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Management Practices to Increase Yield and Yield Stability of Pearl Millet in Africa

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Abstract

Pearl millet is a staple cereal adapted to the poor soils and low rainfall areas of the semi-arid tropics. The low annual production growth rate in the West African region is attributed to three factors: inherent low soil fertility, limited and untimely cultural operations, and frequent drought periods. Improved millet production depends on plant material and management practices that overcome these limitations while providing stable yields and maintaining or improving the production resource base. Production systems should maximize yield in the good years and guarantee some yield in unfavorable years.

This paper describes fertility, soil, and crop management practices that could have an impact on improving millet production in the major millet growing areas of Africa. These factors are examined in terms of their potential impact on production and their availability to the resource-poor farmer. Important practices that optimize the use of available water are discussed. If farmers of the semi-arid tropics of West Africa improve the fertility of their soils and move from hand tools to using animal traction, increased and stable yields are possible in this drought-prone region.

Résumé

Pratiques de culture visant à augmenter et à stabiliser le rendement en Afrique : *Le mil est une céréale de base adapté aux sols pauvres et à la faible pluviosité des zones tropicales semi-arides. Le faible taux de croissance annuel en Afrique de l'Ouest est attribué à trois éléments : la mauvaise fertilité inhérente du sol, des opérations culturales restreintes et non synchronisées ainsi que des sécheresses fréquentes. L'amélioration de la production du mil dépend du matériel végétal et des pratiques de culture qui permettront de surmonter ces contraintes tout en stabilisant le rendement et en conservant ou améliorant les ressources liées à la production. Les systèmes de production devraient assurer un rendement maximum en année favorable et garantir une production suffisante en année défavorable.*

Cette communication décrit les différentes pratiques d'aménager la fertilité, le sol et la récolte, susceptibles d'améliorer la production dans les importantes zones de culture du mil en Afrique. Ces facteurs sont considérés en termes de leur impact potentiel sur la production et leur accessibilité au paysan démuni. Certaines pratiques d'optimisation de l'eau disponible sont étudiées. L'amendement de la fertilité du sol et le remplacement de la culture manuelle par la culture attelée permettra au paysan ouest africain d'augmenter et de stabiliser les rendements même dans cette région touchée par la sécheresse.

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Pearl millet (*Pennisetum americanum*) is a staple cereal best adapted to the low fertility soils and frequently drought-prone semi-arid tropics of Africa and India It is grown on an estimated 27 million ha in these two regions, with 56% of the production in Africa (FAO 1985a) In Africa, major pearl millet growing areas are in West Africa (83%) and the Sudan (8%), in the Sahelian (300-600 mm annual rainfall) and the Sudanian (600-900 mm) bioclimatic zones Of the 14 million ha grown in West Africa, Nigeria (28%) is the largest producer, followed by Niger (22%), and Mali (10%) The discussion in this paper is confined to implications for these principal millet-growing regions of Africa

Of all the regions of sub-Saharan Africa (SSA) West Africa has shown the slowest growth rate for total food production, mainly due to the very low production rate of the major staples sorghum and millet and the decline in the groundnut cash crop production (Spencer and Sivakumar 1987) The small increase in total food production has been almost exclusively due to increases in cultivated area (Swindale 1985) The new land tends to be in poorer, marginal cropping areas This suggests technological change has had little impact on food production in general, and millet production in particular Early descriptions (Dumas 1905) of millet farming systems in the region differ little from current farming methods Pieri (1985a) cites FAO statistics that indicate for Africa to meet its food needs in the year 2000, increased production will have to come from increased yield per hectare (51%), rather than from expanded cultivated areas (27%), or from more than one crop per year on the same land (22%)

Millet is traditionally reserved for light sandy low fertility soils in areas where rainfall is low and drought common Few yield-increasing inputs are used Management strategies using mainly hand labor, are extensive rather than intensive The crop is grown with low plant populations, normally in association with other crops, particularly cowpeas (*Vigna unguiculata* [L] Walp) and sorghum (*Sorghum bicolor* [L] Moench) Millet grain is used primarily for human consumption, however the straw is important for construction and as standing dry fodder for animal production system

Improved millet production in the West African semi-arid tropics (WASAT) should rely on management practices that increase yields, when possible, while improving production stability in both good and poor rainfall years Farmers' production can be stabilized ... yield variation from year-to-year, and by insuring a carryover of grain from good to poor years.

