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Improving Millet-Cowpea Productivity and Soil Fertility with Crop Rotation, Row Arrangement and Cowpea Density in the Sahel, West Africa

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Abstract: We intercropped cowpea (*Vigna unguiculata* line TN256-87) at three densities (low, 5882-6275 stands ha^{-1}; medium, 10 558-11 503 ha^{-1}; and high, 29 412-32 418 ha^{-1}) with a local cultivar of millet (*Pennisetum glaucum* 'Hini Kirey') at low density (5882-6275 ha^{-1}) in one of two row arrangements (1:1 and 4:4 millet to cowpea) under rainfed conditions on sandy soil for 3 years in western Niger. It was also tested crop rotation between years. Crop rotation increased total biomass by 21%, millet biomass by 24% and millet grain yield by 38%. The 4:4 row arrangement increased cowpea biomass by 25% and the highest crop density increased it by 132%. N input and N uptake by cowpea plants tended to be higher under crop rotation. Total soil N and organic C in the surface 15 cm of soil were increased under crop rotation. It could be concluded that the 4:4 row arrangement and crop rotation would improve yields for farmers in the Sahel who must cope with poor soil fertility on insufficient land and who cannot afford to buy enough mineral fertilizer.

Key words: 4:4 row arrangement · Cowpea density · Millet / cowpea rotation · Sandy soil · Intercrop · West Africa

INTRODUCTION

West Africa is poorly endowed in soil fertility. Recent decades have seen large population increases, the breakdown of traditional shifting cultivation systems and a rapid decline of land productivity and soil fertility [1].

Pearl millet (*Pennisetum glaucum*), sorghum and maize are important food crops in the rainfed Sahelian environment, where little or no nutrients are applied. The ability of pearl millet to extract N from poor sandy soils and its better drought tolerance are the primary reasons for its use in the Sahel, where it produces a moderately reliable grain yield [2]. Millet is traditionally cropped with cowpea (*Vigna unguiculata*). Both crops are sown at very low densities (<5000 hills ha^{-1}) with no fertilizer [3].

Although improved millet cultivars have been developed, farmers still grow local landraces, which provide grain for humans, fodder for livestock and stalks for fencing. Although millet is tolerant to heat and drought [2], low levels of nutrients limit its productivity [4]. In Niger, most millet is grown on sandy soil with low nutrient-holding capacity and low levels of P and N [5]. Small doses of mineral fertilizer increased production [6, 7], but farmers cannot afford to buy mineral fertilizer and thus low-cost inputs must be found. Suitable alternatives include intercropping and cereal-legume rotation at increased planning density with improved cultivars of cowpea [3, 8-14].

Different row arrangements in cereal-legume intercrops have been compared [15-17], but not equal row-space arrangements with cereal-legume rotations: no information is available on the 4:4 row arrangement, which would facilitate rotation.

Crop rotation and planting density in intercropping may jointly affect crop productivity [8, 14, 18, 19]. By crop rotation, the use of legume crops such as cowpea improves soil fertility by incorporating nitrogen from the atmosphere [20]. The objective of this study was to evaluate the effect of crop rotation, row arrangement and cowpea density on crop productivity and soil fertility in millet-cowpea intercropping in the Sahel.

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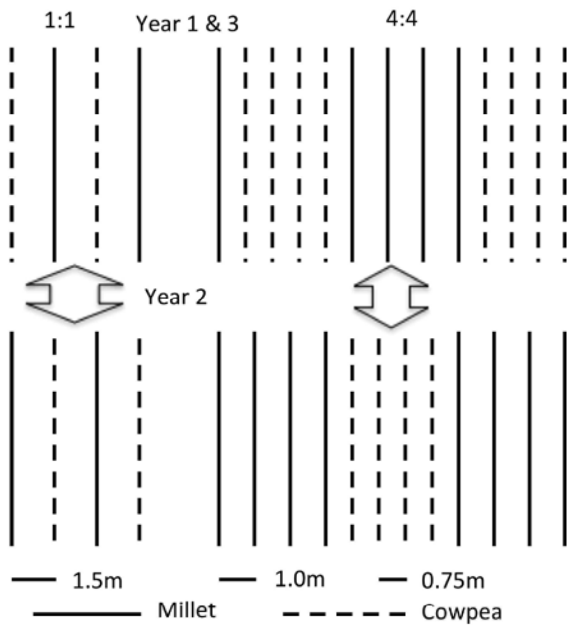

Fig. 1: The 1:1 and 4:4 row arrangements in year 1 and their rotations in years 2 and 3.

