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PEARL MILLET-BASED INTERCROPPING SYSTEMS IN THE SEMIARID AREAS OF SENEGAL

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ABSTRACT

Pearl Millet (*Pennisetum glaucum* (L.) R. Br.) is one of the principal cereal crops grown in the semiarid agroecosystem of Senegal. It usually is cultivated as a monocrop but yields are low because of inappropriate management and erratic rainfall. The objective of this study was to investigate the potential of agronomic practices, cultural methods and application of organic manures in maintaining crop productivity in pearl millet-based intercropping systems. On-farm research was conducted from 1989 to 1995 to evaluate performance of different millet varieties intercropped with grain and forage cowpea (*Vigna unguiculata* (L.)Walp.) in two ecozones in the peanut zone of Senegal. The treatments imposed on the experimental units comprised of appropriate cultural techniques and application of compost and rock phosphate. The ecozones were the Central North Region (CNR) and the Central South Region (CSR). Mean rainfall in CNR ranges from 300 to 500 mm y^{-1} and in the CSR it ranges from 500 to 750 mm y^{-1}. High-yielding millet varieties selected were IBV 8004 and Souna3 for the CNR and CSR. Sole-crop yields were higher than intercrop yields for both species but the millet-grain cowpea intercrop association was more productive than sole crops with a Land Equivalent Ratio of more than one. Millet variety IBV 8004 in sole crop as in intercrop association was more stable than was Souna 3. The yield of selected millet varieties increased more than 40% by compost application as compared to the control with no nutrients applied. There was an additional 10% increase in yield when compost was supplemented with rock phosphate.

Key Words: Compost, intercrop association, land equivalent ratio, *Pennisentum glaucum*

RÉSUMÉ

Le millet (*Pennisetum glaucum* (L.) R. Br.) est l'un des principaux céréals plantés dans la région agro-écologique semi-aride du Sénégal. Il est souvent cultivé en monocrop mais le rendement est généralement faible à cause de la gestion inappropriée et des pluies érratiques. L'objectif de cette étude était d'évaluer le potentiel des pratiques agronomiques, méthodes de cultures et l'application des matières organiques pour maintenir la productivité dans le système d'interculture basé sur pennisetum glaucum. Des recherches sur champs étaient conduites entre 1989 et 1995 pour évaluer la performance des différentes variétés du millet en combinaison avec le niébé (*Vigna unguiculata* (L) Walp.) dans deux zones écologiques de la cacahuète au Sénégal. Les traitements imposés sur l'unité expérimentale comprenaient des techniques de cultures appropriées et l'application des compostes et du phosphate des roches. Les zones écologiques étaient la région centrale du nord (RCN) et centrale du sud (RCS). La moyenne pluviométrique dans le RCN rangée entre 300 et 500 mm y^{-1} et dans le RCS elle range entre 500 et 700 mm y^{-1}. Les varétés du millet à forte rendement sélectionnées étaient IBV 8004 et Souna 3 pour le RCN et RCS. Le rendement associé à la monoculture était élévé pour les deux espèces mais le millet-niébé combiné était plus productive que la monoculture avec un taux de terre équivalent de plus que un. La variété IBV 8004 en monoculture comme en combinaison était plus stable que le Souna 3. Le rendement des variétés de millet sélectionnées augmenta de 40% avec l'application du composte comparées au contrôle sans intrants. Il y avait une augmentation de 10% en rendement quand le composte était ajouté au phosphate des roches.

Mots Clés: Composte, interculture, taux de terres équivalentes, *Pennisentum glaucum*

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is one of the principal cereal crops cultivated in the semi-arid environment of Senegal with approximately 600,000 T y^{-1} (Anon., 1995). The millet production represents about 60% of total cereal production which covers only 52% of cereal population needs (Anon., 1986). The principal millet production regions are the semi-arid areas of central Senegal known as the peanut zone.