Although Egharevba (1979), Nwasike et al (1982), and Njoku and Mijindadi (1985) have proposed other limiting factors, the authors consider the principal factors limiting millet yields in WASAT to be in order of priority (1) inherent low soil fertility, (2) limited and untimely cultural practices, and (3) the frequent occurrence of drought periods The first two factors are more limiting than moisture in most years In years when rainfall is inadequate, water-use efficiency and yields can be improved by inputs that address these two factors The improvement of millet production will rely on management practices that overcome these limitations while insuring yield stability and maintenance or improvement of the production resource base Inputs by necessity, will have to be available to the resource-poor farmer

Fertility Management of Millet Production Systems

The poor fertility of millet soils in WASAT is t principal limitation to increased millet yields Orga matter (OM), available phosphorous (P), total trogen (N), and the cation exchange capacity (CE are all low (see Table 4, Spencer and Sivakum 1987) Consistently low yields per hectare in t region are indicative of this poor fertility Traditic ally, farmers have managed these poor soils, mai Entisols and Alfisols, by extended fallowing. Tl permits build up of available N, P, and OM (Ch reau 1972, Nye and Greenland 1960, Jones and W 1975) The increase in land use due to sedentari tion and population growth has reduced or elin nated the fallow period and farmers have be forced to cultivate marginal lands

Millet production is largely determined by t availability of P and N in the soil particularly (Fig 1), and moisture The Dutch-Malian Projet production secondaire (PPS) concluded that t principal limiting factor to animal and plant produ tion in the Sahel region was low soil fertility P and deficiencies are more limiting than low and irregul rainfall (Penning de Vries and Djiteye 1982). High yields and intensified use patterns will remove mo nutrients and deplete the resource base for the fo lowing crop, unless the nutrients are replaced. Su prisingly, this scenario has had little influence i national fertilizer use in sub-Saharan Afric is the lowest in the world at 6 4 kg ha^{-1} (FAO

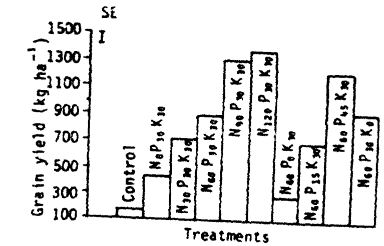


Figure 1 Effect of different rates of nitrogen, phosphorus, and potassium on pearl millet grain yield (Sadore 1985)

Many fertilizer trials have shown that low P and N are major constraints to millet production in WASAT soils (Mughogho et al 1985) The practice of recycling crop residue by incorporating it as compost raw mulch or manure does help to replenish P and N and maintain yields (Charreau and Nicou 1971 Tourte 1971 Pichot et al 1974 Ganry et al 1978 and Pieri 1985a who cites Sedogo and Ganry and Bertheau) Additional benefits occur when fertilizer use and OM maintenance techniques are used together (Fig 2), but the limited availability of these products restricts the application of this strategy to

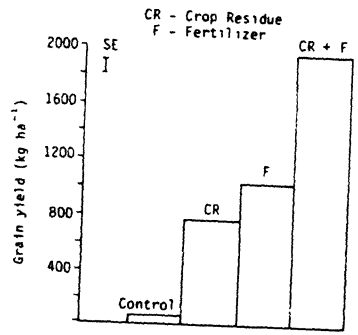


Figure 2. Effect of pearl millet grain response to fertilizer and crop residue application (Sadore, Niger 1985)

maintain soil fertility While immediate soil fertility improvement will largely come from added chemical fertilizers the incorporation of crop residues and manure into the production system are needed to insure its stability (Pieri 1985a)

Although other nutrients such as sulfur, may assume importance in some areas only P and N will be considered because of the general and preponderant limitations they place on production

Phosphorous

Marked P deficiencies in the millet producing soils of WASAT are well documented Research by the French government Tropical Agronomy Research Institute Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) and the WASAT national programs and more recently work of the International Fertilizer Development Center (IFDC) and ICRISAT shows that the major millet producing soil groups are low in P (IRAT 1975 Bationo et al 1985) During 1950-1980 millet responded well to imported combined phosphate fertilizers (Bationo et al 1985) A 1 5 fertilizer/grain yield ratio is possible (Fig 3, and Pichot and Roche 1972) Such substantial yield increases have been achieved with local, improved, and exotic cultivars Moreover, the yield superiority of improved cultivars generally occurs in the presence of adequate soil P (Fussell, personal communication)

Several countries of WASAT have natural rock phosphate (RP) deposits The use of RP for direct application appeared to be an economic means of P fertilization This encouraged early researchers to look at RP as a P source (Jones 1973, Truong et al 1978) The effectiveness of RP depends on its chemical and mineral composition, soil factors and the crop grown Unfortunately, early research on the West African RPs found their agronomic effectiveness limited due to low reactivity, with a resultant inability to supply adequate P in the soil solution (Truong et al 1978) Nonetheless, the RPs of Mali (Tilemsi RP) and Niger (Tahoua RP) are sufficiently soluble to be used for direct application Lack of initial response to the added RP discouraged their use In Niger even though national production, distribution and extension efforts have been established to market Tahoua RP the adoption rate by farmers has been low

