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Influence of legumes on Nitrogen (N) fertilizer recommendations for succeeding sorghum in the Guinea Savannah of West Africa

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The nitrogen (N) fertilizer equivalencies and effects of the N_2-fixing legume crops, cowpea (*Vigna unguiculata* (L.) Walp.), groundnut (*Arachis hypogea* (L.)) and soybean (*Glycine max* (L.) Merr.) on succeeding sorghum (*Sorghum bicolour* (L.) Moench) yields were studied during two years (2000 and 2001) at Farakô-Ba (4° 20' West, 11° 6' North and 405 m above sea level) in the Guinean Savannah zone of Burkina Faso. Sorghum was cultivated in rotation with maize (*Zea mays* (L.)) and the three legumes. The two cereal-cereal rotations (Sorghum-Sorghum and Maize-Sorghum) were used as controls. The optimum yields of sorghum increased from 14, 20, and 35% when it was cultivated after soybean, groundnut or cowpea, respectively. Only 74% of the potential agronomic yield was achieved with cereal-cereal rotations. But 84, 89, and 100%, respectively, of the potential agronomic yields of sorghum were achieved when soybean, groundnut and cowpea were used as previous crops. Soybean, groundnut, and cowpea had N fertility equivalencies of 30, 35, and 42 kg N ha^{-1}. Considering the N fertilizer equivalents (NFE) of the legumes, the recommended doses of N fertilizer for sorghum were 37, 38, 44, 50, and 53 kg N ha^{-1} when the previous crops were maize, soybean, sorghum, groundnut or cowpea

Key words: Legume, fertilizer, nitrogen, crop rotation, sorghum.

INTRODUCTION

Nitrogen (N) deficiency is one of the main soil fertility constraints limiting crop yields in the Guinean savannah zone of West Africa. High responses to fertilizers are commonly observed because of the low inherent N supply of soils (Pichot et al., 1981; Berger et al., 1987; Pieri, 1989; Bationo and Mokwunye, 1991; Bado et al., 1997). African farmers use less than 10 kg ha^{-1} of fertilizers per season (McIntire, 1986; Stoorvogel and Smaling, 1990). Many factors such as the lack of capital investment and financial credit, inefficient distribution systems, poor supportive policies and other socio-economic factors limit farmers' access to mineral fertilizers. The cost of mineral N fertilizer at the farm gate is two to six times higher in Africa than in North America or Europe (Donovan, 1996). Affordable and efficient means of improving soil fertility and productivity are therefore necessary. N_2-fixing legume crops such as groundnut (*Arachis hypogea* L.), soybean (*Glycine max* (L.) Merr.) and cowpea (*Vigna unguiculata* (L.) Walp.) were reported to improve soil fertility of cropping system

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Table 1. Main physico-chemical characteristics of the topsoil (0 to 20 cm).

Clay (%)	7
Sand (%)	74
Silt (%)	19
Organic C (%)	0.61
Total N (mg kg^{-1})	409
Total P (mg kg^{-1})	69.8
Available $P_{Bray\ I}$ (mg kg^{-1})	5.6
Available K (mg kg^{-1})	531
pH H_2O	6.5
pH KCl	5.6
Ca^{++} ($cmol^+$ kg^{-1} soil)	1.08
K^+ ($cmol^+$ kg^{-1} soil)	0.02
Mg^{++} ($cmol^+$ kg^{-1} soil)	0.46
ECEC (cmol+ kg^{-1} soil)	1.82

as a consequence of N supplied by legumes via biological N fixation (Bagayoko et al., 2000; Bationo and Ntare, 2000). Sorghum (*Sorghum bicolour* (L.) Moench) and maize (*Zea mays* L.) are the first and second cereal crops cultivated by farmers in Burkina Faso. Groundnut and cowpea are important components of the cropping systems for resource-poor farmers; serving as food as well as cash crops. They can eventually provide necessary financial resources to buy agricultural inputs, for instance fertilizers. Soybean seems to be an interesting cash crop that can also improve the productivity of farmers' systems. Some extension services are trying to encourage farmers to introduce soybean as a cash crop in their cropping systems.

