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Biomass production, yields and water use efficiency in some pearl millet/legume cropping systems at Sadoré, Niger

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Abstract From 1986 to 1989 different cropping systems combining pearl millet (*Pennisetum glaucum*) and legumes (*Vigna unguiculata*, *Sesbania pachycarpa*, and *Stylosanthes hamata*) were evaluated at the ICRISAT Sahelian Center, Sadoré, Niger. Pearl millet was grown continuously as a sole crop or as an intercrop for three years. In the last year (1989), only the cereal was grown in all treatments to compare residual effects of the legumes. Water use was monitored throughout the different cropping seasons from 1987 to 1989. Total biomass production and grain yields results from 1986 to 1989 showed competition and residual effects. The continuous pearl millet/forage legume system seems to be the most efficient in terms of production and water use efficiency.

INTRODUCTION

During the past two decades the average growth rate of cereal production in the Sudano-Sahelian region of West Africa has been 1% compared to an average population growth rate of 3%. The increase in production has resulted mainly from the extension of the area under cultivation and the use of marginal lands previously devoted to livestock for browsing and grazing. Farmers have reduced, and in some cases ceased, the traditional practice of regenerating the soil by fallowing and consequently the resource base is degrading. The use of inputs such as fertilizer allows the production to increase through increased productivity per unit area under cultivation and helps rehabilitate the soils and improves the sustainability of the system. However, farmers in the region cannot afford high cost inputs and, therefore one of the goals of our research programme is to identify low cost inputs, test them at the research station and transfer them to the farm level in collaboration with the National research programmes and extension services.

Fertilizer applications have been and are still studied by various research institutions. Phosphorus is the most limiting nutrient in the soils and its use at economical rates such as 24 kg P_2O_5 ha^{-1} (ICRISAT, 1987) is strongly recommended. Nitrogen application is more critical. The use of nitrogen at the farm level for pearl millet production cannot be generalized for various reasons. It seems preferable to rely on nitrogen fixation by legumes with subsequent transfer to the cereal. This may partly or entirely substitute for N fertilization in intercrops, and relay crops composed of simultaneously growing legume and non leguminous species. Another important aspect is the improvement of the nutritive value of the pearl millet straw by the addition of legume hay (Renard & Garba, 1989).

At the ICRISAT Sahelian Center (ISC), Sadoré, we started research on pearl millet cropping systems associating a grain legume, cowpea and forage legumes, *Sesbania pachycarpa* DC. and *Stylosanthes hamata* (L.) Taub. Cowpea is traditionally intercropped in pearl millet in the Sahel. *Sesbania* is an indigenous annual legume, which is widespread in Niger. *Stylosanthes hamata* is a short perennial legume that originated in Colombia (Humphreys, 1981). The cereal/legume association, particularly when a perennial legume is associated, allows a better use of limited natural resources: water and nutrients. However, proper design and management of the system must be studied to maximize the productivity and to minimize any adverse effects of competition. This paper presents the results of water-use and growth studies in a number of cereal/legume mixtures throughout four rainy seasons.

MATERIAL AND METHODS

The experiments were conducted between 1986 and 1989 at the ICRISAT Sahelian Center located at Sadoré, Niger. The characteristics of the site, the climatology, and soil properties are given by Sivakumar (1986) and Sivakumar *et al.* (1990).

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) cv CIVT was grown either as a pure crop or in association with cowpea (*Vigna unguiculata* (L.) Walp.), *Sesbania pachycarpa* DC., and two cultivars of Stylo (*Stylosanthes hamata* (L.) Taub.) cv 147 from CIAT (Centro International de Agricultura Tropical, Colombia) and Verano from Australia.

The experiment used is a complete randomized block design with 13 treatments and four replications. Of the 13 treatments, eight had been designed to compare the residual effect of the intercropped legume on pure pearl millet the following year. Those eight treatments will not be considered here, since they do not contribute to the subject of this paper. The treatments under consideration here are given in Table 1. From 1986 to

Table 1 Experimental treatments of the pearl millet/legume associations, ISC, Sadoré, Niger 1986–1988

Treatment	1986-1988	1989
1	PM	PM
2	PM/C	PM
3	PM/S	PM
4	PM/147	PM
5	PM/V	PM

PM = Pearl millet; C = cowpea; S = Sesbania pachycarpa; 147 = Stylosanthes hamata cv 147; V = Stylosanthes hamata cv Verano.

