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Crop rotation and soil amendments: impacts on cotton and maize production in a cotton-based system in western Burkina Faso

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ABSTRACT

Crop production in the semi arid zone is limited by nutrients availability. Farmers in the area are unable to afford chemical fertilizers because of their low financial conditions. The design of cropping system with low inputs is therefore of importance for farmers. A crop rotation and soil amendment techniques study was carried out from 2000 to 2005 in Farakô-Ba research centre, western Burkina Faso to observe effects on maize and cotton seed yields. The treatments included six crop rotation systems and four soil amendments. The results showed a significant impact of crop rotation on both maize grain and cotton seed yields when a legume was included in the rotation. The yields were low when the rotation included only cereals and cotton. Soil amendment techniques including farmyard manure and phosphate rock generated the highest impact on crops yields while they were lowest when the straight fertilizers (urea, KCl, phosphate rock) were used. No significant interactions were found between crop rotation and soil amendment techniques. This suggests the possibility to save on fertilizers for maize while a minimum input is essential to support good cotton seed production. A crop rotation including a legume combined with organic manures is suitable to ensure a sustainable crop production in the semi arid zone of Burkina Faso.

Key words: Cotton, legumes, maize, rotation, soil amendments

INTRODUCTION

In the West African Sahel an erratic and declining rainfall pattern combined with rapid population growth are straining the natural resource base (Zougmore, 2003). Crop yields are declining because of continuous and intensive cropping without restoration of the soil fertility (Bationo et al., 1998). Soil organic matter, the most important source of nutrients for crop production in the region, is almost lacking or very low (Pieri, 1989). In order to maintain production levels, farmers devote more and more land to crops leading to increase rate of degradation of natural resources (INERA, 2003).

The most limiting nutrients for crop production in the area are N, P and K (Bado and Hien, 1998; Compaoré et al., 2001; Traoré et al., 2001). The balance of these nutrients is always negative (Bationo et al., 1998). Sustainable increases in productivity in the area can be achieved only through a combination of external inputs, such as fertilizers with organic nutrients sources. Because of limited financial conditions of the farmers in the Sahel, the average intensity of fertilizer use of roughly 8 kg per ha throughout Sub-Saharan Africa remains much lower than elsewhere in the world (Jayne et al., 2003). Low cost alternatives to supply N, P and K to the cultivated fields is therefore of importance for thousands of the smallholders in the Sahel.

In western Burkina Faso, the cropping system is cotton based. Cotton is generally followed the next season by maize which benefits from the residual fertility of the cotton field. During the third year farmers produce sorghum or maize. The subsistence of local population is exclusively based on natural resources and the farming system is the shifting cultivation system (Bationo et al, 1998). The fallowing technique used to restore soil fertility was almost abandoned and lands are continuously cropped without any fertilization plan (INERA, 2003). As a consequence, the crops yields are decreasing from year to year.

The objective of the current study is to evaluate the effect of crop rotation including a legume crop combined with soil organic and inorganic amendments on cotton seed and maize productivity in western Burkina Faso. We hypothesize that a good crop rotation can potentially increase maize and cotton productivity. Effects could be higher if a good crop rotation is combined with organic and inorganic amendments.

MATERIAL AND METHODS

Site description

The experiment was carried out from 2000 to 2005 in Farako-Bâ research center in Burkina Faso, West Africa. The geographic coordinates of the centre are 11°06'latitude north, 4°20' longitude west and 405 m altitude. The climate is south soudanian (Guinko, 1984). Average annual rainfall (1995-2005) in the area is 950 mm with a cropping season of 5 months (May-September). Average minimum and maximum temperatures during the cropping season are respectively 10 and 32°C. The main soil types encountered in Farako-Bâ research center are Ferrasols (FAO classification) (Bado, 2002). The trial was carried out in a field previously cropped for more than 10 years.

Methods

The experiment was a split plot design with four main treatments and six secondary treatments. The fertilizations (F1-F4) were allocated to the main plots while the rotations (R1-R6) were applied to sub-plots. Tables 2 and 3 give the definition of fertilizations and rotations. The size of each experimental unit was 40 m^2 (4 m × 10 m) for the main plots and 20 m^2 (2 m × 10 m) for the secondary plots. The distance between the plots was 1 m and 0.5 m for the main and the sub-plots respectively. All the treatments were arranged in complete randomized blocks. The fertilizers used during the trial were: urea (46% N), KCl (60 % K_2O), NPKSB (15-20-15-6-1), Burkina phosphate rock (25 % P_2O_5) and farmyard manure (1 % N; 0.35 % P_2O_5; 1.5 % K_2O; 0.67 % MgO and 0.8 % CaO). Table 4 shows the quantity of nutrients applied per crop. In plots receiving the phosphate rock and farmyard manure, they were applied at ploughing as starter fertilizers. For those receiving NPKSB and KCl, the fertilizers were applied at 15 days after sowing. The urea was applied twice at 15 and 40 days after emergence.