Millet is cultivated either as sole crop or in association with crops such as cowpea, sorghum and peanut. Millet yields on farm fields are generally less than 750 kg ha^{-1} (Diouf, 1990; Bationo *et al.*, 1993). Previous exploratory studies identified five causes responsible for poor millet yields at farm level: 1) low and unreliable rainfall; 2) infertile soils; 3) poor cultural practices; 4) use of low-yielding varieties; and 5) high cost of fertilisers and pesticides (Fofana and Mbaye, 1990). Little information is available on the potential of cultural practices and intercropping as strategies to overcome these problems.

The present study presents the results of seven years of on-farm research on improved millet varieties with emphasis on millet plant spacing, fertilization and intercrop association with cowpea (*Vigna unguiculata* L. Walp).

This research had two objectives: 1) to assess the adaptability of millet improved varieties across different environments; and 2) to identify suitable millet varieties, best plant spacing, and fertiliser practices for intercrop production of millet and cowpea.

MATERIALS AND METHODS

The study was carried out under dryland production in the peanut basin of Senegal from 1989 to 1995 on farmers' fields in the Central North (CNR) and Central South (CSR) regions. Mean rainfall (1986-1995) in CNR (Louga, Diourbel, Thies) ranges from 300 to 500 mm y^{-1} and in the CSR (Kaolack, Fatick) it ranges from 500 to 750 mm y^{-1} with mean annual temperature throughout these regions ranging from 20 to 35°C (ISRA, 1995). Average length of the cropping season which starts in June is 90 and 120 days in the CNR and the CSR, respectively (Khalfaoui, 1991). Generally, soils of this zone are sandy, have low organic matter content and are highly leached with a preponderance of iron concretions (Blondel, 1971; Ganry, 1974; Badiane *et al.*, 2000). Soil pH, clay+silt, total carbon, total nitrogen, and extractable phosphorus, determined by standard analytical methods for tropical soils (IITA, 1977), are presented in Table 1.

Three major field studies were conducted from 1989 to 1995: adaptability, intercrop association and fertility trials. In all trials there were 24 farms, 12 in each zone.

Adaptability trial. Six improved millet varieties were tested on farm fields in the CSR and CNR regions. The varieties were Souna 3, GAM 8203, IBV 8001 for the south, and IBV 8004, GAM 8301 and IBMV 8402 for the north. Local varieties from each region also were included in the test. Plant spacing was 90 cm by 90 cm. The plot size was 12 rows of 13 hills, with 90 cm between and within the rows. Basal fertiliser application was carried out at the rate of 150 kg NPK ha^{-1} as 10-21-21 and two side-dressed applications of 50 kg N ha^{-1} as urea after 15 and 40 days after sowing. Sowing dates varied from the first and the second weeks of July in the CSR and the CNR, respectively. The varieties were compared in a randomised complete design, with four replicates. The experiment lasted three years, 1989 to 1991. Grain yield was determined from the centre ten rows of each plot and ajusted to 12.5% moisture content.

Intercrop association. This study was conducted from 1992 to 1994. The highest yielding varieties from the adaptability trial were selected for intercopping with cowpea. These were Souna 3 and IBV 8001 for the south and IBV 8004 and IBMV 8402 for the north. The intercrop cowpea varieties were Ndiambour for grain and 58-74 for forage.

Three spatial planting arrangements were tested. First, millet was spaced 100 cm between rows and 90 cm within row with one row of forage or grain cowpea seeded between the millet rows. The plot size was 9 rows of 13 hills for millet and 8 rows of 19 hills for cowpea. The second arrangement was 90 cm within and 150 cm between millet rows with two cowpea rows sown between the millet rows. The plot size was 7 rows of 13 hills for millet and 12 rows of 19 hills for cowpea. The third pattern was the same as the second except that the within row spacing of millet was 60 cm instead of 90 cm. The plot size was 7 rows of 19 hills for millet and 12 rows for 19 hills of cowpea. The sole crop spacings were 90 by 90 cm for millet and 50 by 60 cm for the cowpea. The plot size of the sole crops were 11 rows of 13 hills for millet and 19 rows of 19 hills for cowpea.

