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INFLUENCE OF TIME OF APPLICATION ON THE PERFORMANCE OF GLIRICIDIA PRUNINGS AS A SOURCE OF N FOR MAIZE

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SUMMARY

Asynchrony between nitrogen (N) released by organic materials and N demand by the crop leads to low N use efficiency. Optimizing the time of application could increase the N recovery. A field experiment was designed to determine the effects of time of application of *Gliricidia sepium* prunings and of the addition of small doses of inorganic N fertilizer on N recovery and yield of maize. Six split applications of gliricidia prunings (in October, December and February) were compared. The prunings were incorporated into the soil while fresh. The application in October was done four weeks before planting the maize. Higher N uptake and maize yields were obtained when gliricidia prunings were applied in October than when applied in December and February. The corresponding substitution values were 0.66, 0.32 and 0.20. Split applications of prunings prolonged mineral N availability in the soil until March but did not increase N uptake and maize grain yield compared to a sole application in October. Combinations of gliricidia prunings and inorganic fertilizer increased N uptake and maize yield over prunings alone but the effect was only additive. We concluded that application of gliricidia prunings in October was more efficient than application in December and February.

INTRODUCTION

In most agroforestry systems where tree prunings are used as a source of nitrogen (N), recoveries of N vary between 6 and 30 % (Heal *et al*., 1997; Vanlauwe *et al*., 2001). The low N recovery by the associated crops is ascribed to asynchrony between the release of N by the organic materials and the demand of N by the crop, leading to high losses of N. Synchronizing the release of N from the decomposing organic materials with the demand for N by the crop should reduce N losses and may lead to increased N-use efficiency of the applied organic materials (Swift, 1987; Myers *et al*., 1994). One of the 12 hypotheses proposed by the Tropical Soil Biology and Fertility Institute (TSBF) for synchrony of nutrient release and nutrient demand by the crop states that the maximum crop yield achievable by the use of inorganic (mineral fertilizer) inputs can be approached when using organic materials if time of application, placement and quality of the organic materials are optimized (Myers *et al*., 1997). Mulongoy *et al*. (1993) examined the effects of time of application of prunings on N uptake by maize,

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and found that organic materials applied between two weeks before, and two weeks after planting supplied more N than those applied at four and six weeks after planting. Mafongoya *et al*. (1997a) reported that application of prunings at the time of planting increased N uptake and yield. In Malawi, the current recommendation is to apply tree prunings two weeks before planting (ICRAF, unpublished). However, it is difficult to recommend the time of application precisely because the onset of rain is very unpredictable.

Gliricidia prunings have phytotoxic effects on maize seedlings when fresh prunings are applied at the time of planting (Tian and Kang, 1994). The phytotoxins, produced by the prunings as decomposition begins, hinder the development of maize roots and also lead to the development of leaf chlorosis (Makumba, 2003). Since the phytotoxins have a short life and disintegrate easily (Kimber, 1973), the problem of phytotoxicity may be overcome by applying the fresh materials well in advance of maize planting and not at the same time. In simultaneous intercropping of gliricidia with maize, pruning at two weeks after planting is not feasible because land preparation is difficult before the gliricidia trees have been pruned.

As it has been shown that high crop yields are achieved by multiple split applications of inorganic N (e.g. Cassman *et al*., 1995), it could also be suggested that split applications of high quality tree prunings may reduce N losses and increase N use efficiency by the crop. The prolific regrowth that follows regular pruning of gliricidia trees offers an opportunity for repeated applications of the prunings during the maize growing season. Earlier studies on time of application of prunings have provided information on N recovery fractions but information is still lacking on (1) the course of N release by organic materials applied at various times during the crop growing period and its relationship with N uptake, and (2) the corresponding substitution values and the fertilizer N equivalency of the tree prunings.

We hypothesized that split applications of organic materials during the growing season could prolong the availability of nutrients in the soil and may increase the nutrient-use efficiency by the crop. A field experiment was set up with the following objectives (1) to determine the effects of split applications of gliricidia prunings on maize grain yield and N uptake, (2) to assess the substitution values of gliricidia prunings applied at various times during the year, (3) to examine the interaction between inorganic N fertilizer and gliricidia prunings, and (4) to monitor soil mineral N in the topsoil during the course of maize growth.

MATERIALS AND METHODS

Site description

The research was conducted at Makoka Agricultural Research Station, in Zomba, Malawi (lat. 15°30′S, long. 35°15′E; 1029 m asl) in the 2001/02 season. The soil physical and chemical characteristics were as follows: 33 % clay, 57 % sand, bulk density 1.27 g cm^{-3}, pH 5.8, organic C 4.2 g kg^{-1} of soil, P-Olsen 12.5 mg kg^{-1} of soil, exchangeable K 2.6 mmol kg^{-1} of soil, exchangeable Ca 47.7 mmol kg^{-1} of soil, exchangeable Mg 13.7 mmol kg^{-1} of soil. Sulphur (S) deficiency, which could possibly interfere with the uptake of the N, was not a problem at the site because in the past single super phosphate, which contains a substantial amount of S, had been applied. Gliricidia prunings were carried from tree plots and applied in non-tree plots.

