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CROTALARIA OCHROLEUCA AS A GREEN MANURE CROP IN UGANDA

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ABSTRACT

The potential of *Crotalaria ochroleuca* as a green manure crop was evaluated in a series of on-station and on-farm trials on reddish kaolinitic loam and sandy clay loam soils in Uganda. Production of the green manure by intercropping Crotalaria with either maize or beans was found to be feasible with little reduction in food crop yield and a mean Land Equivalent Ratio of 1.3. The large amounts of N in the Crotalaria indicates that large quantities of N were biologically fixed. Mean maize grain yields following Crotalaria sole crop were 180% and 240% of maize grain yields following maize in two on-station trials and nine on-farm trials, respectively. Mean maize grain yield following bean in rotation were not significantly less compared to maize following Crotalaria, but grain yields were low in both seasons of on-station trials due to adverse conditions. Mean maize stover yield following Crotalaria was 185% of the stover yield when maize followed beans in rotation. In on-farm trials, maize grain yield following Crotalaria was 160% of the maize yield following beans. Bean seed yields in the second season after Crotalaria production were 120 and 150% in plots with Crotalaria in the first season as compared to maize and bean as the first season crop. A green manure of Crotalaria was effective in improving the productivity of the system but there may be opportunities to improve the efficiency of use of the large amounts of nitrogen biologically fixed by the Crotalaria.

***Key words*: Phaseolus bean, *Crotalaria ochroleuca*, green manure, maize**

RÉSUMÉ

Le potentiel de *Crotalaria ochroleusa* comme une culture de fumier vert a été évalué dans une série d'essaia à la station et en ferme, sur des sols terreaux kaolinitiques reugeatres et terreaux glaises sablonneux en Ouganda. La production du fermier vert en intercalant le Crotolaria ou avec le maïs ou avec les haricots s'est averée faisable, avec peu de réduction en rendement des cultures et un Rapport Equivalent de Terre (RET) de 1.3. Les grandes quantités de N dans le Crotalaria indiquent que de grandes quantités de N ont été fixees biologiquement. Des rendements moyens de maïs après une seule culture de Crotalaria étaient 180% et 240% des rendements des graines de maïs après le maïs dans deux essais à la station et neuf essais en ferme, respectivement. Le rendement moyen de grains de maïs après les haricots en assolement n'était pas significativement inférieure par rapport au rendement de maïs après le Crotalaria, mais les rendements de grains étaient bas dans toutes les deux saisons d'essais à la station dû aux conditions défavorables. Le rendements moyens de paille de mais après le Crotalaria était 185% de celles obtenues quand le maïs a été

planté après les haricots en assolement. Dans des essais à la ferme, les rendements de grains de maïs après le Crotalaria était 160% du rendement de maïs après les haricots. Les rendements de grains des haricots dans la seconde saison après la production de Crotalaria étaient 120 et 150% de ceux obtenus dans les parcelles qui avaient respectivement le maïs et les haricots dans la première saison. Un fumier vert de Crotalaria était effectif dans l'amélioration de la productivité du système, mais il peut y avoir des perspectives à améliores l'efficacités de l'utilisation des grandes quantité d'azote biologiquement fixées par le Crotalaria.

***Mots Clés*: *Haricot phaseolus, Crotalaria ochroleuca,* fumier vert, maïs**

INTRODUCTION

Low soil nitrogen availability is a major constraint to crop production on many soils in East Africa. Soil organic matter levels, as well, are often at sub-optimal levels and continue to decline. In many parts of the tropics, fertilizer use is limited by poor infrastructure, market accessibility or high prices. However, both nitrogen and carbon are renewable resources in the sense that the atmosphere contains large quantities and that the nutrients can be trapped by plants and incorporated into the soil. Use of green manures to accomplish this is an ancient practice, but not often used in East Africa.

Several studies in Eastern Africa have demonstrated positive effects of green manure on subsequent crops (Potts *et al.*, 1989; Onim *et al.*, 1990; Gama *et al.*, 1992). However, Stephens (1967) reported the beneficial effects of green manure to be of shorter duration than rotation with Napier grass. The Napier grass was found to improve soil aggregate stability and Stephens concluded that improvement of soil structure was more important to the productivity of these Ugandan soils than increased soil nitrogen.