Partial acidulation increases the solubility of RP and insures a better initial response by a short-season crop such as millet Recent research in Niger

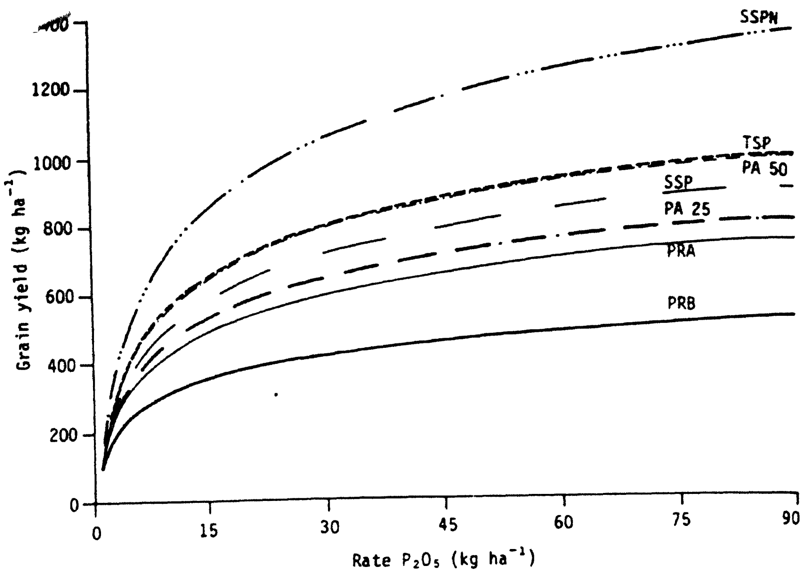


Figure 3. Effect of phosphorus sources and rates on millet grain yield ISC, Niger, rainy season 1985. (SSP = single superphosphate; SSPN = SSP + nitrogen, TSP = Triple superphosphate; PA 50 and PA 25 = partially acidulated rock phosphate treated with 50 or 25% sulfuric acid; PRA = rock phosphate applied annually; PRB = rock phosphate applied as a basal dose triannually).

shows that most RPs, such as found at Parc-W and Kpeme, increase yields up to 95±17.5% of Single Super Phosphate added (equivalent quantity of P) when they are 50% acidulated (Fig. 3, and Bationo et al. 1985). More than three-fold increases in millet yield have been produced on Entisols in Niger. Similar results have been demonstrated in Mali, Burkina Faso, and Senegal (Bationo et al. 1985).

Findings at the farmer level have been less spectacular (44-130% yield increases) but economical even in the severest drought years (ICRISAT 1985). Financial returns were highest at 24 kg ha^{-1} of acidulated RP when millet was sown with the first rains of 369 and 422 mm in two villages in western Niger. Moreover, there were important residual effects of P in the second year because unused P undergoes little leaching as compared to N. This is consistent with other results (ICRISAT 1985).

The importance of mycorrhizal activity to improve P availability in WASAT is under investigation by ICRISAT. Preliminary data indicate high levels of mycorrhizal activity. This research should receive a high priority in the light of the good crop responses to small applications of P. Better understanding of mycorrhizal effects on P uptake and its possible manipulation should lead to more efficient use of applied P.

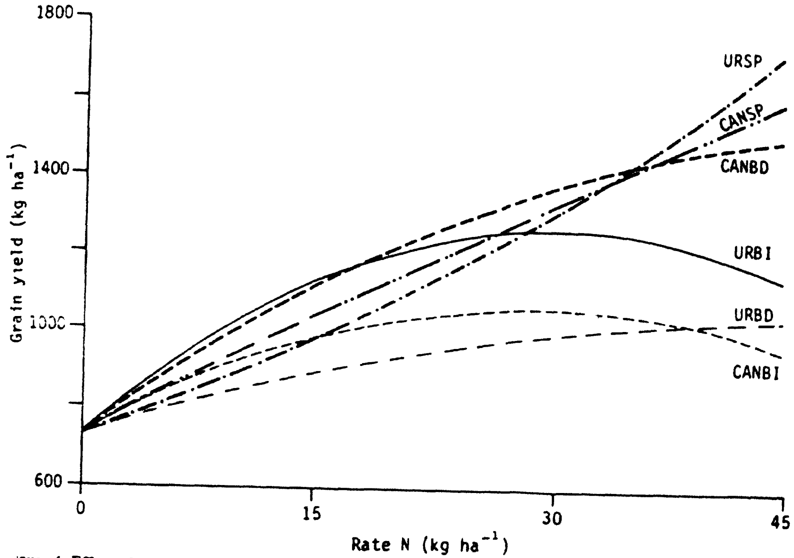
Substantial, financially feasible yield increases are possible at the farm level through the use of partially acidulated local RP. Adapted cultivars, with improved fertilizer-responsiveness, will enable the farmer to increase his return from fertilizer use. Moreover, because P fertilizers can be applied and incorporated before planting, the additional labor requirements do not interfere with critical planting or crop maintenance operations. Acidulated RP has a physical form similar to SSP and applied. Currently, in Niger and Burkina Faso, local authorities are considering local production and distribution of acidulated RP.