The N effect of legumes on soil fertility improvement could be easily demonstrated in cropping systems where legume residues are recycled in soil. But the total N yield and the quantity of N fixed by legume crops do not reflect their real contribution to improving soil N status because of the removal of residues to feed animals. However, N_2-fixing legumes crops may increase soil organic N through the fallen senescent leaves and belowground parts. The N input effects of legume crops should be studied in terms of quantity of N supplied by previous legumes to the subsequent non-fixing crop. Even though it's obvious that previous crops may affect fertilizer recommendation for the succeeding crop, fertilizer recommendations are still usually made today for mono-cropping. Considering the N contribution of the N_2-fixing legume, fertilizer recommendations for the succeeding crops need to be calculated, taking into account the N effects of legumes. For example, how large a quantity of N fertilizer must be applied on sorghum in cowpea-sorghum rotation? The concept of N fertilizer equivalents (NFE) is used to assess the effective N contribution of legume crops to the succeeding non-fixing sorghum. The concept of NFE states that, when a legume is rotated with a non N_2-fixing-crop (sorghum, for example), the NFE of this legume is defined as the quantity of N fertilizer that should be applied on monocropped sorghum to achieve the same yield of sorghum as from a legume-sorghum rotation (Hesterman et al., 1987).

So, the NFE is estimated in lack of N fertilizer application on sorghum (control treatment) in the legume-sorghum rotation, and the quantity of N fertilizer applied on monocropped sorghum is considered to have the equivalent N effect of the legume.

This research aims to evaluate the N effect of three N_2-fixing legumes (cowpea, groundnut, and soybean) on the succeeding sorghum yields. We hypothesized that N from N_2-fixing legume crops contribute to succeeding crop nutrition and specific fertilizer N recommendations need to be developed for succeeding sorghum followed by legume. A better management of N fertilizer in cropping systems is the main goal of this work.

MATERIALS AND METHODS

Recommended improved varieties of sorghum (Sariaso), maize (SR22), cowpea (KVX-61-1), soybean (G 196) and groundnut (RMP-12) were used in a field experiment curried out at the agronomic research station of Farakô-Ba (4° 20' West, 11° 6' North and 405 m above sea level), located in the Guinean savannah zone of Burkina Faso. This agro ecological zone has one rainy season per year, starting in May to June and ending in October. In both years, planting dates occurred in June and harvesting was done in October. In general, the annual rainfall of this ecological zone varies from 900 to 1000 mm. During the two cropping seasons of the experiment, annual rainfall was 1058 mm in 2000 and 715 mm in 2001.

Despite the low quantity of rainfall received in 2001, a good distribution rain was observed during this year. The experimental field was a six-years-old fallow, where the soil was an Ultisol, a weakly acid sandy soil with low clay and organic carbon contents. Available P (P-Bray I), exchangeable Ca, Mg, K and ECEC were very low (Table 1).

Table 2. Effects of previous crops (cultivated in 2000) and N fertilizer applications on succeeding sorghum grain and stover yields in 2001.

Previous crops r	Grain (kg ha^{-1})	Stover (kg ha^{-1})	Biomass (Kg ha^{-1})
Sorghum	1521^{e}	4968^{c}	6489^{b,c}
Maize	1467de	5562^{b}	7029^{b}
Soybean	1789^{bc}	6403^{a}	8192^{a}
Groundnut	1857^{ab}	6580^{a}	8437^{a}
Cowpea	1961^{a}	6475^{a}	8436^{a}
Fertilizer (kg N-P-K ha^{-1})			
0N-10P-11K	1353^{b}	4601^{c}	5954^{d}
20N-10P-11K	1745^{a}	5957^{b}	7702^{b,c}
40N-10P-11K	1824^{a}	6128^{b}	7952^{a,b}
60N-10P-11K	1868^{a}	6661^{a}	8529^{a}
80N-10P-11K	1804^{a}	6640^{a}	8444^{a}

Values affected by the same letter in the same column are not significantly different at $p < 0.01$, according to Fisher's test.

Agronomic experiment

The succeeding sorghum responses to N fertilizer and NFE of the three legumes were studied during two years (2000 and 2001). During the first year (2000), a simple randomized block experiment with five treatments corresponding to the five crops (sorghum, maize, groundnut, cowpea, and soybean) was cultivated in four replications with experimental plots of 4 × 15 m (60 m^2). During the second year, sorghum was sowed in all main plots. But each main plot was split into five sub plots of 12 m^2 (3 × 4) receiving five increasing doses of N fertilizer (0, 20, 40, 60, and 80 kg N ha^{-1}) in the form of urea. N fertilizer treatments were randomized in the sub plots. Then, the experimental design became factorial 5 × 5 treatments (5 crop rotations and 5 doses of N) in a split-plot arrangement with four replications. Hence, in the second year (2001), the two cereal-cereal rotations (sorghum-sorghum, and maize-sorghum) were used as controls in comparison with legume-sorghum rotations (cowpea-sorghum,groundnut-sorghum and soybean-sorghum), allowing assessment of the effect of previous legumes on succeeding sorghum yields. In line with farmers' practices, residues of previous crops were taken off.