Green manure crops are typically incorporated into the soil while immature. Disadvantages of this approach are that decomposition occurs at a high rate and the nutrient release often greatly exceeds the immediate nutrient demand of the crop increasing the likelihood of nutrient losses to volatilization and leaching; and most of the carbon of the low C : N material is converted to CO_2 with little contribution to the stable soil organic matter fraction. Allowing a green manure crop to mature gives greater biomass production, and more N fixation if the crop is leguminous. Nutrient release from the mature biomass is gradual and probably does not exceed crop demand. Because of the higher C:N ratio and high fiber content of the mature biomass and the subsequent lower rate of decomposition, the mature biomass is expected to make a greater contribution to the stable soil organic matter fractions. Gama *et al.* (1992) observed similar yield increases in cotton following incorporation of immature as compared to mature biomass of *Crotalaria ochroleuca*.

Crotalaria ochroleuca has a number of characteristics that suggest it has potential as a green manure crop for many parts of East Africa. It is relatively easy to establish a good plant stand and it grows vigorously, competing well with weeds once established. It matures within five months or a single growing season. It is easy to control and not a potential weed problem. It nodulates effectively with indigenous Rhizobia strains and apparently fixes much nitrogen. It produces a good supply of seed. It produces much biomass which can contribute to, or increase, soil organic matter levels. It apparently has few, if any, serious pest problems in Uganda. A disadvantage of this Crotalaria species is that it does not give a palatable fodder. Another possible problem is that Crotalaria is one of many hosts to Bean Common Mosaic Virus and bean stem maggot. While there is no evidence that this will be a problem, and may be advantageous if it also harbors insects that prey on the bean stem maggot, it needs to be watched.

On-station and on-farm trials were conducted from 1991 to 1993 to evaluate the potential of *Crotalaria ochroleuca* as a green manure crop in farming systems of central Uganda. The objectives of the research were to determine the feasibility of producing Crotalaria in association with a food crop and to determine the green manure crop's effects on the performance of subsequent crops.

MATERIALS AND METHODS

Four sets of trials of three seasons duration were conducted at Kawanda Agricultural Research Institute (1175 m above sea level, latitude 0°19'N, longitude 32°35'E, 1224 mm mean annual rainfall). The sets of trials included two sets with intercropping of maize and Crotalaria, and two sets with bean and Crotalaria intercropping. Sets were initiated in both the 1991a and 1991b seasons. Maize and bean sole crops were grown on all plots of the trials in the second and third seasons of the sets, respectively. On-farm trials of two seasons duration were conducted in Iganga and Mpigi districts, which have similar climatic conditions as Kawanda. The soils were reddish kaolinitic loams and sandy clay loams.

Season 1 of on-station trials. The first season of the maize-Crotalaria trials consisted of four treatments:

1. maize (Longe 1) in sole crop (90 x 50 cm with 2 plants per hill in the 1991a season, but 75 x 60 cm x 2 plants in the 1991b season);
2. as #1 but with 30 kg N ha^{-1} applied as urea in the two following seasons (also applied in the first season of the trial initiated in 1991b);
3. maize and Crotalaria intercropped (alternating two rows in 1991a, but one row in 1991b, of Crotalaria with one row of maize sown as in #1);
4. Crotalaria in sole crop sown in 30 cm rows.

In the first season, the bean-Crotalaria trials consisted of five and seven treatments, respectively, in 1991a and 1991b:

1. a popular bean cultivar, K20, in sole crop (50 x 10 cm spacing);
2. a well-adapted but highly competitive bean cultivar (11), White Haricot (WH), in sole crop (50 x 10 cm spacing);
3. K20 intercropped with Crotalaria in alternate rows with the beans sown as in #1;
4. WH intercropped with Crotalaria in alternate rows with the beans sown as in #2;
5. Crotalaria in sole crop sown in 30 cm rows;
6. K20 as in #1 but with 30 kg N ha^{-1} applied as urea in the two following seasons (also applied in the first season of the trial initiated in 1991b);
7. WH as in #2 but with 30 kg N ha^{-1} applied as urea in the two following seasons (also applied in the first season of the trial initiated in 1991b).

Plot size was 5 x 5 m for the maize-Crotalaria trials and 4 x 5 m for the bean-Crotalaria trials. The outside rows were excluded from the measured yields. A randomized complete block design of four replications was used.