Nitrogen

Nitrogen improves millet yields in WASAT only in the presence of adequate P (Ganry et al. 1974, Troaré 1974). Furthermore, the erratic rainfall and poorly buffered soil conditions increase the risk of losing applied N without any yield increase. But with adequate moisture and P, the judicious use of N on millet is an important management strategy. The following discussion considers only the use of chemical and plant nitrogen sources. This does not overlook the importance of mineralized N, especially early in the season, and the importance of timely planting with the first substantial rains to optimiz mineralized N uptake and yields (Greenland 1951 Jones and Wild 1975, Egharevba 1979).

Inorganic N Sources

A number of researchers in WASAT have demonstrated increased millet yields with the use of nitrogenous fertilizers (Ganry et al. 1974, Troaré 1974, Egharevba 1979, FAO 1982, ICRISAT 1984, 1985, 1986, Mughogho et al. 1985, Pieri 1985a). With limited rainfall and newly cleared land, the response to N has been limited. With adequate rainfall and continuous cropping, the response to N is pronounced and varies with N source, application method and timing (Fig. 4). However, the recovery rates are poor, as low as 26% (Mughogho et al. 1985). While it is possible that recovery efficiencies



igure 4. Effect of different sources, rates, time, and methods of placement of nitrogen application on pearl illet grain yield, ISC, Niger, rainy season 1985 (URSP = urea split application; CANSP = calcium mmonium nitrate, split application; CANBD = CAN banding 30 DAE, URBI = urea broadcasting with corporation 30 DAE; URBD = urea banding 30 DAE; CANBI = CAN broadcasting with incorporation 15 AE).

will improve when N is applied in split doses after planting (Fig 4, and Mughogho et al 1985), this may not always be the case (Egharevba 1978) Using split dosages can conflict with other activities, such as weeding, if there is a labor shortage at this time

Organic N Sources

The use of leguminous crop rotations (Pieri 1985a) and intercrop plantings with cereals to provide N are important fertility management practices In Niger, millet yields increased more than two-fold where millet followed 1 year of groundnuts (Brown 1978) Similar observations have been made in the groundnut basin of Senegal It is not clear whether the increased yields were due to the residual effect of N from the legume, or the residual P not used by the legume (Pieri 1985a) However, there is evidence of a combined residual effect of the two (ICRISAT 1985) In low rainfall years the amount of symbiotic N fixed is reduced by as much as 60% in a groundnut crop, but it still constitutes an important and inexpensive source of N (Pieri 1985a, who cites Ganry and Wey)

A viable management strategy is to apply P to a leguminous cash crop and follow this with nonfertilized millet Such a legume/millet crop rotation has been widely practiced in Senegal for many years, and may in part account for the higher average millet yields in Senegal compared to Niger It is possible that strip cropping cereals and legumes could contribute to improved wind erosion control as well as providing a workable crop rotation system

Strategic management of a leguminous intercrop in a given year can also increase millet yields In Mali total crop yield increased up to 100% with a millet/cowpea system where the cowpea intercrop was removed 60 d after the crops were sown It appears that limited amounts of symbiotically fixed N may become available to the millet portion of the intercrop after the cowpea harvest

The productivity of the pastoral system is important to the WASAT economy The use of extended fallow periods has been an important fertility maintenance strategy Research on the possible contributions of leguminous pastures to fodder and N fertility level has been neglected Oversowing legumes such as *Stylosanthes*, into a millet crop is a management strategy that merits study It may contribute N to the following millet crop and provide high quality pastures as well

Agroforestry is important as a source of N to millet cropping systems Species such as *Acacia albida* Del add up to 1 kg ha^{-1} of N to the cropping system for every tree present There are also important windbreak effects (Charreau and Vidal 1965) Such species are cultivated and encouraged in the traditional systems and crops under the trees yield much higher than those away from the trees (Charreau and Vidal 1965) However, this situation could be misinterpreted because of the scavenging nature of the roots that are away from the trees, and because the trees are used by birds for roosting and by cattle for shade, resulting in manure being concentrated around the trees (Breman et al 1984, personal communication) Nonetheless because of the importance of agroforestry in reducing wind erosion and increasing yields (see later sections), the use of leguminous trees in association with millet production should be encouraged