Applications of 14, 10, and 11 kg K ha^{-1} were used on the three legumes at sowing with 100 kg ha^{-1} of NPK fertilizer during the first year (2000). 10 and 11 kg K ha^{-1} in the form of triple super phosphate and potassium chloride, respectively, were applied at sowing on maize (first year only) and sorghum during the two years. Two applications of 30 Kg N ha^{-1} were applied on maize at sowing and 40 days after sowing (DAS) (46 kg N ha^{-1}) in the first year. Two applications of 23 Kg N ha^{-1} were applied on sorghum at sowing and 40 DAS (46 kg N ha^{-1}) in the first year. Urea was split on sorghum (half dose of N at sowing and then 40 DAS) for all N treatments in the second year. Legume crops were not inoculated. Recommended planting density of 62 500 plants per hectare was used for sorghum and maize. Plant densities were 62 500 plants per hectare for groundnut and 125 000 per hectare for both cowpea and soybean, respectively.

Data analysis

The five crops were cultivated in the first year (2000) so as to evaluate their effects as previous crops on succeeding sorghum. So, we were mainly interested in data from the second year (2001). The SYSTAT software was used for statistical analysis of agronomic data using rotations and N fertilizer applications as first and second factors, respectively. N response curves were used to study sorghum response to N fertilizer applied for different previous crops. Different model response curves have been tested in order to use those that had highest coefficients of regression. The graphical linear-plateau model (Cerrato and Blackmer, 1990) has been used for the determination of optimum doses of N fertilizer. NFC of the three legumes were graphically determined using the response curves (Hesterman et al., 1987).

Soil analysis

The original soil of the experiment was characterized during the first year (2000). Soil samples were taken from the top 20 cm depth. Soil pH was measured in 1 N KCl using a 2:1 solution to soil ratio. Organic carbon was measured by the wet chemical digestion procedure of Walkley and Black (1934). Total N was determined by the Kjeldahl procedure. Exchangeable bases (Ca, Mg, K, and Na) were displaced with ammonium acetate. Calcium and Mg were determined by atomic absorption spectrophotometry, while K and Na were determined using flame photometry. Effective cation exchange capacity of the soil (ECEC) was calculated by the total exchange bases. Available phosphorous was determined using the Bray I method (Fixen and Grove, 1990).

RESULTS AND DISCUSSION

Sorghum yields

A general analysis of data indicated that, despite the removal of residues, the succeeding sorghum grain and stover yields were affected by previous cropping ($p < 0.01$) and N fertilizer applications ($p < 0.01$) (Table 2). Interactions were not observed between the two factors,

