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Integrated soil management for the savanna zone of W. Africa: legume rotation and fertilizer N

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Abstract

Integrated soil management with leguminous cover crops was studied at two sites in the northern Guinea savanna zone of northern Nigeria, Kaduna (190 day growing season) and Bauchi (150 days). One-year planted fallows of mucuna, lablab, and crotalaria were compared with natural grass fallow and cowpea controls. All treatments were followed by a maize test crop in the second year with 0, 30, or 60 kg N ha^{-1} as urea. Above ground legume residues were not incorporated into the soil and most residues were burned early in the dry season at the Kaduna site. Legume rotation increased soil total N, maize growth in greenhouse pots, and dry matter and N accumulation of maize. Response of maize grain yield to 30 kg N ha^{-1} as urea was highly significant at both sites and much greater than the response to legume rotation. The mean N fertilizer replacement value from legume rotation was 14 kg N ha^{-1} at Kaduna and 6 kg N ha^{-1} at Bauchi. With no N applied to the maize test crop, maize grain yield following legume fallow was 365 kg ha^{-1} higher than natural fallow at Bauchi and 235 kg ha^{-1} higher at Kaduna. The benefit of specific legume fallows to subsequent maize was mostly related to above ground N of the previous legume at Bauchi, where residues were protected from fire and grazing. At Kaduna, where fallow vegetation was burned, maize yield was related to estimated below ground N. The results show that legume rotation alone results in small maize yield increases in the dry savanna zone.

Introduction

Provision of sufficient N is critical for cereal production. The savanna zone of West Africa is no exception (Elemo, 1993; Jones and Wild, 1975). Integrated N management can take advantage of biological nitrogen fixation to reduce fertilizer N requirements (Greenland, 1985). This may be accomplished using adopted grain legumes (Greenland, 1985), herbaceous cover legumes (Weber, 1996) or forage legumes. A set of herbaceous legumes was screened throughout the savanna zone of Nigeria in 1993 and 1994 to assess ecological adaptability of various species and to observe characteristics that would influence their introduction in farming or cropping systems. The species selected for a one-year fallow in rotation with cereals in the northern Guinea savanna zone were *Mucuna pruriens* var. cochinchinensis, *Lablab purpureus*, and *Crotalaria ochroleuca*. Although intercropping of soil-improving legumes may be more acceptable to farmers (since it allows a yearly cereal crop), it is necessary to assess the maximum potential short-term benefit of a sole legume rotation because legume biomass (and potential benefit to the soil) will be reduced when intercropped with a cereal in the short growing season zone. Reduction of legume biomass in association with a cereal was shown for *Mucuna pruriens* by Sanginga et al. (1996), for *Crotalaria ochroleuca* by Wortmann et al. (1994), and for mucuna, crotalaria, and *Lablab purpureus* by Fischler (1996).

In the subhumid zone of Brazil (Lathwell, 1990) the yield of maize following mucuna was equivalent to maize receiving 50 to more than 100 kg N ha^{-1} following maize. However, these results were observed in systems where the mucuna residues were ploughed into the soil at flowering and a maize crop was planted very soon after legume incorporation. When residues were left on the soil surface, the fertilizer replacement value was much lower, 10 – 20 kg N ha^{-1} in the subhumid zone and 30 kg N ha^{-1} in the humid zone (Burle et al., 1992). The reduced effect of mulched mucuna is due in part to loss of N by volatilization, judging from the results of a greenhouse trial reported by Costa et al. (1990), in which 45% of N in surface-applied mucuna was not accounted for after 178 days.

The beneficial effects of leguminous fallows are known to be short-lived. When mucuna was grown for three years on the same plots, the fertilizer N replacement value was 55 kg ha^{-1} in the first year, 20 kg ha^{-1} in the second maize crop, and 10 kg ha^{-1} in the third (MacColl, 1990). Carsky (1989) reported no appreciable fertilizer N replacement value in the second maize crop after ploughing in mucuna in the subhumid zone of Brazil.

Adoption of herbaceous legumes in Africa is generally low (Thomas and Sumberg, 1995) although there are some promising trends for some species. Adoption of mucuna is occurring in southern Benin Republic (Manyong et al., 1996). Also, farmers are using *Crotalaria ochroleuca* as an improved fallow in parts of Tanzania (Balasubramanian and Blaise, 1993). *Crotalaria ochroleuca* has recently been intensively studied by Wortmann et al. (1994) and Fischler (1996). Mean maize grain yields following a crotalaria sole crop were 80% higher than after maize in two trials conducted on-station and 140% higher in nine trials conducted on farmers' fields (Wortmann et al., 1994).