1988, pearl millet was grown either as a pure crop or as an intercrop. In 1989, all plots were sown to pure pearl millet to evaluate the residual effect of the associations from the previous years.

Pearl millet and cowpea were sown at a density of 10 000 hills ha^{-1}. The other legumes were sown in rows at the rate of 4 kg ha^{-1}. Pearl millet was sown with the first sowing rains and the legumes, two or three weeks after. Before sowing, 13 kg P ha^{-1} had been broadcasted in all plots and nitrogen was applied at a rate of 15 kg ha^{-1} after the first weeding.

Soil moisture measurements were made during the 1987, 1988 and 1989 seasons using a neutron probe (Solo 25, Nardeux Humisol, France). Two neutron probe access tubes 3 m deep were installed in two plots in each treatment. Measurements were taken at depths of 10, 20, 30 cm and thereafter every 20 cm down to 250 cm every two weeks from the start of the rainy season until November.

RESULTS

Climate

Figure 1 shows monthly rainfall data for the 1986 to 1989 cropping seasons. The seasons of 1986 and 1988 were characterized by rainfall well above the long-term average and the rains were well distributed throughout the whole period. In 1989 rainfall was also above average, and even though there was a three-week drought period in late July, the crops were only slightly affected. The 1987 season was more critical and started late (15 July). Rainfall was well below the long-term average (20%). A drought period occurred at the

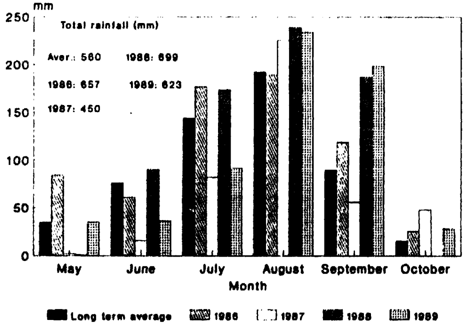

Fig. 1 Monthly total rainfall from May to October 1986 to 1989, and long term average. ISC, Sadoré, Niger.

end of August and had a severe effect on the pearl millet crop. Fortunately rains in the second week of September and in the following four weeks, helped the pearl millet to recover and some yields, though well below the normal, were obtained in most of the treatments.

Biomass production and yields

Data for biomass production and grain yields for pearl millet and cowpea are given in Tables 2, 3, 4 and 5. Biomass production of the forage legumes is

Table 2 Yields (t ha^{-1}) of pearl millet, legumes and total biomass. ISC, Sadoré, Niger 1986 (for symbols, see Table 1)

Treatments	*Pearl millet:* *Straw*	*Panicles*	*Grain*	*Legumes*	*Total biomass*
PM	2.56	1.51	1.00	-	4.07
PM/C	2.52	1.42	0.94	0.08	4.03
PM/S	2.05	1.22	0.78	0.03	3.30
PM/147	2.84	1.69	1.12	0.02	4.55
PM/V	2.42	1.50	0.96	-	3.92
SE ±	0.66	0.31	0.21	0.02	0.96

given in the same tables. In 1986, grain yields and biomass production (Table 2) of pearl millet were high and there were no significant differences between the various treatments. Production of the legumes was very low and cowpea gave the highest yield of the three legumes. In 1987, the establishment of pearl millet was very poor, strong sandstorms buried and destroyed the young seedlings. In the sole millet and millet/cowpea intercrop no yield was obtained (Table 3). In the other associations, pearl millet gave some yield suggesting that the presence of the legumes provided some protection against the sand storms. Legumes production in 1987 was above that in 1986 and the legumes took advantage of the full light, particularly in the case of *Stylo* cv 147. Nevertheless the stand was quite heterogeneous.

In 1988, pearl millet established very well and cereal yields and biomass production were substantial (Table 4). The production of the forage legumes was also high, particularly for the two *Stylo* cultivars. No significant competition effect between the legumes and the cereal was noticed.

In 1989, all the legumes plants were removed and pearl millet yields were different among the treatments (Table 5). The highest yields were recorded in the pearl millet after *Stylo*. Both treatments gave significantly higher yields than the other three treatments.