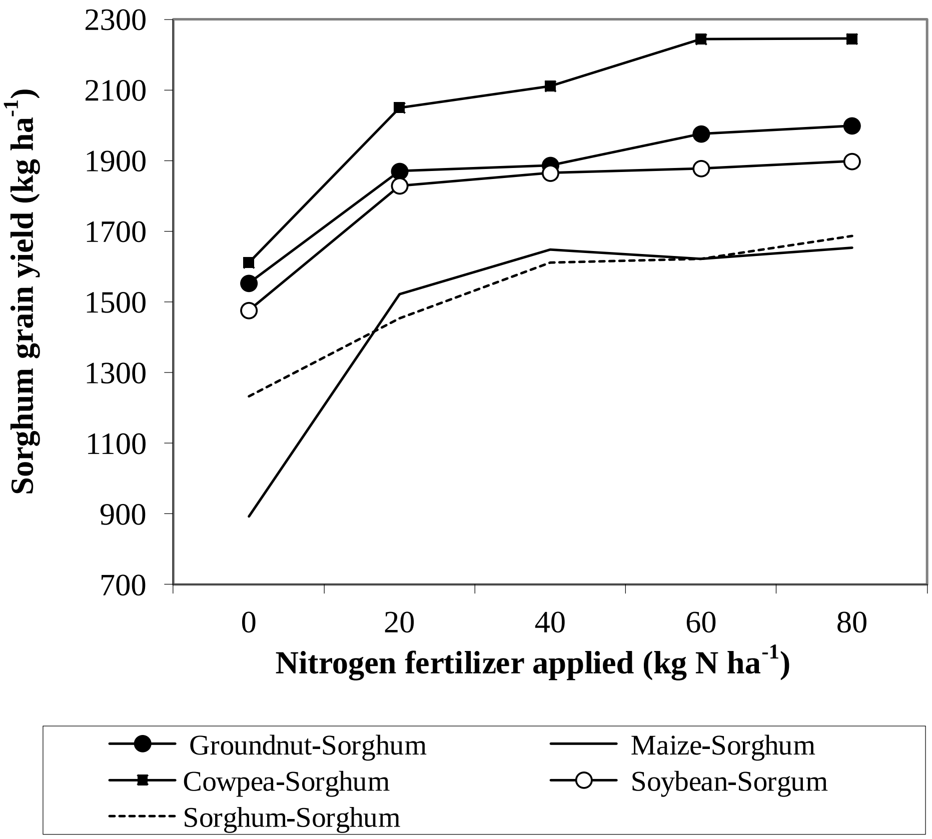

Figure 1. Effects of previous crops (cultivated in year 2000) on succeeding sorghum response to N fertilizer applications in year 2001.

but N fertilizer always increased sorghum yields in the five rotations. In the absence of N fertilizer application, monocropping of cereals (sorghum-sorghum and maize-sorghum rotations) produced 1.2 and 1.0 tonnes ha^{-1} of grain, respectively, which reflected the yield levels obtained by farmers (1 tonne ha^{-1}), where monocropping of cereals is commonly used (Sedogo et al., 1991). Highest yields were obtained when sorghum was cultivated after legumes while lowest yields were obtained in monocropped sorghum or when it was cultivated after maize. High yields were particularly observed when sorghum was rotated with cowpea or groundnut (Figure 1). Grain yields varied from 1.4 to 1.9 tonnes ha^{-1} under different levels of N fertilizer application. Yields varied from 1.4 to 2.0 tonnes ha^{-1} between different previous crops, indicating that, integrated management of fertilizer and crop rotations can improve the productivity of traditional farmers' systems. Beneficial effects of N_2-fixing legumes on succeeding crops have been reported by many researchers (Wani et al., 1995; Chalk, 1998; Bagayoko et al., 2000; Kouyaté et al., 2000). Peoples and Crasswell (1992) reported that in legume-cereal rotations, legumes can increase cereal yields from 50 up to 350%. Bationo and Ntare (2000) found that cowpea increased pearl millet yields by 58 to 100%.

Nitrogen fertilizer equivalencies of legumes

The sorghum grain yield response functions of fertilizer N applications after five different previous crops can be described by the following equations. In these equations, Y is the yield (kg ha^{-1}) and N is the level of N fertilizer (kg N ha^{-1}):

$$\text{Sorghum-Sorghum: } Y = -0.114\, N^2 + 15.38\, N + 1184;\ R^2 = 0.97 \quad (1)$$

$$\text{Maize-Sorghum: } Y = -0.2276\, N^2 + 26.20\, N + 969;\ R^2 = 0.93 \quad (2)$$

$$\text{Soybean-Sorghum: } Y = -0{,}123N^2 + 14{,}308\, N + 1512;\ R^2 = 0.91 \quad (3)$$

$$\text{Groundnut-Sorghum: } Y = -0.0828\, N^2 + 11.61\, N + 1586\ ;\ R^2 = 0.97 \quad (4)$$

$$\text{Cowpea-Sorghum: } Y = -0.2765\, N^2 + 29.37\, N + 1495;\ R^2 = 0.97 \quad (5)$$

Table 3. Previous crops (cultivated in 2000) and succeeding sorghum optimum yields, optimum doses of N fertilizer and N fertilizer N equivalencies of the three legumes in 2001.

Previous crop	Optimum dose of N kg N ha^{-1}	Yield kg ha^{-1}	Yield of maximum(%)	NFE kg N ha^{-1}
Sorghum	44	1661^{d}	74	na
Maize	37	1661^{d}	74	na
Soybean	38	$1886^{b,c}$	84	30
Groundnut	50	1998^{b}	89	35
Cowpea	53	2245^{a}	100	42

Values affected by the same superscripted letter in the same column are not significantly different at $p < 0.05$, according to Fisher's test, NFE: Nitrogen Fertilizer Equivalencies, effect of legume, estimated as fertilizer N effect on succeeding sorghum (kg N ha^{-1}).