Lablab purpureus (also classified as *Dolichos lablab*) is a grain and forage legume well adapted to the sub-humid zone (Tardieu, 1962). Very few observations have been made on the benefit of lablab rotation to a cereal crop. Fischler (1996) estimated the benefits of mucuna, crotalaria, and lablab to a subsequent maize crop in the bi-modal rainfall zone of Uganda. Compared to continuous maize, preceding mucuna and crotalaria increased maize grain yield by 50% and preceding lablab increased yield by 40% (averaged over about 15 on-station and on-farm replicates). On-station maize yields after the legumes were greater than or equal to maize with 90 kg N ha^{-1} after a maize crop.

Cowpea is a legume that originates in the dry savanna zone and is commonly grown in the Guinea savanna. In spite of being harvested for grain, cowpea may contribute to soil fertility because of its low nitrogen harvest index. Cowpea is susceptible to insect pests and when not adequately protected may produce very little grain, leaving more N to the soil. Estimates of the benefit of cowpea to soil N supply are 80 kg ha^{-1} when residues from two successive cowpea crops are left in the field (Horst and Hardter, 1994) and 60 kg ha^{-1} when residues from one cowpea crop were incorporated into the soil (Dakora et al., 1987). The contribution of cowpea rotation to soil N supply can be hypothesized to be lower than these estimates if residues are not incorporated into the soil, and even more if they are not maintained in the field during the long dry season.

Our objective was to obtain realistic estimations of fertilizer N equivalence of cover crop fallows in maize-based systems of the savanna zone with 6 – 7 month dry season with (1) late planting to simulate relay intercropping, (2) no irrigation, and (3) without incorporating the residues into the soil. All previous fallow treatments were followed by three rates of N fertilizer to estimate interactions. It is often observed that highest yields are obtained with a combination of inorganic fertilizer and an organic amendment such as farmyard manure (Jones and Wild, 1975; Pieri, 1989). Positive interactions for farmyard manure and inorganic fertilizer have been documented by Mokwunye (1980). Similar positive interactions can be hypothesized for herbaceous legume fallows.

Materials and methods

Trial site descriptions

The trial was conducted in one site in central Kaduna State (10°24′N; 7°42′E) and one in southern Bauchi State (10°01′N; 9°47′E) in northern Nigeria. The Kaduna site is on the border of the northern and southern Guinea savanna zones. Average annual total rainfall is approximately 1350 mm and the length of growing period is 180–190 days. The vegetation in the area around Kaduna is typical of the Guinea savanna. The area around the Kaduna site is flat but dissected by inland valleys. The trial was established on an erosion-prone upper slope of an inland valley. In previous years, the farmer had applied some inorganic fertilizer but no animal manure or other organic amendments and tillage was by hand hoe with little incorporation of crop or fallow residues. The soil in the four blocks at the trial site before planting in 1995 had 25 – 35% clay, 40 – 55% sand, 0.6 – 0.8% organic carbon, 4 – 6 μg g^{-1} of available (Bray-1) P, and pH (1:1 ratio of soil:H_2O) of 6.2 – 6.8.

The Bauchi site is on the border of the northern Guinea savanna and the semi-arid zone in the rainfall shadow of the Jos Plateau. The rains come later in Bauchi and are often poorly distributed until late June. Average annual total rainfall is approximately 900 mm and the length of growing period is 140–160 days. The vegetation around the Bauchi site is more typical of Sudan savanna (abundant thorny tree species). The landscape at the Bauchi site is generally flat with numerous rock outcrops. Seasonal streams and waterlogging are commonly observed during July to September. The trial site was an isolated bush field (approximately 1.5 km from the farmer's compound) that had been cropped for several years without organic manure or inorganic fertilizer and tilled by hand hoe with very little incorporation of crop and fallow residues. The topsoil (0 – 15 cm depth) in the four blocks at the trial site before planting in 1995 had 4 – 9% clay, 75 – 80% sand, 0.2 – 0.5% organic carbon, less than 1 μg g^{-1} of available P, and pH of 6.4 – 6.7.