The treatments were laid out in a randomized complete block design with three replicates. The millet was sown in the first and second weeks of July in the CSR and in the CNR, respectively. The cowpea was sown one week after the millet.

In each system, grain yield was determined from the central rows, not included in the last row of each side of the plot. The Land Equivalent Ratios of the associations were calculated to determine the efficiency of land use relative to the sole crops using the formula:

LER = (Millet yield in association/millet yield in sole crop) +(Cowpea yield in association/ cowpea yield in sole crop).

Fertility trial. In the third study, the effects of fertility treatments on intercrop productivity were determined from 1994-1995. Fertility trial was conducted with the best suitable variety for intercrop association in each zone. The treatments were the control with no nutrients applied, 2 t ha^{-1} compost, and 2 t ha^{-1} compost + 13 kg P ha^{-1}, as natural rock phosphate containing 30% P_2O_5 (Ndiaye, 1977). Souna 3 and IBV 8004 were sown in CSR and CNR, respectively, in intercrop association with both the grain and forage cowpea varieties. Millet was sown at 60 x 150 cm with 2 cowpea rows between millet rows. Sole crop treatments were included with plant spacing as in the second study. The treatments were laid out in a randomised complete block design with three replications. Millet was planted in mid-June and

TABLE 1. Soils characteristics of representative sites of the Central North and Central South regions of Senegal

Sites	Depthcm	pH		Clay + silt	Total C	Total N	Total P	Extractable
		H_2O	KCl			%		µg g^{-1}
				Central North				
Bambey	0-20	6.60	5.94	6.00	0.32	0.03	0.03	82
	20-40	6.18	5.20	6.80	0.17	0.02	0.02	60
Ndiamsil	0-20	5.20	4.30	11.20	0.22	0.02	0.03	33
	20-40	5.10	4.20	14.60	0.2	0.02	0.03	40
Babak	0-20	5.80	4.90	7.00	0.31	0.03	0.31	505
	20-40	4.10	4.90	7.90	0.29	0.03	0.32	483
				Central South				
Nioro	0-20	5.86	5.23	12.30	3.70	0.32	0.37	204
	20-40	5.55	4.99	15.00	2.68	0.25	0.32	107
Diofior	0-20	7.00	6.60	8.60	3.90	0.40	0.40	282
	20-40	7.40	7.00	8.80	2.70	0.30	0.50	218

cowpea in the first week of July. Weeds in all the experiments were controlled by hand cultivation.

Stability of the systems was determined by regressing grain yield of each system against average yields of each location (Hilderbrand and Russell, 1996) and using the slopes and standard error of the slope as evaluation criteria (Eberhart and Russell, 1966). Statistical analyses were performed using SPSS (Norusis, 1997) and MSTAT-C (Anon., 1988).

RESULTS AND DISCUSSION

Soil. Soils were highly variable among sites for P and pH (Table 1). Extractable P ranged from 33 at Ndiamsil to 505 ppm at Babak, and pH from 4.1 in the subsoil at Babak to pH 7.4 in the subsoil at Diofior (Table 1). The high amount of phosphorus in Babak soil is related to the presence of natural rock phosphate deposit in this area (Collot, 1952; Bouyer, 1954; Ndiaye, 1977). The analyses confirmed sandy structure (>80% of sand) and low organic matter content of soils in the peanut basin as mentioned by Badiane *et al.* (2000).

Adaptability trial. Results of the improved millet variety trials for the two regions are presented in Table 2. Variety IBV 8004 yielded most (1310 kg ha^{-1}) and the local cultivar least (960 kg ha^{-1}) in CNR with a mean yield for all varieties of 1100 kg ha^{-1} across all sites and years. Yield of IBV 8004 exceeded the mean yield in 66% of the site years and was judged to be the best variety for diffusion in the CNR.