Improved Fertility and Water-Use Efficiency

Improved fertility may or may not increase water use, but it does improve water-use efficiency (WUE) In two contrasting rainfall years at the ICRISAT Sahelian Center (ISC) (1984, 254 mm rainfall, 1985, 540 mm rainfall), millet crops with and without fertilizer used similar amounts of water within each year (ICRISAT 1984, ICRISAT 1985) The use of fertilizer produced up to 75% more total dry matter (TDM) and grain yield As a result water-use efficiency was much higher under improved fertility Improving the fertility of the soil will improve WUE, help stabilize production in poor years, and enable the crop to exploit good rainfall years

Soil Management of Millet Production Systems

The physical properties of the sandy-textured soils where millet is grown are poor Low surface porosity weak structure, susceptibility to crust formation, and low water-holding capacity are the important limiting properties Improved cultivation practices enhance the benefits from the use of organic and inorganic fertilization (Tourte 1971, Charreau and Nicou 1971, IRAT 1975, Egharevba 1979, Pier 1985a) Earlier researchers explored benefits from primary tillage, and in recent years, the effects of modifying the soil surface config have received attention (Nicou and Charreau

Tillage

The beneficial effects of tillage result from reduced (soil) bulk density, which enhances root proliferation, thereby increasing fertilizer recovery and improving WUE Tillage also incorporates organic matter improves weed control, and improves soil moisture conservation Yield increases due to tillage alone are quantitatively modest in the absence of other management techniques (Fig 5) The synergistic effects of tillage with added fertility and improved genotype are critical to its value When tillage was accompanied by other inputs Nicou and Charreau (1985) reported an average 22% yield increase from 38 different experiments Yield advantages from primary tillage are stable or increase in the driest years (Pieri 1985b Pocthier cited by Pieri 1985a)

Reduced bulk density and increased porosity even in very sandy soils improves root penetration (Nicou 1974, Chopart and Nicou 1976, Chopart 1983, Nicou and Charreau 1985) Porosity increases are normally in the order of 10 20% (Nicou and Charreau 1985) which doubles root dry weight during the first 50 d (Chopart 1983) Extensive rooting improves access to existing and applied fertility (Charreau and Nicou 1971) Since the plant can more fully exploit the profile, it can use more of the available moisture, and may be better able to resist drought (Chopart 1975) At the ISC, bulk densities prior to tillage are in the order of 1 55-1 65 t m^{-3} After tillage they are reduced to 1 30 t m^{-3} (ICRISAT 1985) In 1984, an extreme drought year (240 mm), TDM yields increased by 17-29% due to plowing or ridging (ICRISAT 1985) In 1985, an average rainfall year (540 mm) the yield increase due to

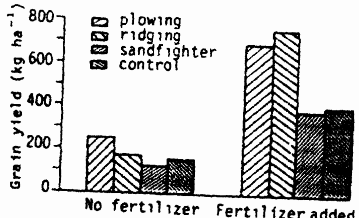


Figure 5. Grain yield responses of pearl millet to fertilizer and presowing cultivation, ISC, Niger 1985. Standard error for comparing tillage means at same or different levels of fertility = ±66 kg ha^{-1}.

tillage in the presence of adequate fertility was 76% at the ISC, a result of increased rooting and improved moisture use (Fig 5)

Because the millet soils of WASAT are acidic, poorly structured and buffered, have low cation exchange capacity and water holding capacity, managing their organic matter status is important The use of tillage to incorporate crop residue (Fig 2), and animal manures, may improve organic matter status

Weeds are controlled by primary and secondary tillage, as well as through weeding operations after the crop has emerged Profile-inverting primary tillage, which buries weeds, or a thorough first weeding, or both operations combined, reduce the need for subsequent weedings thus saving labor Weeding is one of the critical labor bottlenecks in many WASAT traditional systems With adequate weed control competition for nutrients and moisture is reduced during the critical seedling establishment stage

Soil moisture can be conserved at the end of the season with end-of-season tillage operations that eliminate weeds (Charreau and Nicou 1971, Jones 1975, Nicou and Charreau 1985) This may have an important beneficial effect on the following crop, if the season is dry (Dancette and Nicou 1974, cited by Dancette and Hall 1979, Chopart and Nicou 1976)

The benefits of tillage only become substantial in association with other improved practices like the use of important plant materials A fertilizer-responsive genotype, grown with adequate fertility, improved tillage, and improved cultural practices will yield substantially higher than the traditional cultivars with traditional cultural practices