MATERIALS AND METHODS

This experiment was conducted during the 2008, 2009 and 2010 cropping seasons at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) Research Farm at Sadore, Niger (13°14′N, 2°17′E, 231 m above sea level). The agriculture system in the area is rainfed millet-based crop-legume rotation with livestock. Sadore is in the bioclimatic Sahelian agroecological zone, which has a unimodal rainfall pattern and an annual rainfall of 550 mm [21]. The annual average rainfall from 1983 to 2004 at Sadore was 541 mm. In 2008, the mean annual rainfall was 462.4 mm within 33 days of rain and in 2009 it was 515.6 mm within 45 days of rain. The temperature ranged from 23.5 to 35°C in 2008, from 23 to 36°C in 2009 and from 21.7 to 35.9°C in 2010. The sandy, siliceous isohypothermic soils are classified as Psammentic Paleustalf [22]. The site soil is sandy (90%) with a pH of 4.7.

Local millet cultivar was grwon (110 days to harvest), ‘Hini Kirey’ and a dual-purpose medium-maturity cowpea line (85 days), TN256-87 [19, 23]. The experiments were conducted in a strip-plot design with three replications. The plots measured 12.75 m × 6 m and the millet was planted and thinned to three plants after 2 weeks. Cowpea was grown at one of three planting densities (low, 5882-6275 stands ha^{-1}; medium, 10 588-11 503 ha^{-1}; and high, 29 412-32 418 ha^{-1}) with millet at low density (5882-6275 ha^{-1}) in one of two row arrangements (1:1 and 4:4 millet to cowpea). In the 1:1 arrangement, millet plants were spaced 1.5 m × 1.5 m apart and cowpea at 1.5 m × 1.5 m (low), 0.75 m (medium), or 0.25 m (high) apart. In the 4:4 arrangement, millet plants were spaced 1 m × 1 m apart and cowpea at 1 m × 1.5 m, 0.75 m, or 0.25 m apart. Millet was planted in June and harvested in October each year. Cowpea was planted in July and harvested in October each year. In 2009 and 2010, plots were divided in two (6 m × 3 m) and the planting positions of cowpea and millet were swapped within one half (rotation), but were retained in the other half (no rotation; Fig. 1). At physiological maturity, plants in each plot were harvested and partitioned into ears and stalks. After drying, the ears were threshed and the total biomass was determined. All aboveground crop residues were removed from the plots at end of each cropping season.

Soil samples were taken from the top 15 cm, air-dried, crushed and sieved (2-mm mesh) for chemical analysis. Following wet digestion with salicylic acid-thiosulfate, the total N content was measured colorimetrically at 660 nm with a Technicon Auto-Analyzer II (Pulse Instrumentation Ltd., Saskatoon, SK, Canada) [24]. After extraction with Bray No. I solution, available P was measured by the molybdenum blue method [25]. Organic C content was determined by the Walkley-Black method [26].

About 3 months after harvest, the air-dry plant samples were ground; 200 mg of each sample was digested with salicylic acid-thiosulfate and the total N content was measured colorimetrically at 660 nm with the Technicon Auto-Analyzer II.

N uptake was determined by multiplying the N concentration by the plant biomass and the N balance was calculated as atmospheric N minus N uptake. The ratio of atmospheric N in cowpea was taken from Yakubu *et al*. [27].

The results were tested by analysis of variance (ANOVA) followed by Student’s *t*-test in JMP v. 9.0.0 software (SAS Institute, Cary, NC, USA).

RESULTS

Crop rotation increased total biomass by 21% ($P < 0.05$), millet biomass by 24% ($P < 0.05$) and millet grain yield by 38% ($P < 0.01$; Table 1). The highest crop density increased cowpea biomass by 132% and grain yield by 97% ($P < 0.001$). The 4:4 row arrangement increased cowpea biomass by 25% ($P < 0.01$). Trends in biomass and grain yield was differed by crop and by year. Cowpea produced its biggest biomass in 2008, which