Treatments

In 1995 five fallow vegetation treatments (mucuna, lablab, crotalaria, cowpea, and natural fallow) were combined factorially with three levels of N fertilizer (0, 30 and 60 kg N ha^{-1} as urea) applied to the maize test crop in 1996. The experimental design was a split plot with fallow vegetation mainplots (9 m $\times$ 10 m) and N fertilizer subplots (3 m $\times$ 10 m) in four replications. Mucuna was *Mucuna pruriens* var. cochinchinensis obtained from the Institut de Recherche Zootechnique (IRZ) in Garoua, Cameroon in 1992. Lablab was a variety of *Lablab purpureus* with cream seed color obtained from the market at Zaria, Kaduna State, Nigeria. Crotalaria refers to *Crotalaria ochroleuca* that was obtained from the Institut de Recherche Agronomique (IRA) in Maroua, Cameroon to which it came originally from southeastern Africa. IT89KD-288 (a spreading cowpea cultivar developed by IITA) was used in the Bauchi trial, but a spreading traditional cultivar of cowpea was used for the trial in Kaduna because it was expected to be better adapted to the more humid conditions found there.

Trial management

At the Kaduna site, care was taken to avoid living trees and recent stumps when laying out the plots. Maize was planted on May 24 and grown for 7 weeks to assess uniformity of the plots. Growth of the maize confirmed that the field was sufficiently uniform within blocks but the data were retained for future analysis of covariance. Before removing the maize, the height of ten plants was determined as well as the dry weight of four plants.

Mucuna, lablab, crotalaria, and cowpea were planted on July 14 95 at 0.75 m interrow spacing. Legume fallow plots were weeded on August 10 and September 9 and biomass of legumes and natural fallow was sampled approximately 91 and 112 days after planting (DAP) using two 0.5 m lengths of row for crotalaria and one 1 $\times$ 1 m quadrat for the others. Oven-dry biomass was ground and N concentration determined using a semi-macro digestion (Bremner, 1965). Cowpea was treated once with Sherpa Plus (1.0 l ha^{-1}) on September 1 and cowpea grain yield was estimated at maturity (October 25 95). The field was fenced at the beginning of the dry season but fire from neighbouring fields affected many of the experimental units. Therefore, we burned the rest of the plots and visually ranked the amount of residue remaining on the soil surface.

For the greenhouse bioassay soil was taken from 0 to 15-cm depth from each plot on May 10 or 11, about one month before planting of the maize test crop. The soil was transported to Ibadan, given a blanket dose of P and K and placed in pots. Nine kg per field plot was divided and placed in three pots. Before maize planting, soil was sampled to 10-cm depth for determination of total N concentration. Maize was planted in July, thinned to two stands per pot at 14 DAP, and harvested after 42 days of growth. Above ground and below ground maize biomass was weighed separately.

The maize test crop (commercial hybrid Oba Super 1) was planted on June 4 96. Thirty kg N ha^{-1} was applied to both N treatments after first weeding (22 DAP). The second part of the 60 kg N ha^{-1} treatment was applied at 42 DAP. Nitrogen was placed approximately 5 cm from the maize plant and 2 cm deep by making a hole with the handle of the hoe then covering the hole. At the same time, the height of ten maize plants was measured by holding a level just above the plant and measuring from the ground to the level. The second plant from the end of the row was taken at both ends of the central rows. Plants were oven dried, weighed, ground, and N concentration determined. At maize maturity (115-120 DAP), all plants from the central rows were counted and harvested after discarding 1m of row from both ends. Stalks and ears were weighed separately. A sample of 10 ears was husked, shelled and weighed. Moisture content was estimated with a grain moisture meter. A sub-sample of stalks was selected, weighed fresh, oven-dried, and weighed again. Grain and stalk subsamples were ground and N concentration was determined.

At Bauchi a blanket application of single superphosphate (200 kg ha^{-1}) was broadcast and incorporated to overcome low soil P. Maize was planted on 26 May and grown for 7 weeks to assess uniformity of the plots. Fresh weight of maize was determined on 14 July 95 in subplots of 3 × 10 m for use as a covariate in future analyses. Mucuna, lablab, crotalaria, and cowpea (IT89 KD-288) were planted on July 19 1995 at 0.75 m interrow spacing and weeded during the establishment phase. Above and below ground biomass was estimated at 70 DAP and 112 DAP. At 70 DAP, samples consisted of two 0.5 m lengths of row and at 112 DAP they consisted of two 1 m lengths of row for crotalaria and two 1 × 1 m quadrats for spreading legumes. Depth of root sampling was 10–15 cm. Cowpea grain yield was extremely low and therefore not estimated. The field was fenced at the beginning of the dry season which hindered (but did not totally prevent) entry of animals into the plots.

The maize test crop (commercial hybrid Oba Super 1) was planted on June 14 1996. Thirty kg N ha^{-1} were applied to both N treatments at first weeding (14 DAP). The second part of the 60 kg N ha^{-1} was applied at second weeding (35 DAP). Nitrogen was applied in the same manner as at Kaduna but the hole was not covered. Bioassay, 6 week maize sample, and maize harvest (at 115 DAP) were performed as described above for the Kaduna site, except that N was not determined in harvest subsamples.