Land Forming

A variety of land forming techniques exist, including terracing, graded or nongraded benches, and leveling Only three hold much promise as management practices for WASAT farmers bedding, as practiced in the broadbed-and-furrow system, ridging, as traditionally practiced in Nigeria (Buntjer 1971), Mali, Senegal, and Niger, and hilling, as practiced in several locations in the Sahelian Zone, including the Seno Plain in Mali

Only ridging is discussed here because on a micro level the effects of ridging, hilling, and bedding are similar At the ISC, where infiltration rates are high (in excess of 150 mm h^{-1}), the effects of ridging on controlling wind erosion and protecting millet seedlings have been noteworthy In 1984 a severe drought year ridging improved the stand by 50% The combination of ridging and the use of genetic material selected for better crop establishment will significantly improve yield Where infiltration rates are lower and where ridges slope ridges tend to concentrate water and increase both runoff and erosion However 'ridge tying and furrow-damming reduce this problem encourage uniform infiltration and considerably increase yields especially in the drier years (Lawes 1963 Kowal and Stockinger 1973 Nicou and Charreau 1985) In wetter years and heavier soils erosion and water stagnation may be aggravated (Kowal 1970a and b)

Ridging concentrates fertility and organic matter in the ridge increasing its availability to the seedling (Kowal and Stockinger 1973) Permanent bed or ridge systems also reduce the total area necessary to till and limit the compacted area to the furrow

Graded beds and furrows improve infiltration by slowing water movement down the slope In addition in permeable soils such as those found at the ISC concentrating water in the furrow increases its effective head Consequently the moisture moves further down the profile (Klaij personal communication) and is less subject to evaporation losses than at the surface At the ISC in 1984 this partly accounted for the advantages that were observed in planting on ridges

The effects of ridging on bulk density organic matter incorporation and improved rooting are similar to those of plowing or other primary tillage techniques

Animal Traction

The majority of tillage planting weeding and farm transport in WASAT is done by hand Developing adequate animal traction systems will increase human efficiency by improving farmers ability to mechanize farm operations and transport capability Animal traction use is relatively widespread in some areas of WASAT (e g the groundnut basin in Senegal) In the Sudanian Zone there are several instances where its acceptance has been instrumental in intensifying the cropping system (e g the cotton zone in Mali) Due to the cost of tractors and their maintenance it is only with animal traction systems that it is possible to replace the large scale use of human labor as a power source for basic farm operations Further more the advantages of primary tillage to crop growth may only be realized through the acceptance of animal traction on a widespread scale Management options are increased by precision farming with improved animal-drawn tool carriers (ICRISAT 1983) Husbanding traction animals provides other benefits to the farmer such as meat skins calves milk production and manure all of which can improve farmer net worth and income

Successful introduction of effective animal traction systems for the full range of crop operations will increase basic options available to WASAT farmers However there is a long learning curve for the use of animal traction and providing the capital and developing the infrastructure to support animal traction systems are inherent problems It is however the only practical means in the foreseeable future to increase the farmers efficiency and the timeliness and precision of operations

Crop Management of Millet Production Systems

Millet crop management based on the choice of an appropriate cultivar cropping method rotation and cultural operations can increase production of the total cropping system improve WUE and provide a more stable return to the farmer

Cultivar Choice

Traditional millet cultivars used by farmers in WASAT are well adapted to the low fertility and low management production systems With better management (e g P and tillage) the choice of a millet cultivar assumes importance Synergistic effects occur with the use of management responsive cultivars in these situations Under conditions of good tillage and management local cultivars maintain low harvest indices (HI ~20%) yet increase leaf area and biological yield Under these conditions improved cultivars have less leaf production yet good biological yields with higher harvest indices (> 35%) Their lower and more efficient water use under improved conditions are a result of a close relationship to leaf area and TDM (Kowal and Kassam 1978 Azam Ali 1983 Azam Ali et al 1984). Research into cultivars that have a higher WUE than cultivars of equivalent cycle length would be productive (Kassam and Kowal 1975) Initial results indicate at least a 20% difference in WUE between cultivars of equivalent duration (ICRISAT 1984)

Farmers need a choice of well adapted millet cultivars of different maturity groups Because rainfall has been below average for the last 15 years in WASAT Higher and consistently stable yields across these low rainfall seasons are the result of growing shorter duration varieties This is understandable as there is a positive linear correlation between crop water requirements and the length of the growing period (Dancette and Hall 1979 Dancette 1983) In optimum growing conditions a 75-day GAM dwarf variety (Group d Amelioration du Mil) uses 390 mm of moisture whereas a 120-day sanio millet uses 630 mm Short duration cultivars of equivalent yield potential are an important management strategy in drought prone WASAT where the probabilities of drought are high at the beginning and end of the season (Spencer and Sivakumar 1987) Methods that predict the growing period will allow millet varieties to be tailored to specific agroclimatic conditions (Dancette 1976) Early maturing millet also conserves moisture in the soil profile that may help the next seasons crop (Hall and Dancette 1978)