The mean yield for CSR was 1446 kg ha^{-1}. Souna 3 yielded most (Table 2) and exceeded the mean in 75% of the site years as compared to 25% for the local cultivar. Souna 3 was judged to be the best variety for CSR. Yield of GAM 8203 was superior to that of IBV 8001 and the control but the differences were not significant.

Intercrop association. Yields of millet and cowpea in sole crops and in associations are shown in Table 3. In CNR, intercrop millet yields were not significantly less than sole crop yields with grain cowpea but were significantly reduced with forage cowpea as the associated crop. Intercrop yield of millet and cowpea were 82% and 38%, respectively of the sole crop. Land Equivalent Ratios (LER) of the intercrops averaged over cropping patterns are presented in Table 4. The LERs for intercropping with grain cowpea ranged from 0.99 to 1.08 and were higher than for forage cowpea intercrop where LER ranged from 0.93 to 1.03. There is no yield advantage to intercropping millet with in the CNR but farmers may prefer intercropping as a strategy to ensure food security.

In CSR, competition with both grain and forage cowpea resulted in reduced millet yields as compared to sole crop millet. Intercrop grain cowpea relative to sole crop yield was less reduced in CSR compared to CNR, while intercrop forage cowpea was much reduced in CSR as well. The millet-grain cowpea intercrop association is much more promising in the CSR than in CNR with LERs ranging from 1.22 to 1.5. The LERs for intercropping with forage cowpea were near 1 however, with no yield advantage as compared to sole crop production.

The effect of planting pattern on yield was not significant for millet nor cowpea. Sowing a single row of cowpea between millet rows spaced at 100 cm with 90 cm within row spacing had slightly higher LERs than other planting arrangements. Intercropping millet with grain cowpea was more stable than that of forage cowpea as indicated by low standard error of the slope (s.e.=0.06) but was less responsive to favorable environment with a slope of 0.59. This is in agreement with earlier studies which indicate that intercropping systems reduce yield variability and increase stability in ecosystems (Fussel and Serafini, 1986).

TABLE 2. Yields of millet varieties averaged across sites and years in the Central North and Central South regions of Senegal

Region	Variety	Yield (kg ha^{-1})
Central North	IBV 8004	1310
	GAM 8301	1070
	BMV 8402	1065
	Local	960
LSD 0.05		215
Central South	Souna 3	1775
	GAM 8203	1500
	IBV 8001	1300
	Local	1210
LSD 0.05		360

Conversely, millet intercropped with forage cowpea was less stable (s.e. = 0.24) and relatively more responsive to good environment, slope =0.98 (Table 5).

Fertility trial. The effect of compost on variety IBV8004 in association with cowpea for CNR is depicted in Table 5. In this case, pure millet or millet intercropped with grain cowpea (Ndiambour) yielded higher than did the millet/ forage cowpea (58-74) intercrop.

In the CNR region, application of compost gave a yield of 1343 kg ha^{-1}, and compost supplemented with rock phosphate resulted in an additional 13% increase in yield. Clearly, millet fertilised with compost and rock phosphate was most responsive to this environment as shown by the slope (1.47). The non-fertilised millet was the least responsive to environment with a slope of 0.3. These findings are in agreement with Dirks and Bolton (1981) who reported that crops do better under good management and favorable environments.

TABLE 3. Yields (kg ha^{-1}) of millet and cowpea varieties averaged across cropping patterns in the Central North and Central South regions of Senegal

Cropping system	Millet variety	Cowpea variety	
	——— kg ha^{-1} ———		
	Central North		
	IBV 8004	Ndiambour	58-74
Sole	1740a†	1023a	777a
Intercrop	1415b	200b	160b
	IBMV 8402	Ndiambour	58-74
Sole	1456a	1023a	777a
Intercrop	1220ab	178b	140b
	Central South		
	Souna 3	Ndiambour	58-74
Sole	1534a†	1093a	812a
Intercrop	1170ab	650b	185b
	IBV 8001	Ndiambour	58-74
Sole	1605a	1093a	812a
Intercrop	1270ab	615b	180b