The crop density was 80 cm x 40 cm for cotton, maize and sorghum, 40 cm x 40 cm for peanut and mucuna and 40 cm x 30 cm for cowpea. Rice was planted on continuous lines and the distance between rows was 25 cm. The cotton and cowpea were protected against pest damages by application of insecticides every 14 days, starting from the 40^{th} day after sowing. The crop varieties used in the experiment were FK37 for cotton, SR21 for maize, Sariasso 02 for sorghum, FKR19 for rice, RMP 12 for peanut, IAR7 for cowpea and *Mucuna cochinchenensis* for Mucuna.

Sampling and analyses

Soil samples were taken before sowing at a depth of 0-20cm. The samples were taken at random in five different places in the field. Samples from the five sampling places were mixed and constitute the composite sample for the field.

Above ground biomass samples were taken at maturity in each experimental plot for crop yield estimation. The soil samples were sun dried, grounded and sieved at 2 mm. In soil samples, total C, N, P and K were determined respectively by Walkey-Black, Khejdahl, auto analyzer and flam spectrophotometer methods (Houba, 1985). All the data collected were statistically analyzed using Genstat version 7. The means were separated using the least significant difference (LSD) at 5% probability.

RESULTS

Soil physical and chemical characteristics at sowing

Table 1 summarizes some physical and chemical properties of soils sampled in the experimental field before sowing. The results showed that the soils are sandy. They are low in clay and organic matter content. The soils are slightly acidic and poor in N and P (Table 1). Data on soil properties changes due to crop rotation and soil organic and inorganic amendments are discussed in another paper.

Table 1: Physical and chemical characteristics of a composite soil sampled before sowing at depth 0-20 cm. Farako-Bâ, 2000.

Clay (%)	7.8
Silt (%)	11.8
Sand (%)	80.4
Organic matter (%)	0.8
Total N (%)	0.03
Total P (mg kg^{-1})	91
Available P (mg kg^{-1})	2.0
Total K (mg kg^{-1})	531
Available K (mg kg^{-1})	41
pH_{H2O} (1:2.5)	5.5
pH_{KCl} (1:2.5)	4.8
CEC (Cmol.100 g-1)	1.82

CEC = Cationic Exchange Capacity

Table 2: Main treatments (fertilizations).

Treatments	Treatment definition
F1	Burkina phosphate rock (BP) + KCl + urea
F2	Farmyard manure (5t.ha^{-1}) + BP
F3	NPKSB + urea
F4	Farmyard manure (2t.ha^{-1}) + BP + urea

Rainfall pattern during the six cropping years

As expected in the Sahel, rainfall distribution was different during the six cropping years. Total rainfall was normal in 2000 (1073.5 mm), 2001 (769.0 mm), 2003 (1155.1 mm), 2004 (816.7 mm), 2005 (869.4 mm) while in 2002 (674.6 mm) it was lower than the long term average. Difference in soil moisture conditions during the cropping seasons has probably affected crop yield as shown in Tables 6 and 8.

Crop productivity

Only maize and cotton seed yields are presented here because those two crops are the most important for farmers in the area. Cotton is used as a source of income while maize is used as food to feed the family during the year. Sorghum is planted in the field when farmers are not able to buy chemical fertilizers.

Maize productivity

Both soil amendments techniques and rotations systems significantly affect maize productivity (Tables 5 and 6).

The impact of fertilizations on maize productivity was in the order F3 > F2 > F4 > F1. The high dose of farmyard manure combined with phosphate rock (F3) was the highest. In fact, maize yield with F3 was 158%, 70% and 15% higher compared respectively to F1, F2 and F4. The recommended fertilization by the extension office (F2) was lower compared to F3. The lowest maize grain yield was obtained in the straight fertilizer (F1).