Planting and Cultural Techniques

Timely crop management practices are necessary to sustain high millet yields (Ogunlela and Egharevba 1981) Planting with the first substantial rains maximizes grain production in most years Early weeding and thinning contribute to good yields (Monnier 1976 Egharevba 1979) This is particularly important because there are positive synergistic effects between improved soil P and N tillage weed control and higher plant populations (Fig 6 Tourte and Fauche 1953 Tourte and Fauche 1955 Nebos 1970 Nwasike et al 1982 Egharevba et al 1984)

Crop Associations

Millet is traditionally intercropped in WASAT In Niger up to 87% of the millet area is intercropped (Swinton et al 1984) and similar figures are reported for Nigeria (Norman 1974) and Burkina Faso (Sawadogo and Kabore 1984) The most common associations are millet cowpea millet sorghum millet maize millet groundnut and millet/sorghum cowpea In these systems millet is normally sown first and acts as the dominant crop The percentage yield contribution of the crop or crops grown with the millet decreases with decrease in rainfall

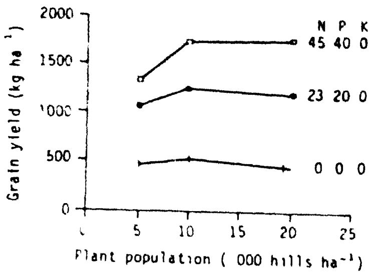


Figure 6 Grain yield response to increases in plant population and fertilizer ISC, Niger rainy season 1985 Standard error for comparing plant population means at the same or different fertilizer level + 56 kg ha

Management strategies designed to increase and stabilize millet yields in WASAT must consider the advantages of traditional cropping patterns and the inherent production goals of the farmer Studies of these traditional systems indicate that a total yield advantage exists and that intercrops are more stable than sole crops (Baker 1978 Baker 1979, Fussell and Serafini 1985) In general millet yields are reduced in an intercrop such as with rampant cowpea, but this is not always the case (Fig 7 Fussell 1985 Serafini 1985) Delayed planting of the intercrop consistently protected cereal crop yields (Serafini 1985) The yield advantages of intercrop systems vary from 10 100% in millet (Fussell and Serafini 1985)

Moreover Norman (1974) concludes mixed cropping is a rational strategy both for profit maximization and risk minimization Production and income stability are important features of the systems (Abalu 1976) which also alleviate seasonal labor peaks (Norman 1974)

The most advantageous millet intercropping systems exploit temporal differences between the crops Millet is generally cropped with a later maturing species such as cowpea (Fussell 1985 Serafini 1985) or sorghum (Baker 1979) There is a temporal separation of the most competitive growth periods and the intercrop is able to utilize those resources not fully used by the millet During the 1985 cropping season at ISC there was little reduction in millet yields while cowpea hay yields increased substantially (Fig 7) Cowpea planted a week later than

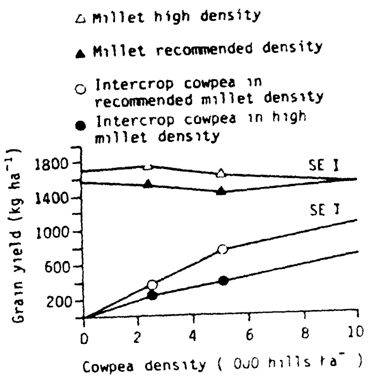


Figure 7 Pearl millet grain yield and cowpea hay responses in a pearl millet/cowpea intercropping system at three cowpea densities ISC, Niger, rainy season 1985

millet exploited the moisture and nutrients not used by the millet without a large reduction in the millet yield because the cowpea had a longer growth duration than the millet Such systems use water more efficiently than sole millet (Fussell 1985) In a year when drought occurs early in the season the crop planted first millet will substantially suppress the non millet component This protects the production of the staple cereal

Millet intercrop genotypic interactions have not been adequately investigated There should be plant types of both the cereal and the legume that will contribute to increased efficiency and production of the intercrop

The inherent flexibility of millet intercropping systems is an important aspect of their use The producer is able to decide when and how much of the second crop should be planted because millet is planted first Should there be an early season drought the density of the intercrop can be reduced or eliminated On the other hand if millet establishes poorly the density of the second crop can be increased a traditional practice the authors have observed in farmers fields in Niger and Mali

Considering these aspects intercropping millet with other crops is consistent with other management strategies such as animal traction designed to increase yields and stabilize production (McIntire 1983)