The data were combined for analysis of variance using both sites wherever possible for the bioassay, 6-week maize sample, and maize yield. If site was a significant factor in the ANOVA, then the data are reported separately. Separate analysis by site was done for legume biomass and accumulated N and for maize yield components. Separate analyses of maize yield included the covariate (7-week-old maize biomass from the uniformity trial) to attempt to improve precision.

Fertilizer N equivalence from legume rotation was estimated as the ratio of the increase in maize grain yield after legumes without N to the increase with 30 kg N ha^{-1} applied after natural fallow, multiplied by 30 kg ha^{-1}. Nitrogen fertilizer use efficiency was calculated as the increase in grain yield per unit of N fertilizer applied for each fertilizer rate. Apparent recovery of fertilizer N was calculated as the ratio of the incremental maize N uptake to the incremental fertilizer application rate. Average grain N of 1.18% and stover N of 0.56% (observed at Kaduna) were used for both sites.

Results and discussion

Fallow vegetation dry matter and N content

At Kaduna, above ground dry matter of crotalaria was 5 t ha^{-1} at 91 DAP and 8 t ha^{-1} by 112 DAP (Table 1). Mucuna dry matter was estimated at 4 and 6 t ha^{-1}, respectively. Biomass of lablab and natural fallow was approximately 2 t ha^{-1} at both 91 and 112 DAP. Lablab did not grow well because of foliar diseases and insect damage during August and September. The natural fallow was dominated by grasses. Cowpea vine dry matter was 0.6 t ha^{-1}. Cowpea grain yield estimate was 277 (±77) kg ha^{-1}. The total N in the above ground vegetation varied from 21 to 137 kg ha^{-1} at 91 DAP and from 16 to 154 kg ha^{-1} at 112 DAP. Cowpea had the lowest above ground N accumulation because of removal in the grain. Mucuna and crotalaria had the highest accumulation of above ground N. Lablab grew better in the late rainy season but dry matter was not determined after 112 DAP. After burning during the dry season the amount of residue on the soil surface was visually ranked as fallow > crotalaria > lablab > cowpea = mucuna.

At Bauchi, above ground biomass of mucuna and crotalaria were highest, reaching well over 3 t ha^{-1} by 112 DAP (Table 2), lower than at Kaduna. Natural fallow accumulated 2.5 t ha^{-1} and cowpea 2.3 t ha^{-1} by the same time. Lablab grew poorly as it did at Kaduna. At 112 DAP, above ground mucuna N accumulation was highest (85 kg ha^{-1}) and natural grass fallow was lowest (38 kg N ha^{-1}). Accumulation of N in cowpea vines at 112 DAP (58 kg ha^{-1}) was substantially greater that at Kaduna (16 kg ha^{-1}). Root dry matter in the top 15 cm of soil was estimated at almost 400 kg ha^{-1} for crotalaria and below 100 kg ha^{-1} for mucuna, lablab, and cowpea.

Effects on soil

The previous vegetation treatments did not have a statistically significant effect on total soil N (0 – 10 cm depth) when sampled before planting the subsequent maize test crop (Table 3). However, at Kaduna all of the legume treatments had higher N levels than the natural fallow. The mean total N in the legume plots was 0.065% compared with 0.055% after natural fallow,

Table 1. Dry matter (kg ha^{-1}) and N accumulated (kg ha^{-1}) in fallow vegetation at Kaduna in 1995

Treatment	91 DAP			112 DAP		
	D.M	%N	Accumulated N	D.M.	%N	Accumulated N
Mucuna	3980	3.30	131	6170	2.54	154
Lablab	1860	3.83	71	1950	2.45	47
Crotalaria	5020	2.82	137	8030	1.40	114
Cowpea	610	3.10	21	620	2.65	16
Natural	2300	1.57	36	2160	1.35	29
SE	400	0.2576	13.6	668	0.166	15.8

Table 2. Dry matter (kg ha^{-1}) and N accumulated (kg ha^{-1}) in fallow vegetation at Bauchi in 1995

Treatment	70 DAP			112 DAP		
	D.M.	%N	Accumulated N	D.M.	%N	Accumulated N
Mucuna	1720	3.1	53	3370	2.6	85
Lablab	580	3.9	23	1760	2.8	49
Crotalaria	1980	3.2	63	3250	2.3	52
Cowpea	1440	3.1	45	2310	1.8	58
Natural	2070	1.4	29	2490	1.5	38
SE	280	0.13		415	0.24	8.3