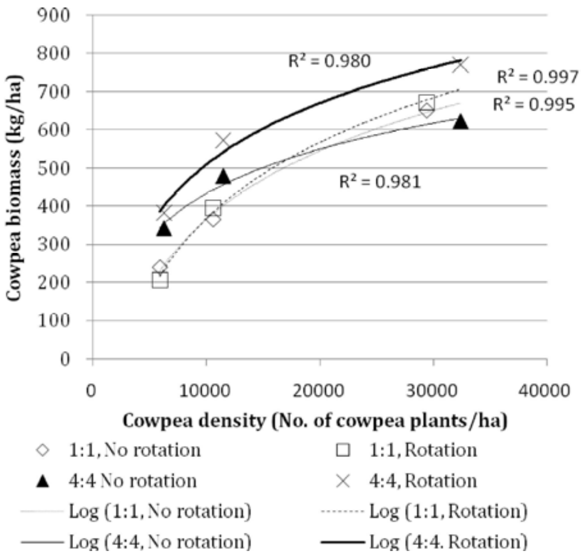

Fig. 2: Relationship between cowpea biomass and density in millet-cowpea intercropping.

contributed to the biggest total biomass of all 3 years and its highest grain yield in 2009. In 2010, millet biomass greatly exceeded cowpea biomass and millet produced its highest yield.

The relationship between cowpea density and biomass was differed among row arrangements (Fig. 2). Biomass increased asymptotically with density, most noticeably in the combination of the 4:4 row arrangements with crop rotation.

The removal of crop residues from the plots reduced the soil N content each year (Table 2). The 4:4 row arrangement and higher cowpea densities produced a higher N input and uptake, especially by cowpea, which resulted in a lower ratio of N uptake to N input. Crop rotation increased N uptake by millet, which resulted in a lower N balance, but a (non-significantly) higher N input.

Total N and organic C were accumulated under rotation, with no clear effect of row arrangement or cowpea density (Table 3).

Table 1. Effect of row arrangement, cowpea density, crop rotation and year on crop biomass and grain of millet / cowpea intercrop

Treatment		Biomass ($kg\ ha^{-1}$)			Grain ($kg\ ha^{-1}$)	
		Total	Millet	Cowpea	Millet	Cowpea
Row arrangement (R)	1:1	2433	2012	421b	278	55
	4:4	2254	1726	528a	241	55
Cowpea density (CD)	Low	2268	1976	292c	276	39b
	Medium	2369	1916	453b	249	49b
	High	2394	1715	678a	254	77a
Crop rotation (CR)	No rotation	2120b	1671b	449	218b	53
	Rotation	2567a	2067a	500	301a	57
Year (Y)	2008	2905a	1833b	1072a	162b	59b
	2009	1603b	1308c	295b	147b	85a
	2009	2523a	2466a	57c	469a	23c
R		n.s.	n.s.	**	n.s.	n.s.
CD		n.s.	n.s.	***	n.s.	***
CR		*	*	n.s.	**	n.s.
Y		***	***	***	***	***
R X CD		n.s.	n.s.	n.s.	n.s.	n.s.
R X CR		n.s.	n.s.	n.s.	n.s.	n.s.
R X Y		n.s.	n.s.	n.s.	*	n.s.
CD X CR		n.s.	n.s.	n.s.	n.s.	n.s.
CD X Y		n.s.	n.s.	***	n.s.	n.s.
CR X Y		n.s.	n.s.	n.s.	*	n.s.
R X CD X CR		n.s.	n.s.	n.s.	n.s.	n.s.
R X CD X Y		n.s.	n.s.	n.s.	n.s.	n.s.
R X CR X Y		n.s.	n.s.	n.s.	n.s.	n.s.
CD X CR X Y		n.s.	n.s.	*	n.s.	n.s.

*, **, *** indicate significantly different at 0.05, 0.01 and 0.001 level, respectively.
n.s. indicates no significant.
Different alphabet indicates statisistucally significant at 0.05 level by Student t test.

Table 2. Effect of row arrangement, cowpea density and crop rotation on N balance in millet / cowpea intercrop, 2008 and 2010