The impact of crop rotation on maize production was in the order R3= R5 = R6> R1= R2= R4. The results showed that the highest maize grain yield was obtained when a legume was included in the rotation (R3, R5 and R6). But, maize yield was comparable for all the rotations including legume. The nature of legume used in the rotation was not significant even though there was a tendency for rotation with cowpea to show higher maize yield than for rotations with peanut or *Mucuna*. The lowest yields were observed when a cereal (sorghum and maize) was included in the rotation (R1).

Cotton seed productivity

Fertilizations and crop rotations all affected cotton seed production (Tables 7 and 8). But, the impact of fertilization ($p<0.001$) was much higher than the impact of crop rotation ($p= 0.010$). No significant interaction was found between the two factors.

The impact of fertilizations on cotton seed production was in the order F3 > F2 = F4>F1. Again, the fertilization system combining the higher dose of farmyard manure and phosphate rock generated the highest cotton seed yield while the straight fertilizers gave the lowest ones. In fact, cotton seed yield was 500% higher for F3 compared to F1 and 150% higher compared to F2 and F4. Cotton seed yield was comparable for the recommended fertilization by extension office (F2) and the lower dose of

Table 3: Secondary treatments (Rotations).

	Year					
Rotations	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
R1	Sorghum	Cotton	Maize	Sorghum	Cotton	Maize
R2	Maize	Upland rice	Cotton	Maize	Upland rice	Cotton
R3	Peanut	Cotton	Maize	Peanut	Cotton	Maize
R4	Cowpea	Cotton	Maize	Cowpea	Cotton	Maize
R5	*Mucuna*	Cotton	Maize	*Mucuna*	Cotton	Maize
R6	Cotton	Maize	Cotton	Cotton	Maize	Cotton

Table 4: Quantity of nutrients (kg.ha^{-1}) applied per crop and fertilization

Fertilization		Crops					
		Cotton	**Maize**	**Rice**	**Sorghum**	**Cowpea/ Peanut**	***Mucuna****
F1	N	46	37	46	30	11	0
	P	30	20	40	10	14	0
	K	23	15	30	8	11	0
F2	N	46	38	53	31	11	0
	P	30	20	40	10	14	0
	K	23	15	30	8	11	0
	S	9	6	12	3	4	0
	B	2	1	2	1	1	0
F3	N	50	50	50	50	50	0
	P	31	21	40	20	20	0
	K	75	75	75	75	75	0
	Mg	34	34	34	34	34	0
	Ca	40	40	40	40	40	0
F4	N	45	38	75	32	20	0
	P	30	20	40	10	13	0
	K	30	30	30	30	30	0
	Mg	13	13	13	13	13	0
	Ca	16	16	16	16	16	0

* *Mucuna* is not fertilized

farmyard manure combined with urea and phosphate rock (F4).

The impact of crop rotation on cotton seed production was in the order: R2= R3= R4= R5> R1= R6. The highest cotton seed yield was obtained when rice was included in the crop rotation. Cotton seed yield was comparable when peanut, maize and cowpea were inserted in the rotation system. Cotton seed yield was low when sorghum or *Mucuna* were in the rotation.

Impact of previous crop on cotton seed productivity

Cotton seed yield was high when maize, cotton or rice was used as previous crop and this was independent of the soil amendment technique (Figure 1). The impact of peanut and cowpea on succeeding cotton seed were comparable. The lowest cotton seed yield was obtained when sorghum was used as previous crop.

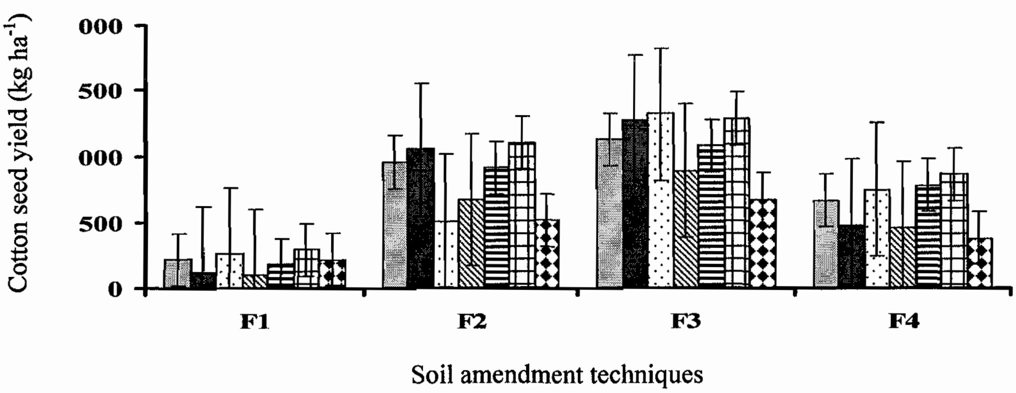

Figure 1: Effect of previous crop on cotton seed productivity. Data from 6 cropping years (2000-2005). Error bars correspond to standard deviation.
Previous crop: Cotton, Peanut, Maize, *Mucuna*, Cowpea, Rice, Sorghum

Table 5: Effects of fertilizations and rotations on maize grain yield (kg ha^{-1}). Average data for six years (2000-2005), n = 148.