Table 3. Effect of 1995 fallow vegetation on total soil N at 0 – 15-cm depth (%) at planting of maize test crop in 1996 and above ground (tops) and below ground (roots) maize dry matter (g pot^{-1}) in greenhouse bioassay using soil taken from 0 to 15-cm depth

Previous vegetation	Kaduna			Bauchi		
	Total N	Tops	Roots	Total N	Tops	Roots
Mucuna	0.062	7.0	5.3	0.037	3.9	2.6
Lablab	0.060	11.2	7.1	0.045	4.2	2.8
Crotalaria	0.070	10.8	7.3	0.047	6.0	3.9
Cowpea	0.067	7.8	5.8	0.036	6.3	4.0
Natural	0.055	5.4	4.2	0.040	3.9	3.1
SE	0.0053	1.75	1.17	0.0075	0.62	0.68
% increase from legume	18	70	52	4	31	7

an apparent increase of 18%. This suggests a substantial contribution of N to the soil plant system, which could be expected because of the high above ground N contents of the legumes (especially mucuna and crotalaria) compared with the natural fallow (Table 1). At Bauchi, mean total N after legume rotation was only 4% higher than previous grass fallow and not consistent among the treatments (Table 3). This reflects the low amounts of N in the above ground dry matter of the legumes compared with the natural fallow (Table 2).

The bioassay results were significantly influenced by site, with dry matter of maize grown in Kaduna soil being about twice as high as in Bauchi soil (Table 3). The ranking of the treatments was different at the two sites although the interaction of site and fallow vegetation effects was not significant ($P = 0.21$). Maize biomass was highest after lablab and crotalaria at Kaduna and after cowpea and crotalaria at Bauchi. At both sites, soil from grass fallow plots gave significantly less maize biomass than the treatments mentioned above. For both sites combined, above ground maize dry matter after legumes was 54% higher and root dry matter was 33% higher than after grass fallow.

42 DAP field sample

Analysis of variance combined over both sites indicated that trial site was a significant factor in the dry matter of 42 day old maize plants but not N uptake. Previous fallow effect was significant at $P < 0.1$ and N application effect was highly significant. There was a significant interaction of site, previous vegetation, and N application.

At Kaduna, unfertilized 42 day-old maize plants were tallest following crotalaria and shortest following natural fallow (Table 4). The response of 42 day-old maize height to N was least for crotalaria and most and statistically significant following natural fallow and lablab. Dry matter of 42 day old maize without N fertilizer was highest following crotalaria and lablab and response to N was least for those two treatments (Table 4). Dry matter was lowest following natural fallow and cowpea whether N was applied or not. Without N applied, total N in the above ground maize crop was highest following lablab, crotalaria, and mucuna, although not significantly higher than previous cowpea or natural fallow. With inorganic fertilizer application, above ground N accumulation was significantly higher following mucuna than with all other treatments.

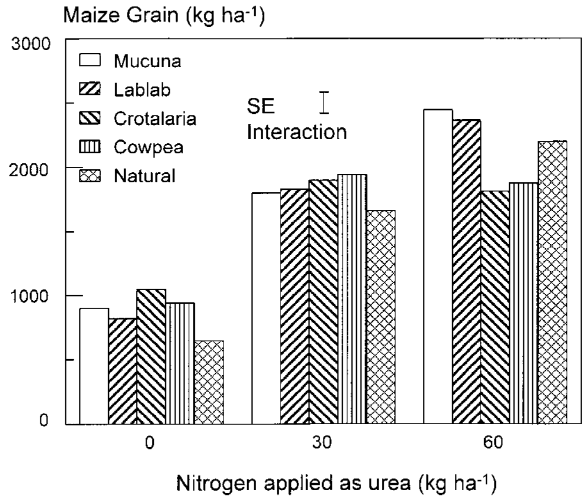

Figure 1. Yield of maize grain in 1996 following 1995 fallow treatments at three levels of N applied in 1996 to the maize crop, Bauchi and Kaduna combined.

At Bauchi, previous vegetation effects were slightly different from the bioassay results. Mucuna effects, in particular, were much more pronounced. When no N was applied, maize height at 42 DAP was significantly greater in previous mucuna plots than in previous lablab or natural fallow. Response of 42 day-old maize height to N fertilizer was statistically significant following natural fallow but not following the leguminous fallow treatments. Maize dry matter without N was also highest following mucuna although not significantly higher than the other treatments (Table 5). The response of dry matter to N fertilizer was also greatest following natural fallow. The N accumulation of 42 day-old maize plants was significantly influenced by previous vegetation, current season N application, and their interactions (Table 5). Without N fertilizer, N accumulation was higher following all leguminous fallows than the natural fallow and significantly higher following mucuna. Response to N application was greatest following natural fallow and least following mucuna.