Treatment		N input from atomosphere (kg N ha^{-1})	N input from atomosphere (kg N ha^{-1})	N iuptake by millet (kg N ha^{-1})	N iuptake by millet (kg N ha^{-1})	N uptake by cowpea (kg N ha^{-1})	N uptake by cowpea (kg N ha^{-1})	N balance (kg ha^{-1})	N balance (kg ha^{-1})	N uptake / N input	N uptake / N input
		2008	2010	2008	2010	2008	2010	2008	2010	2008	2010
Row arrangement (R)	1:1	14.0	0.7b	17.4	39.2a	20.3	1.0b	-23.8	-39.5b	3.4a	91.7a
	4:4	16.3	1.4a	18.0	27.7b	23.6	2.1a	25.4	-28.4a	2.7b	34.1b
Cowpea density (CD)	Low	8.5c	0.7b	21.8	34.2	12.3c	1.1b	-25.6	-34.5	4.3a	69.5
	Medium	14.4b	0.8b	17.5	35.8	21.0b	1.2b	-24.0	-36.2	2.8b	82.0
	High	22.5a	1.7a	13.9	30.4	32.6a	2.4a	-24.1	-31.1	2.1b	37.1
Crop rotation (CR)	No rotation	-	0.9	-	27.8b	-	1.3	-	-28.2a	-	63.4
	Rotation	-	1.2	-	39.1a	-	1.8	-	-39.7b	-	62.3
R		n.s.	**	n.s.	*	n.s.	**	n.s.	*	*	*
CD		***	***	n.s.	n.s.	***	***	n.s.	n.s.	***	n.s.
CR		n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.	*	n.s.	n.s.
R X CD		*	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.	*	n.s.
R X CR		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
CD X CR		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R X CD X CR		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*, **, *** indicate significantly different at 0.05, 0.01 and 0.001 level, respectively, while n.s. indicates no significant.
Different alphabet indicates statisistucally significant at 0.05 level by Student t test.

Table 3. Effect of row arrangement, cowpea density and crop rotation on total soil N, Bray-P and organic C content in millet / cowpea intercrop, 2008 and 2010

Treatment		Total N (mg kg^{-1})		Bray I P (mg kg^{-1})		Organic C (%)	
		2008	2010	2008	2010	2008	2010
Row arrangement (R)	1:1	193.2	151.1	8.6	8.3	24.1	18.5
	4:4	195.2	149.9	9.1	8.8	25.2	19.2
Cowpea density (CD)	Low	201.7	152.4	8.9	9.0	25.3	19.1
	Medium	189.3	147.3	9.0	8.7	24.3	18.7
	High	191.7	152.0	8.5	7.9	24.3	18.8
Crop rotation (CR)	No rotation	-	142.3b	-	8.5	-	18.1b
	Rotation	-	158.8a	-	8.6	-	19.7a
R		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
CD		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
CR		-	*	-	n.s.	-	*
R X CD		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R X CR		-	n.s.	-	n.s.	-	n.s.
CD X CR		-	n.s.	-	n.s.	-	n.s.
R X CD X CR		-	n.s.	-	n.s.	-	n.s.

*, **, *** indicate significantly different at 0.05, 0.01 and 0.001 level, respectively, while n.s. indicates no significant.
Different alphabet indicates statisistucally significant at 0.05 level by Student t test.

DISCUSSION

Farmers in the Sahel rely on millet and cowpea for food, fodder and fencing. Dugue [28] estimated that in Burkina Faso, only 10% of crop residues are left in the field, even though the addition of organic matter improves soil chemical and physical properties [29].

The millet biomass and grain yield increased following cowpea production, as reported before [3, 8, 14]. This increase shows that the cowpea contributed to the following millet yield, largely via its roots and partly via leaf litter [30, 31].

Both the 4:4 row arrangement and higher cowpea densities increased N uptake by cowpea and N input by fixation. The net effect contributed to the accumulation of total soil N and organic C by the end of 2010 (Table 3). Bado *et al.* [32] similarly found that the soils of legume-sorghum rotations provided more N to succeeding sorghum and gave the highest total N uptake by sorghum in legume-sorghum rotations.

The 4:4 row arrangement and crop rotation gave good results with the dual-purpose TN256-87 cowpea. Other cowpea genotypes with different characteristics might give different results. For example, different combinations of millet and cowpea cultivars gave different yield performances [9]; and the selection of genotypes with a suitable combination of traits with a strong relationship with and a direct effect on yield at an appropriate density increased the productivity of cowpea [33]. Oso *et al.* [13] studied two row spacing arrangements (2:3 and 1:1 maize to cowpea) and concluded that the planting pattern in intercropping appears to influence leaf infestation by beetles. Nambiar *et al.* [34] ascribed the effect of intercropping system to the shading of legumes by the cereal and the consequent decrease in photosynthesis.

Further tests of the combination of cowpea genotype, density and row arrangement will therefore be necessary to identifying optimum and affordable combinations in the Sahel.

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