	Rotations						
Fertilizations	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**Average**
F1	777 a AB	587 a A	1816 a B	1090 a AB	1374 a B	1563 a B	**1201**
F2	1912 c B	2391 c C	3440 c D	1493 a A	3785 c D	3149 c D	**2695**
F3	2869 d B	2148 c A	3466 c C	2632 b B	3790 c C	3662 d C	**3095**
F4	1509 b A	1255 b A	2325 b B	1265 a A	2269 b B	2311 b B	**1822**
Average	**1767**	**1595**	**2762**	**1620**	**2805**	**2671**	

*Fertilizations : ***, LSD= 328*
*Rotations :***, LSD= 403*
Fertilizations x Rotations : not significant s, LSD=836

Means in the same column followed by the same letter (lowercase) are not significantly different at 5% probability.
Means in the same line followed by the same letter (uppercase) are not significantly different at 5% probability.

Table 6: Maize grain yield (kg ha^{-1}) as a function of fertilization and cropping year, n = 148.

	Cropping year						
Fertilization	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Mean**
F1	1444 a	856 a	1548 a	736 a	313 a	1520 a	**1070**
F2	2069 b	2604 c	3315 c	917 a	1554 c	3461 c	**2320**
F3	2319 b	2173 b	3710 c	2946 c	1994 d	3622 c	**2794**
F4	1307 a	1186 a	2445 b	1223 b	1186 b	1964 b	**1552**
Mean	**1785**	**1705**	**2755**	**1456**	**1262**	**2642**	

*Year: ***, LSD= 496*
*Fertilizations : ***, LSD= 289*
*Fertilizations x years : *, LSD=993*

Means in the same column followed by the same letter (lowercase) are not significantly different at 5% probability.

Table 7: Effects of fertilizations and rotations on cotton seed yield (kg ha^{-1}). Average data for six years (2000-2005), n = 143.

Fertilizations	Rotations						
	R1	R2	R3	R4	R5	R6	Mean
F1	253 a A	272 a A	248 a A	337 a A	179 a A	147 a A	*239*
F2	318 a A	970 c C	956 c C	637 b B	910 b B	751 c B	*757*
F3	1105 c B	1228 d BC	1317 d BC	1440 d C	1074 d A	887 c A	*1175*
F4	694 b A	677 b A	665 b A	971 c B	891 b B	568 b A	*744*
Mean	*593*	*787*	*797*	*846*	*764*	*588*	

*Fertilizations : ***, LSD= 145*
*Rotations : *, LSD= 192*
Fertilizations x Rotations : not significant, LSD=451

Means in the same column followed by the same letter (lowercase) are not significantly different at 5% probability.
Means in the same line followed by the same letter (uppercase) are not significantly different at 5% probability.

Table 8: Cotton seed yield (kg ha^{-1}) as a function of fertilization and cropping year, n = 148.

Fertilization	Cropping years						
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**Mean**
F1	328 a	255 a	285 a	219 a	82 a	339 a	**251**
F2	935 c	723 b	1211 c	1053 c	1047 b	152 a	**853**
F3	838 b	888 b	1363 c	1228 c	1223 b	1424 c	**1161**
F4	622 b	438 a	897 b	515 b	1003 b	1054 b	**755**
Mean	**681**	**576**	**939**	**754**	**839**	**742**	

*Year: ***, LSD= 496*
*Fertilizations: ***, LSD= 289*
*Fertilizations x years : ***, LSD= 993*

Means in the same column followed by the same letter (lowercase) are not significantly different at 5% probability

DISCUSSION

Effect of crop rotations on yields

The present results showed that including cowpea or peanut in the current cotton based system can potentially increase the following maize yield and this can reduce the need for N fertilizer. These results are of importance for smallholders. The impact of a legume crop in a rotation on the following cereal productivity was already reported by previous studies under the same soil and climate conditions (Bado, 2002). According to the same author, the effect of the legume crop is N accumulation in the soil through symbiotic fixation system which supports good N nutrition for the following crop. The importance of N accumulated by the legume is specie dependant and cowpea was showed to synthesize 1.65 times more N than peanut (Bado, 2002). The trend showed by our data validated this statement, even though the means were not significantly different (Table 5).