Maize yield at maturity

At both sites maize biomass at 49 DAP in the uniformity trial before planting the leguminous fallows in 1995 was not a significant covariate with maize yield in 1996. These results suggest that either the site was uniform (Bauchi) or that blocking successfully reduced variability due to inherent soil fertility (Kaduna).

Table 4. Effect of 1995 fallow vegetation and N fertilizer application on height (cm), dry matter and N accumulated (kg ha^{-1}) in 42 day old maize at Kaduna in 1996. N fertilizer was applied at 22 DAP

Previous	Height		Dry matter		Accumulated N	
vegetation	–N	+N	–N	+N	–N	+N
Mucuna	70.6	79.4	324	810	5.0	16.5
Lablab	65.4	82.7	411	506	6.6	10.6
Crotalaria	81.2	87.4	412	489	6.0	9.9
Cowpea	63.3	72.2	179	398	3.0	7.2
Natural	55.5	72.2	135	251	1.7	6.4
Mean	67.2	78.8	292	491	4.5	10.1
SE N effect		1.6		37.3		0.8
SE veg × N		3.6		83.4		1.8
% increase from legume	26	11	146	119	203	73

Table 5. Effect of 1995 fallow vegetation and N fertilizer application on dry matter (kg ha^{-1}) and N accumulated (kg ha^{-1}) in 42 day old maize plants at Bauchi in 1996 (N fertilizer applied 14 and 35 DAP)

Previous	Height		Dry matter		Accumulated N	
vegetation	–N	+N	–N	+N	–N	+N
Mucuna	68.2	75.2	348	264	7.4	7.2
Lablab	55.3	64.3	239	261	4.5	6.7
Crotalaria	63.6	59.5	290	324	5.4	7.5
Cowpea	65.1	68.2	280	357	5.8	8.9
Natural	47.3	64.1	175	306	3.4	8.2
Mean	59.9	66.3	266	302	5.3	7.7
SE N effect		1.6		19.9		0.48
SE veg × N		3.49		44.4		1.07
% increase from legume	33	4	65	–1	70	–8

The main effect of previous fallow vegetation on maize grain yield was not statistically significant at either site. At Kaduna, a significant (P = 0.1) interaction between previous fallow vegetation and current season N application masked the fallow effect. At Bauchi, the interaction was not significant. The fallow × fertilizer interaction at Kaduna can be seen in the pattern of fertilizer response after planted fallow treatments. Maximum response to N was observed at 30 kg N ha^{-1} for the crotalaria and cowpea treatments and at 60 kg ha^{-1} for the mucuna and lablab treatments (Table 6). These response patterns were very similar at Bauchi and also similar for stover yield at both sites. When data from both sites were combined, the interaction of previous fallow and N fertilizer on maize yield had a probability level of P = 0.086. The interaction was a negative one, with the benefit of legume rotation decreasing as subsequent season fertilizer N application increased (Figure 1). With no N applied, maize yield following legumes was on average 280 kg ha^{-1} or 43% higher than maize following natural fallow. With 30 kg N ha^{-1} applied, improvement of maize yield from previous legumes averaged approximately 200 kg ha^{-1} or 12%. When 60 kg N ha^{-1} were applied, the average benefit of legume rotation was reduced to nil although yield after mucuna and lablab was much greater than after crotalaria and cowpea. Highest yields were achieved with 60 kg N ha^{-1} and mucuna and lablab rotation. It appears that maize yields after mucuna and lablab – but not after

Table 6. Effect of 1995 vegetation and 1996 fertilizer on maize dry matter yield and above ground N accumulated (kg ha^{-1}) at harvest at Kaduna and maize yield at Bauchi in 1996