Table 3 Yields (t ha^{-1}) of pearl millet and legumes, total biomass, water use (mm), and water use efficiency (kg ha^{-1} mm^{-1}) of five different cropping systems. ISC, Sadoré, Niger 1987 (for symbols see Table 1)

Treatments	Pearl millet: Straw	Panicles	Grain	Legumes	Total biomass	Total water use	Water use efficiency
PM	-	-	-	-	-	323	0.07*
PM/C	-	-	-	0.18	0.18	328	0.19*
PM/S	0.10	0.08	0.05	0.36	0.54	335	2.20
PM/147	0.11	0.06	0.02	1.74	1.91	357	5.72
PM/V	0.30	0.18	0.14	0.18	0.65	344	2.42
SE ±	0.08	0.03	0.02	0.1**	0.21	8.2	1.33

* *Not included in the analysis of variance.*
***For PM/147 the SE was estimated to be 0.6 t ha^{-1}.*

Table 4 Yields (t ha^{-1}) of pearl millet and legumes, total biomass, water use (mm) and water use efficiency (kg ha^{-1} mm^{-1}) of five different cropping systems. ISC, Sadoré, Niger 1988 (for symbols see Table 1)

Treatments	Pearl millet: Straw	Panicles	Grain	Legumes	Total biomass	Total water use	Water use efficiency
PM	1.37	1.11	0.71	-	2.46	519	4.77
PM/C	1.14	0.87	0.50	0.17*	2.18	585	2.58
PM/S	1.21	0.94	0.55	0.71	2.81	595	4.99
PM/147	1.25	0.97	0.62	3.04	6.03	634	8.45
PM/V	1.00	0.91	0.51	5.37	7.28	599	12.45
SE ±	0.23	0.17	0.11	0.36	0.38	14	1.16

* *Not included in the analysis of variance.*

Table 5 Yields (t ha^{-1}) of pearl millet, total biomass, water use (mm) and water use efficiency (kg ha^{-1}mm^{-1}) of five different cropping systems. ISC, Sadoré, Niger 1989 (for symbols see Table 1)

Treatments in previous years	Pearl millet: Straw	Panicles	Grain	Total biomass	Total water use	Water use efficiency
PM	1.27	0.61	0.34	1.88	440	4.55
PM/C	1.20	0.79	0.44	1.99	449	2.53
PM/S	1.57	0.85	0.49	2.42	436	7.73
PM/147	1.82	1.14	0.66	2.96	439	5.59
PM/V	2.09	1.18	0.71	3.26	433	7.35
SE ±	0.26	0.12	0.07	0.37	4.7	0.89

Water use by the different systems

In 1987, water use ranged from 323 to 357 mm (Table 3). The highest water consumption was recorded in the pearl millet/*Stylo* cv 147 association which produced much more biomass than the other systems. This treatment also gave the highest water use efficiency. However, as previously stated the heterogeneity among the plots was very high.

The 1988 results confirmed the advantage of the pearl millet/*Stylo* associations in making better use of the soil water (Table 4). All pearl millet/legume associations consumed more water than the pure pearl millet but only the two pearl millet/*Stylo* mixtures were characterized by a more efficient use of water than the others.

Positive residual effects of the legumes on the subsequent pearl millet the following year are also reflected in terms of water use efficiency (Table 5). Though the water consumption was not different among the various crops in 1988, higher biomass production by pearl millet after the association with *Sesbania* and *Stylo* cv 147 resulted in significantly better water use efficiency.

Soil water profiles

Figure 2 shows soil water extraction patterns for the five different cropping systems on four selected dates during the 1988 season: at sowing time (18 June); when the profile had been well recharged by a good rain (28 August); after the harvest of pearl millet (15 October); and just before the harvest of the legumes, (22 October). Soil water profiles in June show that water was extracted from the top layer of the soil (30 cm) at the beginning of the rainy season. The August profile shows how well the soil has been recharged with water down to 2.5 m deep. Soil water profiles on 15 October show that there was a clear difference between the *Stylosanthes* cv 147 and the other legumes in terms of root activity and depletion of the profile. The soil water curves on 22 October confirm this and also show that the cultivar Verano was still extracting water but to a lesser extent.

DISCUSSION

Many results from various sources show that competition from the legume can decrease cereal grain yields in an intercrop situation (Snaydon & Harris, 1981; Haque, 1984; Chetty 1983; Dalal, 1974; Schmidt & Frey, 1988). The negative effect can have various causes. Geometry of the intercrop: one can decrease the density of the cereal to reduce the shading effect on the associated legume. This is the case in the maize/groundnut intercrop (Schmidt & Frey, 1988) or in the pearl millet/groundnut intercrop (ICRISAT, 1988). In that situation the benefit from the associated legume compensates for the cereal yield loss.