The rotation including sorghum showed the lowest maize yield and this can be attributed to the fact that the two cereals are potentially exploiting the same soil depth, leading to an overuse of nutrients for that soil profile. These results show that cereal-cereal rotations can guide to rapid soil nutrients depletion.

The effects of crop sequence on cotton seed yield was in the same line as those reported for maize production. But here, the rotation including the rice showed an important impact on cotton seed yield. This is probably due to the fact that after rice, important quantities of nutrients was probably left in the soil.

The yield of cotton seed reported here was often below the average yield reported for the area (1200 kg ha^{-1}) (INERA, 1996). The data presented are averages from all the six cropping years, which include these very low crop yields during bad years. The large variation between years is due to changes in rainfall conditions since other conditions were similar between years.

Effect of fertilizations systems on yields

For both maize and seed cotton yield, the soil amendment technique F3 generated the highest yields. This is due to the fact that F3 supplied more N and K compared to other fertilizations systems (Table 4). Furthermore, the application of organic amendment has probably improved the mineralization of the phosphate rock as reported by previous studies (Akande et al., 2005). F3 fertilization by supplying Mg and Ca and improving soil organic matter has probably improved soil chemical (especially CEC) and physical characteristics (Delville, 1996). In total, the positive impact of F3 fertilization treatment showed all the importance of soil organic amendment for crop production in the area. This is consistent with the results reported by Pieri (1989), Sedogo et al. (1991) and Delville (1996) under similar experimental conditions with farmyard manure.

The lowest response of F1 fertilization was surprising because this fertilization was potentially able to supply soil with essential nutrients for cotton and maize production. Our results can be attributed to environment and soil conditions. In fact, when urea is incorporated into a soil with low organic matter content it can be rapidly transformed by soil enzymes into ammonium, which, in turn, is nitrified to nitrate by soil microorganisms. Nitrification is fast in warm soils. Furthermore, the nutrients from the straight fertilizers urea, KCl, and BP (Burkina phosphate rock) could have been lost either through the sandy soil profile or by win and/or water erosion (FAO, 2005). The recommended fertilization (F2) showed almost the same yield as F3 fertilization because it supplied enough nutrients to the soil to support plant growth. But, with F2, the plants were supplied with less P compared to F3 because of the low mineralization rate of the phosphate rock when directly incorporated into the soil without soil organic amendment (IAEA, 2002).

Interactions between fertilizations and crop rotations

The results showed no significant interactions between fertilization techniques and crop rotations. These results show the importance of both factors on maize and cotton seed production. The effect of both factors was highly significant for maize production and this shows the possibility to get a good maize production either with a good crop rotation or with a good fertilization technique. But that hypothesis needs to be verified with more experiments. The impact of crop rotation on cotton seed yield was much lower than the effect of fertilizations. These results suggest that for good cotton seed production, it is essential to supply the soil with nutrients.

Conclusion and recommendations

The current study showed that crop rotations and fertilization both have important impacts on maize grain and cotton seed yield. The highest yields are observed when a legume was included in the rotation. The nature of the legume was not significant but, the rotations with cowpea show tendency for higher yield compared to peanut and *mucuna*. The lowest yields were found when sorghum was included in the rotations.

The fertilization technique including high dose of farmyard manure and Burkina phosphate rock (BP) generated the highest maize and cotton seed yields. The lowest yields were obtained when the straight fertilizers (urea, KCl, BP) where used. Consequently, the application of organic amendment was necessary to support high crop production.

No significant interactions were found between fertilizations techniques and crop rotation. This suggests a possibility to save on fertilizers for maize production while for cotton production, the application of mineral fertilizers is essential for good cotton seed productivity.

In the light of the above conclusions we can suggest to farmers in western Burkina Faso the use of a legume crop in crop sequence for higher maize and cotton seed production. They should also focus on the intensive use of organic amendments at higher dose (5 t ha^{-1}). The organic amendment should be combined with the local phosphate rock. The local phosphate rock can be added either during organic matter preparation; for example in the compost pit or applied as a fertilizer directly in the field.

The high variability between years for crops yields demonstrates the necessity to apply soil and water conservation measures for sustainable crop productivity in the area.

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