification and rotation yield stability impacts on risk. In press: (Agronomy Journal).

18. Hendrix J.W., Jones K.J. & Mesmith W.C., 1992, Control of pathogenic mycorrhizal fungi in maintenance of soil productivity by crop rotation. J. Prod. Agric. 5, 383-386.

19. Hoshikawa K., 1990, Significance of legume crops in improving the productivity of cropping systems. Paper presented at the International Symposium on the use of stable isotopes in plant nutrition, Soil Fertility and Environmental Studies. Vienna, Austria, 1-5 October.

20. Lal R., 1986, Soil surface management in the tropics for intensive land use and high and sustained production, *in*: Advances in Soil Science, 5, 1-97.

21. Maiti R.K. & Bidinger F.R., 1981, Growth and development of the pearl millet plant. Research Bulletin Nº 6. Pantancheru A.P., India: ICRISAT, 14 pp.

22. Maiti R.K. & Bidinger F.R., 1981, Growth and development of the pearl millet plant. Research Bulletin Nº 6. Patancheru, A.P, India: International Crop Research Institute for the Semi-Arid Tropics.

23. Manu A., Bationo A. & Geiger S.C., 1991, Fertility status of selected millet producing soils of west Africa with emphasis on phosphorus. Soil Science, 152, 315-320.

24. Markowirtz H.M., 1959, Portfolio selection: Efficient diversification of investments, John Wiley & Sons, New York. Pp. 79-97.

25. Oades J.M., 1984, Soil organic matter and structural stability: mechanisms and implications for management. Plant and Soil, 76, 319-337.

26. Palm C.A., Giller K.E., Mafongoya P.L. & Swift M.J., 2000, Management of organic matter in the tropics: Translating theory into practice. In press: Nutrient Cycling in Agroecosystems.

27. Puget P., Chenu C. & Balesdent J., 1995, Total and young organic matter distributions in aggregates of silty cultivated soils. European Journal of soil Science, 46, 449-459.

28. Reddy K.C., 1986, Rapport de l'Agronomie Générale Campagne, INRAN/DRA, Kolo, Niger, 1987.

29. Sanchez P.A., 1976, Properties and Management of Soils in the Tropics. Wiley, New York. 618p.

30. SAS, 1998, StatView reference. SAS Institute Inc. Second edition.

31. Shrader W.D., Caldwell A.R. & Cady F.B., 1966, Estimation of a common nitrogen response function of corn (*Zea mays*) in different crop rotations. Agron. J. 58, 397-401.

32. Shapiro B.I., Sanders J.H., Reddy K.C. & Baker T.G., 1993, Evaluating and adapting new technologies in a high-risk agricultural system-Niger. Agricultural Systems, 42, 153-171.

33. Sivakumar M.V.K., 1990, Exploiting rainy season potential from the onset of rains in the Sahelian zone of west Africa. Agricultural and forest Meteorology, 51, 321-332.

34. Yamoah C.F., Walters D.T., Shapiro C.A., Francis C.A. & Hayes M., 2000, Standardized precipitation index and nitrogen rate effects on yields and risk distribution of maize in rainfed cropping systems. Agriculture, Ecosystems & Environment, 80, 113-120.

C.F. Yamoah, Ghanaian, PhD., Visiting Scientist, International Crop Research Institute for the Semiarid Tropics (ICRISAT), Niamey, Niger.
A. Bationo, Burkinabees, PhD. in Soil Chemistry, AfNET Coordinator, Tropical Soil Biology and Fertility, Nairobi, Kenya.
B. Shapiro, American, PhD., Head-Resource Mobilization, ICRISAT, India.
S. Koala, Canadian, PhD. in Crop and Soil Science, Global Coordinator, Desert Margins Program, ICRISAT Niamey, Niger.