Previous vegetation	N applied	Kaduna Grain	Grain N	Stover	Stover N	Bauchi Grain	Stover
Mucuna	0	815	9.4	1027	5.2	988	1133
	30	1544	18.3	1789	10.6	2053	1787
	60	2376	30.0	2724	16.6	2521	2193
Lablab	0	929	12.1	1706	9.2	713	853
	30	2016	23.8	2398	14.8	1640	1507
	60	2482	31.9	2444	14.0	2253	1767
Crotalaria	0	1212	13.0	1444	7.9	884	1293
	30	2051	23.4	3430	20.6	1745	1527
	60	1975	24.1	2745	14.9	1648	1547
Cowpea	0	895	9.5	1168	6.1	992	1133
	30	1610	19.1	1830	10.8	2276	2160
	60	1572	18.2	1859	9.4	2177	1907
Natural	0	734	8.0	867	4.3	565	720
	30	1214	14.2	1649	9.3	2107	1687
	60	2111	23.4	2233	11.5	2286	1653
SE (vegetation)		205	2.66	296	1.86	296	204
SE (N)		89	1.14	125	0.99	113	100
SE (vegetation × N)		200	2.55	278	2.21	252	224

crotalaria or cowpea – could have been increased with fertilizer N beyond 60 kg ha^{-1}.

The response to N fertilizer differed between sites only for the previous natural fallow treatments. The response to 30 kg N ha^{-1} was much greater at Bauchi (1500 kg ha^{-1}) than at Kaduna (480 kg ha^{-1}). It is not uncommon to observe a substantial maize grain yield increase with 30 kg N ha^{-1} as at Bauchi. Oikeh (1996) and Elemo (1993) reported high yield increases from small amounts of N fertilizer in the northern Guinea savanna of Nigeria. Lower yield response at Kaduna probably occurred because 56 mm of rain fell within 48 hours after the first N application at Kaduna, leaching a large fraction of the nitrate beyond the rooting zone. Only 20 mm fell at Bauchi during the same period. Nitrogen fertilizer application had a significant effect on maize grain yield components at both sites (Table 7). At both sites, ears per stand and ear weight were significantly increased by application of 30 kg N ha^{-1}. Plant density also responded to N at Kaduna while plant density at Bauchi was relatively constant. The maize crop at Bauchi produced more ears per plant than at Kaduna.

With no N applied, maize grain yield was 230 kg ha^{-1} higher following legume rotation compared to natural fallow at Kaduna and 320 kg ha^{-1} higher at Bauchi. Based on this and responses to 30 kg N ha^{-1}, mean fertilizer N equivalence of legumes was estimated at 14 kg N ha^{-1} at Kaduna and 6 kg N ha^{-1} at Bauchi. The estimates would be lower at Kaduna and higher at Bauchi if an N response curve was fitted to the data over all rates.

The N fertilizer equivalence values are low compared to those often reported (e.g. Dakora et al., 1987; Horst and Hardter, 1994 Lathwell, 1990; MacColl, 1990) mainly because residues were not incorporated into the soil. The fertilizer N equivalence of herbaceous legume rotation is low in the northern Guinea savanna because the dry season is long (six months) and much of the residue disappears due to fire (as was observed at Kaduna), wind, termites, or grazing. Low N fertilizer equivalence was also observed for legume rotation when the residues were not incorporated into the soil. Burle et al. (1992) recorded values of 10 – 20 kg N ha^{-1} for several adapted leguminous cover crops in the subhumid zone of Brazil and 30 kg N ha^{-1} in the humid zone. The dry season lasts approximately three months in the subhumid zone and approximately one month in the humid zone.

Even a low fertilizer N equivalence may be of interest to farmers who have limited access to commercial fertilizer. Those farmers are more likely to

Table 7. Maize yield components and emerged striga at harvest as a function of N applied as urea (kg ha^{-1}) in 1996

N applied	Plants (ha^{-1})	Ears (plant^{-1})	Ear weight (g)	Emerged striga (maize stand^{-1})
Kaduna				
0	32900	0.74	77	0.008
30	36700	0.86	114	0.052
60	40000	0.87	128	0.031
SE	849	0.027	4.1	0.011
Bauchi				
0	35100	0.88	54	2.9
30	37500	0.94	116	3.2
60	37500	0.96	124	4.7
SE	745	0.033	5.5	0.76

adopt a legume that can produce animal feed or human food. Based on these results, cowpea and lablab should be included in the design and development of sustainable cropping systems.

Maintenance of soil N status is an indicator that a farming system is sustainable (Wetselaar and Ganry, 1982). Wetselaar and Ganry (1982) note that although legumes may add N to the soil-plant system, an N balance study indicated that N content of the soil was not necessarily maintained because of removal of N in the crops. It is not clear whether long-term use of legume rotation without incorporation of leguminous residues will maintain soil N. In most long-term trials with legume rotation, the leguminous residues were incorporated into the soil. LeBuanec and Jacob (1981) observed maintenance of soil organic matter with stylosanthes or desmodium rotation over 10 years and declining organic matter over 6 years when the legumes were not included in the rotation. Vine (1953) showed that total N was maintained over at least 10 years when mucuna residue was incorporated but not when it was burned.