Planting of the intercrops was done on the same day. Fertilizer was applied at 30 kg P ha^{-1} and 40 kg K ha^{-1} to all plots. Both the grain and stover were harvested and removed from the fields (maize stover was left on the plots of the 1991b trial). Grain yields were measured.

The Crotalaria was allowed to continue to grow and produce seed after the beans and maize had been harvested. By then, many of the leaves had aged and fallen from the plant, and the stems were very fibrous. The plants were uprooted by hand-pulling and allowed to air-dry in the field. Biomass dry weight was determined. Threshing was done by walking on the plants to break open the pods and shaking to remove the seed. The Crotalaria leaves, pod hulls and small branches which were broken from the stems were incorporated into the soil during land preparation for the next crop. The stems were distributed on the surface as mulch between the rows of the following maize crop.

Season 2, on-station trials. The second season of these trials consisted of growing maize (Longe 1) on all plots of these trials at 75 x 60 cm with two plants per hill. The +N treatment was side-dressed with urea at the rate of 35 kg N ha^{-1} after the second weeding in 1991b. Urea was applied pre-plant to the +N treatment at 46 kg N ha^{-1} in 1992a. No other fertilizer was applied. Maize grain and stover yields were measured.

Season 3, on-station trials. In the third season of these trials, beans (K20) were sown in all plots in 50 cm rows to achieve approximately 20 plants per m^2. Nitrogen was applied to the +N plots as a sidedress of urea at 35 kg N ha^{-1} after the second weeding. No other fertilizer was applied. Bean grain yields were measured.

On-farm trials in Iganga and Mpigi districts. Trials of five treatments and two replications were conducted in a complete block design on nine farms in Iganga district and four farms in Mpigi district in 1992-3. The treatments were:

1. maize sole crop (Longe 1 at 75 x 60 cm x 2

plants/hill);
2. bean sole crop (K20 at 50 x 10 cm);
3. maize-Crotalaria intercrop (as #1, with single rows of Crotalaria alternating with maize rows);
4. bean-Crotalaria intercrop (as #2, with single rows of Crotalaria alternating with bean rows); and
5. Crotalaria sole crop (30 cm rows). Plot sizes were 5 x 5 meters.

Nutrient concentration change in biomass of Crotalaria stem mulch. Crotalaria stems were sampled immediately after threshing and 10 weeks after applying as mulch to determine the changes in concentrations of N, P, K, Ca and Mg. Analyses of nutrient concentrations were done accordong to the CIAT Analytical Services Laboratory procedures for nitrogen (Bremner, 1965), phosphorus (Murphy and Riley, 1962), K, Ca and Mg (Chapman and Pratt, 1961).

Determination of optimal plant densities of Crotalaria. Regression analysis was applied to mature biomass yield data collected from 12 subplots of 1 x 1 m in 1991b to relate plant density to biomass yield.

RESULTS

Maize grain yield was not significantly reduced (P = 0.05) due to competition with Crotalaria but the Crotalaria harvested in the intercrop plots was about 40% of the Crotalaria sole crop yield (Table 1). Bean yields were significantly reduced by intercropping with Crotalaria in the on-farm trials but not much affected in the on-station trials. Crotalaria yields with intercropping were approximately 50% of Crotalaria sole crop yields (Table 2). Crotalaria growth was more suppressed by White Haricot than by K20. Maize grain yields were greater following the Crotalaria treatments than with maize following maize (Table 3). In the on-station trials, yield of maize following Crotalaria was 180% of the maize yield following maize. For nine on-farm trials, the yield of maize following Crotalaria was 240% of the yield of maize following maize. Maize responded to

TABLE 1. First season mean yields of maize-Crotalaria (Cr.) intercropping trials, with means separation by LSD 0.05.

	1991a season		1991b season		13 on-farm trials	
	Maize grain	Crotalaria biomass	Maize grain	Crotalaria biomass	Maize grain	Crotalaria biomass
Treatment			(kg ha^{-1})			
Maize	3597 a		2960 ab		2520 a	
Maize + N	NA		3324 a			
Maize + Cr.	3446 a	5650 b	2530 b	3570 b	2167 a	NA
Crotalaria		15140 a		8250 a		NA
C.V.	18.8	14.6	9.5	8.4	33.5	

TABLE 2. First season mean yields of bean-Crotalaria (Cr.) intercropping trials, with means separation by LSD 0.05.