Agroforestry

The importance of trees in traditional agriculture of WASAT was highlighted by Charreau and Vidal (1965) in research on the role of *Acacia albida* Del Other frequently encountered species include *Butyrospermum parkii* (G Don) Kotschy (karite) *Parkia biglobosa* (Jacq) Benth (nere) *Adansonia digitata* L (Baobab) and *Ballanites aegyptiaca* (L) Del (dattier sauvage) These trees contribute substantially to the diversity and productivity of the farm enterprise through production of oil (karite) fodder (*A albida* and others) firewood (all) fiber (Baobab) food (Baobab Nieri and others) medicine repellants and poisons (von Maydell 1983 Weber 1977 Weber and Hoskins 1983) Browse should contribute 20 25% of the fodder intake in the transhumant pastoral system for cattle sheep and goats (Le Houerou 1980) Balanced and productive millet based systems for the Sudanian and Sahelian Zones are those that exploit the agroforestry and livestock contributions to the system (Taylor and Soumare 1983)

Trees may beneficially affect the microenvironment of a millet crop by having different growing cycles and using the resource base differently than millet *A albida* is a classic example it is deciduous during the rainy season (Charreau and Vidal 1965, Dancette and Poulain 1969) and is deep-rooted exploiting moisture in the profile below that is used by the cereal Using the Bambey (Senegal) region as an example Dancette and Hall (1979) estimate that 650 mm of annual rainfall could support a millet crop which uses 400 mm of water weeds and groundwater rechange of 100 mm leaving 150 mm of water that would support 22 *Acacia* trees ha⁻¹ Trees create air turbulence that lowers evaporative demand by reducing wind speed provide some shade for the crop and protect the soil from erosion (Dancette and Poulain 1969 Bognetteau Verlinden 1980 Ujah and Adeoye 1984) Millet yields have increased by as much as 26% in the presence of adequate tree lines (Bognetteau Verlinden 1980)

Trees are also important in nutrient cycling leached cations are redeposited at the soil surface in the form of fallen leaves and fruits For example, the practice of burning karite leaves just prior to the planting season releases K and Ca for the crop, which may have a critical impact on soil p[illegible] as [illegible] The nitrogen contribution of leguminous trees has been discussed above and is particularly important where the efficiency rates for applied N are low and the chemical forms of N are expensive and difficult to procure

A albida galleries cover many millet fields in WASAT The authors have noted instances where they estimated that *A albida* covered more than 50% of the crop surface Alley cropping systems as suggested by Dancette and Poulain (1969) using *A albida* as well as other adapted trees and shrubs are feasible and may be an advantageous part of any millet management system in WASAT

Conclusions

The poor performance of the WASAT food production system is attributed in part to the very low productivity of the major staple sorghum and millet For the region to meet its food needs in the year 2000 increased production must come from increased yield per unit area Management practices must alleviate the effects of the principal factors limiting millet yields inherent low soil fertility limited and untimely cultural operations and frequent drought periods The first two factors are often more limiting than irregular and insufficient rainfall Higher soil fertility and improved cultural practices will improve WUE and increase yields

Sound management practices to alleviate the primary limitations include

- the use of combined and acidulated rock phosphates
- the use of biological sources of N in particular legume crop rotations, stable and efficient intercropping and agroforestry
- the incorporation of crop residues and animal manures
- efficient primary and secondary tillage using animal traction including land forming techniques
- the choice of management responsive water use efficient varieties tailored to the current agroclimatic conditions
- timely crop management practices and
- maintenance and systemization of trees and shrubs as a part of the millet farming system

The resource poor farmer is not likely to adopt all these management practices Previous experiences indicate that farmers tend to adopt and adapt parts of technical packages Therefore resource management systems need to be developed at a number of levels so farmers may choose strategies and techniques appropriate to their specific situations In some cases infrastructure improvements need to be encouraged and even subsidized by the governments of the region (e g rock phosphate industries) Improved soil fertility is the starting point of any management strategy to increase millet yields in the region Other management options will have positive synergistic effects with improved fertility

Additional management options may result from further research

- increasing the effect of mycorrhizal associations on P uptake
- use of leguminous pastures as a source of N and animal feed
- the examination of the long term effects of tillage and land forming techniques
- choice of varieties both in sole and intercropping systems that maximize production and WUE and
- development of efficient integrated agroforestry systems

Low rainfall does mean lower millet yields None theless yields and WUE can be improved through the judicious use of fertilizers In the presence of adequate fertility other management practices will have a positive impact as well and will improve stability over time Current traditional management practices fail to take advantage of good years because moisture is not the principal limiting factor Management practices are available which in some cases need to be refined that guarantee production in poor years and take full advantage of better rainfall years

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