Effects of the different leguminous cover crop treatments appear to be related to the N content of the fallow biomass and its management at the two sites. At Bauchi, maize grain yield without N fertilizer application (Table 6) was weakly correlated ($r = 0.79$; $P = 0.11$) to N content of the fallow vegetation at 16 WAP (Table 2). At Kaduna however, above ground residue was burned during the dry season. Therefore benefits to the subsequent crop should be more related to root biomass. Ranking of maize grain yields without inorganic N application – crotalaria > lablab > cowpea > mucuna – is similar to the ranking of root dry matter at Bauchi – crotalaria > cowpea = lablab > mucuna. The root dry matter estimates can only be considered as indicative because sampling was done to only 15-cm depth and not all fine roots were recovered. The root:shoot ratio at Bauchi was 2–3% for mucuna, 8% for lablab, 14% for crotalaria, and 6% for cowpea.

The differences observed in the effect of cowpea rotation between the two sites are due to pest management. At Kaduna, cowpea insects were controlled with one insecticide application. As a result, some cowpea grain was produced (280 kg ha^{-1}), and the amount of N remaining in the above ground biomass after grain harvest was approximately 20 kg ha^{-1} (Table 1). At Bauchi, cowpea was not protected against insects and no grain was produced. Cowpea vegetation was substantial and N content was approximately 50 kg ha^{-1} (Table 2). The difference in the effect of cowpea rotation was visible in the bioassay (Table 3) and in the N content of maize at 6 WAP (Table 4 vs. Table 5). Maize grain yield after cowpea was among the lowest at Kaduna and among the highest at Bauchi. Thus effective cowpea pest control may result in less N benefit to the subsequent crop.

Nitrogen use efficiency (NUE) from fertilizer was not increased by legume rotation. It was lower after legumes than after natural fallow for all sites and fertilizer rates (Figure 2). Apparent recovery of fertilizer N gave similar results except at the 30 kg N ha^{-1} rate at Kaduna (Figure 2). Apparent recovery of fertilizer N and NUE were higher at Bauchi than at Kaduna. This

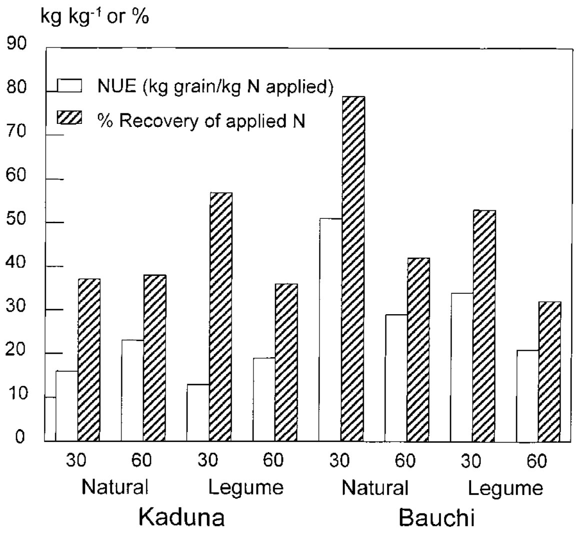

Figure 2. Efficiency of N use (NUE) by maize (kg grain per kg N applied as fertilizer) and apparent recovery (%) of N applied as fertilizer after natural or leguminous fallow at Kaduna and Bauchi.

is related to the high rainfall recorded immediately after N fertilizer application at Kaduna. Wetselaar and Ganry (1982) also reported lower recovery of N under higher rainfall conditions such as those encountered at Kaduna.

Conclusion

In the northern Guinea savanna zone of West Africa, legume rotation can be used to reduce fertilizer N requirement only slightly because of losses during the long dry season (November to April). The mean fertilizer equivalence value was approximately 10 kg ha^{-1} and ranged from 3 to 30 kg ha^{-1} depending on the site and the legume grown. Maize yield was related to above ground N content of the previous legume or, in the case where above ground legume biomass was burned, to root biomass. Therefore, in addition to high levels of biological N fixation, development of improved systems should emphasize preservation of above ground leguminous residues during the dry season. Protection of leguminous residues from livestock using local materials is practised in land abundant areas where fencing material is still plentiful. As land becomes scarce and labor becomes more available, it may be more appropriate to feed the legume to livestock and carry manure back to the fields. Development of improved systems might also benefit from greater allocation of legume N and biomass to the roots, allowing more carryover to the subsequent crop if above ground biomass is removed by fire, grazing or other causes. This characteristic would also confer drought resistance to the legume.

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