	1991a season		1991b season		13 on-farm trials	
	Bean grain	Crotalaria biomass	Bean grain	Crotalaria biomass	Bean grain	Crotalaria biomass
Treatment			(kg ha^{-1})			
Bean (K20)	816 a		1823 b		942 a	
K20 + Cr.	787 a	9888 b	1235 c	5781 b	691 b	NA
K20 + N			1697 b			
Bean (WH)	887 a		1777 b			
WH + Cr.	1017 a	8800 c	1642 b	3727 c		
WH + N			2237 a			
Crotalaria		18650 a		9663 a		NA
C.V.	14.5	11.5	12.5	10.7	28.9	

applied N but the N effect tended to be less than the effect of the Crotalaria.

Maize grain yields were low and did not differ significantly in the on-station Crotalaria-bean trials (Table 4). Stover and total biomass yields were greater, however, following Crotalaria.

TABLE 3. Mean maize yields in the season following Crotalaria (Cr.) production in the maize-Crotalaria trial, with means separation by LSD 0.05.

	Maize grain yield (kg ha^{-1})		
Treatment	1991b	1992a	OFTs (n=9)
Maize : maize	2617 b	2612 b	1141 c
Maize + N : maize	3613 ab	4855 a	
Maize + Cr. : maize	4470 a	4407 a	1928 b
Crotalaria : maize	4165 a	5140 a	2751 a
C.V.	19.4	20.4	10.9

Maize did not respond to applied nitrogen in these trials. The poor performance in the 1991b season was judged to be due to severe potassium deficiency. In the 1992a season, there was low moisture stress at tasseling and pollination time. The increased stover yield indicates that under better conditions the maize crops would have given greater yields following Crotalaria.

In the second season after Crotalaria, there was no response to the Crotalaria, or to the applied nitrogen, in the maize-Crotalaria trials (Table 5). In both seasons, bean yield was least on the maize plus Crotalaria plots. In the bean-Crotalaria trials, the positive effect of the Crotalaria continued in the second season after Crotalaria production (Table 6). Bean yields in plots in which Crotalaria sole crop was grown were significantly higher than in plots where Crotalaria was not grown.

TABLE 4. Mean maize yields in the season following Crotalaria production in the bean - Crotalaria (Cr.) trial, with means separation by LSD 0.05[a].

	1991b season		1992a season		OFTs
Treatment	Maize grain	Maize[b] stover	Maize grain (kg ha^{-1})	Maize[b] stover	Maize grain
K20 : maize	1190 a	1376 c	3288 a	3856 cd	1748 c
K20 + Cr. : maize	1647 a	2322 ab	3856 a	5511 b	2050 b
K20 + N : maize			3122 a	4704 bc	
WH : maize	1434 a	1540 c	2308 a	2989 d	
WH + Cr. : maize	1607 a	2070 bc	2787 a	3663 cd	
WH + N : maize				2796 a	3524 d
Crotalaria	2075 a	2963 a	2652 a	6652 a	2751 a
C.V.	31.3	25.3	23.0	17.4	10.9

[a] Means within a column bearing similar letters are not significantly different.
[b] Cobs excluded from stover weights.

TABLE 5. Mean bean yields in the second season following Crotalaria (Cr.) green manure production in the maize-Crotalaria trials, with means separation by LSD 0.05.

	Bean yield (kg ha^{-1})	
Treatment	1992a	1992b
Maize : maize : beans	320 ab	730 a
Maize + N : maize : beans	273 bc	785 a
Maize + Cr. : maize : beans	260 bc	630 a
Crotalaria : maize : beans	419 a	820 a
C.V.	25.1	16.6

Means within a column bearing similar letters are not significantly different.

TABLE 6. Mean bean yields in the second season following Crotalaria (Cr.) green manure production in the bean-Crotalaria trials, with means separation by LSD 0.05

	Bean yield (kg ha^{-1})	
Treatment	1991b	1992a
K20 : maize : beans	413 b	773 cd
K20 + Cr. : maize : beans	469 b	1025 abc
K20 + N : maize : beans		832 bcd
WH : maize : beans	580 ab	738 d
WH + Cr. : maize : beans	528 ab	850 bcd
WH + N : maize : beans		1055 ab
Crotalaria : maize : beans	719 a	1152 a
C.V.	25.5	17.5

Means within a column bearing similar letters are not significantly different.