Below ground competitions are more intense than those above ground. Competition for nutrients is responsible for the lower production

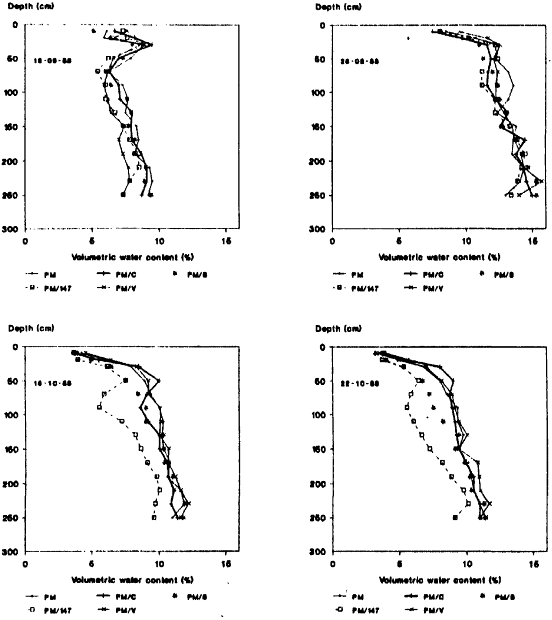

Fig. 2 Soil water profiles in the different cropping systems at four selected dates during the 1988 cropping season. ISC, Sadoré, Niger.

and this is obvious in some cases (Snaydon & Harris, 1981) where water supply is not a limiting factor. At the ICRISAT Sahelian Center, where the water holding capacity of the deep sandy soils is low, competition for water is one of the causes of yield reduction, even though competition for nutrients can play a major role as well (Fussell *et al.*, 1989).

In the case of the pearl millet/cowpea intercrop, different findings at the ICRISAT Sahelian Center show that the choice of the cowpea cultivar and timing of sowing play an important role in reducing these competitive effects (Ntare & Fussell, 1988). Application of fertilizers (N and P) can produce an increase in densities of both crops (Fussell *et al.*, 1987) providing water is not limiting.

In the present experiment, there are some indications of a slight depressive effect of the legume on the cereal (Table 4) but these are not significant, however, in this year, 1988, water was not a factor limiting crop production. Other experiments conducted at ISC in 1989 on the pearl millet/*Stylo* cropping system show that there was a significant depressive effect. Current research is looking at management practices, such as cutting the legume during the season, to minimize the negative effect. This has the advantage to provide fodder which can be sold in the city markets or stored for the next dry season.

The positive effect of a cereal/legumes rotation is well known and has been demonstrated at the ICRISAT Sahelian Center and other research stations in West Africa. The positive effect of a cereal/legume association on the next year cereal is rarely obtained. However, in this case a positive effect was observed for the pearl millet grown after the *Sesbania* and the *Stylo* intercrop. Those residual effects can be attributed to the nitrogen fixation by the legumes and also to the positive effect of the legumes on P availability from the soil (Gardener & Boundy, 1983).

Increased water use and water use efficiency in the intercrops are clear, particularly in a high rainfall year such as 1988. These can be attributed to an increase of production and better exploitation of the soil moisture profile by two crops with contrasting growth habit and mineral uptake (Singh *et al.*, 1988). The legumes compete less with the cereal than other crops and the forage legumes are more efficient than the grain legumes.

Figure 2 shows that both cultivars of *Stylosanthes hamata* exploited the profile better than *Sesbania* and cowpea. This may be because both the *Stylo* cultivars are short perennials while others are annual. The root systems of *Stylosanthes* at the end of the cropping season are deeper and more developed, and are still alive after the harvest of the cereal. Among the two cultivars, CIAT 147 seems to be more effective than Verano.

Finally, the water use efficiency of the millet grown after the cereal/legume association is improved with the three forage legumes (*Sesbania* and both *Stylo* cultivars). This is obviously due to the residual effect and can be attributed to the improvement of the soil nutrients status by the legume, and is similar to the positive effect of fertilizer application on the water use efficiency of the pure pearl millet (ICRISAT, 1985).

CONCLUSION

The study of the five contrasting cropping systems (pure pearl millet and pearl millet intercropped with different legumes) shows the advantages of the mixed crop system in terms of biomass production and water use efficiency. The association with the short perennial forage legume (*Stylosanthes*) is the most efficient due to a better exploitation of the soil profile compared to an association with annual legumes. This system seems promising for the Sahelo-Sudanian zone and proper management practices have to be examined for minimizing competition between both components.

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