†Yields between sole and intercrop by variety in columns followed by the same letters are not significantly different ($P < 0.05$)

TABLE 4. Land equivalent ratios of millet/cowpea associations averaged over cropping patterns

Millet variety	Cowpea variety	
	Ndiambour	58-74
	Central North	
IBV 8004	1.04	0.99
IBMV 8402	1.06	0.97
	Central South	
Souna 3	1.37	1.00
IBV 8001	1.30	1.03

The millet variety Souna 3, as sole crop or in association with forage cowpea, was relatively less responsive to conditions in the CSR as indicated by relatively lower slopes of 0.53. Also, deviations from the slopes were relatively large, (s.e.=0.33) signifying greater variability in yields of the pure millet and millet in forage cowpea association.

As expected, millet fertilised with compost + rock phosphate yielded higher (1560kg ha^{-1}) and was more responsive to conditions in the CSR zone (slope=1.20) and relatively stable (s.e.=0.22). Millet fertilised with compost alone yielded 1453 kg ha^{-1} and similarly moderately responded to site

TABLE 5. Regression of millet yields in cowpea (var. Ndiambour, grain; var. 58-74, forage) millet association against average yields at 12 sites in two agroecological zones

Treatment	Intercept	Slope	s.e.	R^2	Prob.
Millet (var. IBV8004) in association with cowpea					
			Central North region		
Pure millet	1292	0.80	0.18	0.65	0.0014
Millet/Ndiambour	1264	0.59	0.06	0.91	<0.0001
Millet/58-74	1194	0.98	0.24	0.62	0.0022
S.E. (yield)	57				
Compost					
0	892	0.30	0.09	0.48	0.011
2 t ha^{-1} compost	1343	1.20	0.15	0.87	<0.0001
2 t ha^{-1} compost+P_2O_5	1515	1.47	0.17	0.87	<0.0001
Millet (var. Souna 3) in association with cowpea					
			Central South region		
Pure millet	1383	0.53	0.33	0.19	0.1414
Millet/Ndiambour	1387	1.4	0.28	0.70	0.0003
Millet/58-74	1307	1.0	0.32	0.46	0.0106
S.E. (yield)	41				
Compost					
0	1061	0.82	0.19	0.64	0.0018
2 t ha^{-1} compost	1453	0.98	0.21	0.69	0.0009
2 t ha^{-1} compost+P_2O_5	1560	1.20	0.22	0.74	0.0003

conditions of CSR (slope=0.98) and stable (s.e.=0.21). In terms of yield performance, the two treatments with compost out performed the control (without compost).

CONCLUSIONS

In Central North region, which is a low rainfall area of Senegal, the millet variety IBV 8004 was best adapted. Souna 3 was most appropriate in the wetter Central South region. This study shows the importance of site specificity for intercropping systems. First, it seems that in Senegal rainfall of >600mm is required to achieve a significant yield advantage for a millet/cowpea intercrop over sole crops. Secondly, the choice of intercrop cultivars can be important. For millet, it appears that a locally adapted millet variety for each region will work well, whereas for cowpea the variety Ndiambour was best for intercropping in both regions. Thirdly, crop patterns tested in this study were unimportant in terms of yield and LER.

Millet (variety IBV 8004) intercropped with grain cowpea was most stable across environments in the Central North region (s.e.=0.06, R^2=0.91). Pure millet (variety Souna 3) was least responsive to site conditions in the Central South Region (s.e.=0.33, R^2=0.14). The selected millet varieties significantly (P<0.001) responded to compost across environments in the two ecozones.

Overall, this work stresses the importance of considering location/climate, and varietal selection, for intercrop systems. The work shows that more integrated systems that use intercrops and compost soil amendments (rock phosphate) can increase yield stability and reduce risks for farmers.

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