Without N fertilizer application, the succeeding sorghum yields were 1512, 1586, and 1495 kg ha^{-1} when the previous crops were soybean, groundnut and cowpea, respectively. The equivalent doses of N fertilizer that need to be applied on monocropped cereals (sorghum-sorghum or maize-sorghum) to achieve the same yields were 30, 35, and 42 kg N ha^{-1}, respectively (Table 3). Bloem and Barnard (2001) estimated the N effect of cowpea at 32 kg N ha^{-1}. Considering that, N effects of legumes are due to their increase in soil mineral N, Shumba (1990) reported that yield increase in the cowpea-maize rotation came from the addition of 32 kg N ha^{-1} to the soil by cowpea. Similar results have been reported by Bado et al. (2006), indicating that groundnut and cowpea increased soil mineral N by 15 and 22 kg N ha^{-1}, respectively.

Optimum doses of N

By using the linear-plateau model (Cerrato and Blackmer, 1990) to estimate the optimum doses of N, data showed high variations between rotations (Table 3). At least 1.6 tonnes ha^{-1} of grain yield were produced in monocropped cereals (sorghum-sorghum or maize-sorghum rotation), while doses of 37 or 44 N ha^{-1} were necessary to achieve this optimum production level. This indicated that, the N fertilizer recommendation of 45 kg N ha^{-1} was appropriate for monocropping cereals. The maximum grain yield of 2.5 tonnes ha^{-1} was obtained from a cowpea-sorghum rotation with 60 kg N ha^{-1}. We have used it as the agronomic potential yield of our experiment, a reference yield that can be used to compare the effects of previous crops (Table 3). High yields were observed when sorghum was rotated with soybean (1.9 tonnes ha^{-1}), groundnut (2.0 tonnes ha^{-1}) and cowpea (2.2 tonnes ha^{-1}). While monocropping sorghum produced 74% of the maximum yield, the succeeding sorghum produced 84, 89 and 100% of the maximum yield when it was cultivated after soybean, groundnut and cowpea, respectively. However, doses of 38, 50 and 53 kg N ha^{-1} were necessary to achieve these productivity levels.

The good response of sorghum to a combination of N fertilizer applications and crop residues can be explained by the interaction between organic and mineral N. Legume residues increase soil organic N and N supplied by mineral fertilizers stimulates the mineralization of soil organic N, leading to increased soil-available N (Woomer and Swift, 1994). The interaction effect of organic and mineral N probably increased fertilizer N use efficiency by the succeeding sorghum (Varvel and Peterson, 1990).

An analysis of the response curves indicated whether the response was due entirely to N or other factors. For instance, the response curves for monocropped cereals (maize-sorghum or sorghum-sorghum rotations) were parallel and never reached those of the cowpea-sorghum, soybean-sorghum or groundnut-sorghum rotations (Figure 1). This indicated that, factors other than N might play a role in legume benefits. The two types of converging curves, which do not intersect, showed a response to N as well as other factors such as microbial activities (Chalk, 1998). Other researchers have attributed the positive effects of legumes in rotations as well as N supplied by legumes to the improvement of soil biological and physical properties (Hoshikawa, 1990). Legumes are also capable of influencing other factors such as dissolution P by legume root exudates (Gardner et al., 1981).

These results confirm that, N fertilizer recommendations made by the national agricultural institute (45 kg N ha^{-1}) are appropriate for monocropping of sorghum or maize-sorghum rotations. The actual yields of sorghum in traditional cereal-cereal systems can be increased from 1 tonne ha^{-1} up to 2.2 tonnes ha^{-1} with integrated management of N fertilizer and crop rotations with legumes (cowpea, groundnut and soybean). To attain such a yield, sorghum must be fertilized with 40 kg N ha^{-1} in soybean-sorghum rotations and with 55 N kg ha^{-1} in both cowpea-sorghum and groundnut-sorghum rotations. The data suggests that, N fertilizer applications should be increased on cereal crops when the previous legume has a high N effect (groundnut and cowpea). This improves the productivity of the system and the benefits for the farmer. However, N fertilizers must be reduced when the legume has a low N effect, such as with soybean.

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