TABLE 7. Nutrient concentrations (%) of Crotalaria stems at time of application as mulch and 10 weeks later.

Nutrient	Time of mulch application	10 weeks after mulch application	Level of Significance[1]
Nitrogen	0.97	0.73	*a
Phosphorus	0.066	0.066	ns
Potassium	1.08	0.37	***
Calcium	0.40	0.18	**
Magnesium	0.18	0.14	ns

[a]ns, *, **, ***indicate changes in nutrient concentrations were non-significant and significant at P = 0.05, 0.01 and 0.001, respectively.

Responses to applied N were inconsistent in these trials indicating that yields were constrained by one or more factor other than low soil N. Bean yields were low due to low soil K availability in 1992a, but the low yields in 1992b are unexplained.

Nutrient release from the Crotalaria stem mulch. Nutrient concentrations in the above ground Crotalaria plant tissue at flowering time were 2.60% N, 0.25% P, 2.43% K, 0.61% Ca and 0.26% Mg. The nutrient concentrations of the stems prior to application as mulch and 10 weeks after mulching are given in Table 8. As expected, the concentrations of nutrients are much lower than for the whole above-ground plant at flowering time. Nitrogen, potassium and calcium concentrations in the stems were significantly less 10 weeks after mulch application (Table 7). Concentrations of phosphorus and magnesium were essentially unchanged. Gaseous losses of N from the high C:N ratio stems as NH_3 were probably low (Janzen and McGinn, 1991). The removal of nutrients was probably primarily due to leaching from the decomposing organic material to the soil. These measurements do not consider the nutrients added to the soil due to mineralization of the organic fractions of the mulch, but indicate that there is a gradual provision of nutrients from the mulch to the growing crop. The C:N ratio of the stems, however, increased during this ten week period and further decomposition probably required significant immobilization of soil N when the stem remnants were eventually incorporated into the soil (Pinck *et al.*, 1948; Palm and Sanchez, 1991).

Optimal plant densities of Crotalaria. Plant densities in the measured sub-plots ranged from 22 to 86 plants per square meter with a normal distribution. The yield tended to increase with plant density according to the equation: Crotalaria yield (T ha^{-1}) = 5.40 + 0.098 * plants/m^{-2}, R^2 = 0.52. Assuming Crotalaria germination and seedling survival of less than 90%, the sowing rate should be at least 100 viable seeds per m^{-2}.

DISCUSSION

The results show that it is feasible to produce Crotalaria in association with maize or bean, but the Crotalaria produced is much reduced by intercropping (Tables 1 and 2). However, as we expect Crotalaria to normally be grown on soils where fertility has declined and food crops give low yields, it may be best to grow the Crotalaria in pure stand to achieve greater biomass production and more fixation of nitrogen. Because of the high labour requirement for Crotalaria production, whether in sole crop or intercropped, sole crop production of Crotalaria may be preferable, especially when returns to labour invested are of greater concern than returns to the land.

Food crop yields following Crotalaria production can be dramatically increased (Tables 3 and 4). However, if land productivity is constrained by factors other than low soil N availability, including inadequate soil moisture or deficiencies of P or K (Tables 4, 5 and 6), the green manure has little short-term effect on grain yield.

The nitrogen concentration of the above-ground portion of the Crotalaria crop was found to be 2.6% at flowering time. Considering that mean above-ground biomass dry-weights for the Crotalaria sole crop, excluding the leaves which had fallen from the plant, was about 12.5 mt ha^{-1}, over 300 kg N^{-1} were contained in the crop, large but unmeasured quantities of N were fixed by the

Crotalaria. The gains in productivity during the following two seasons, however, account for only a small proportion of this nitrogen. The results suggest that, while some of the nitrogen fixed by the green manure crop may remain in the soil after two seasons, nitrogen use efficiency by the subsequent crops was low. Volatile losses of N as NH_3 from fallen leaves were not expected to exceed 5 to 10% of leaf N over a two month period (Janzen and McQuinn, 1991). Leaching losses may have been significant. N immobilization due to incorporation of Crotalaria stem fragments was probably significant in the seasons when bean was the test crop. The fate of materials carried below ground by termites is not known. N use efficiency might be improved by applying P, K or other limiting nutrients as needed. Also, it may be more efficient to grow the green manure on some small plots, or strips, in a field and then spread more widely the harvested biomass to manure the adjacent areas.

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