Experimental treatments

The treatments comprised six rates of inorganic N fertilizer (0, 24, 48, 72, 96 and 120 kg N ha^{-1}), six combinations of times of application of gliricidia prunings at a total rate of 3 t ha^{-1}, or 87 kg N ha^{-1}, and a control: no gliricidia prunings (NGP). The gliricidia treatments were: (1) all gliricidia prunings applied at once in October (O); (2) half applied in October and the remainder in December (OD); (3) half in October and the remainder in February (OF); (4) half in December and the remainder in February (DF); (5) one third in October, one third in December and one third in February (ODF) and (6) a total of 4 ha^{-1} one quarter in October, half in December, one quarter in February (OD2F).

Calcium ammonium nitrate (CAN) was used as the reference inorganic N fertilizer because of its use by farmers as a source of N in Malawi. The first three N fertilizer rates (0, 24 and 48 kg N ha^{-1}) were combined in a factorial design with the gliricidia prunings (NGP, O, OD, OF, DF, ODF and OD2F). The three high N fertilizer rates (72, 96 and 120 kg N ha^{-1}) represent additional inorganic N fertilizer treatments and were not combined with gliricidia prunings. The use of low rates of inorganic fertilizer is consistent with the findings of Makken (1993) that smallholder farmers in Malawi apply only 20–30 % of the national recommended N fertilizer rate of 96 kg ha^{-1}. The additional fertilizer rates were necessary in order to obtain an adequate number of points for the linear regression analysis. The experiment was arranged in a randomized complete block design replicated three times. The gross plot size was 7.2 × 6.75 m with nine ridges and eight maize planting hills per ridge. Data were collected from the interior net plot measuring 3.60 × 3.75 m with five ridges and four maize planting hills per ridge.

Hybrid maize, NSCM 41, was the test crop. It was planted on 19 November 2001 and harvested in the first week of May 2002. CAN was applied in a single dose on 15 December 2001, and placed in small holes, 30 mm deep and about 60 mm away from the maize plants on the ridge commonly called ‘dollop’. Gliricidia prunings were applied either as a single application or split. The times of application (October, December and February) were chosen taking into consideration (1) the normal time for land preparation for the following crop, and (2) the coincidence of two cutting times and two weeding times (Makumba and Maghembe, 1999). Hence, these times of applications are in line with the normal field activities of smallholder farmers in Malawi. Each time, gliricidia prunings were applied when still fresh. At the first application, on 23 October 2001, gliricidia prunings were laid in the furrows and a new ridge was made burying the biomass. At the subsequent applications (22 December and 22 February), gliricidia prunings were arranged on top of the ridge and were incorporated immediately, during weeding. Dates of application of gliricidia prunings and inorganic N fertilizer, together with daily rainfall are shown in Figure 1.

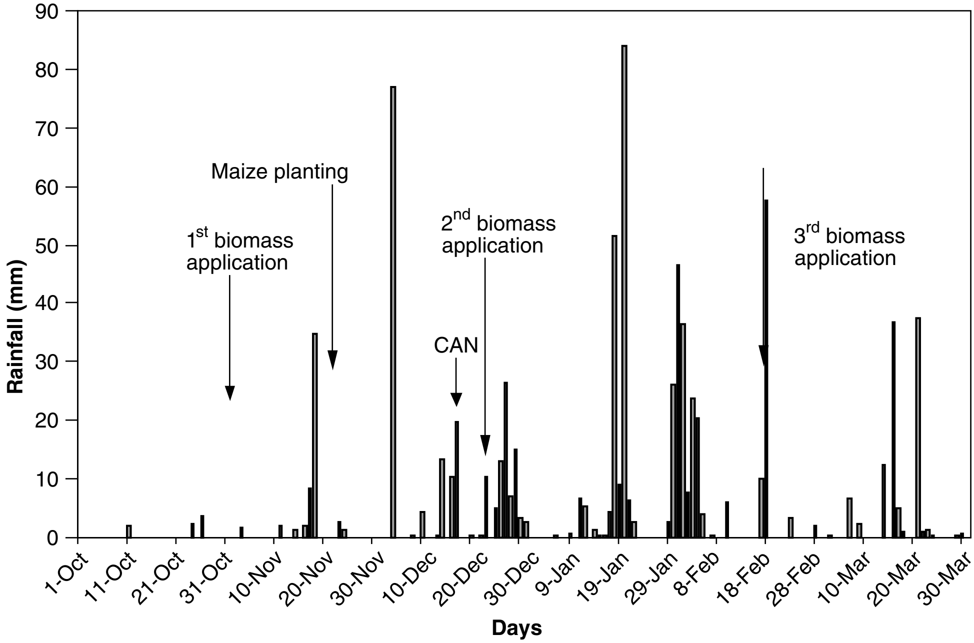

Figure 1. Dates of biomass and CAN application, of planting of maize, and daily rainfall distribution between October and March 2001/02 (total rainfall [Oct–Mar] = 800 mm).

Soil mineral N determination

The N released by gliricidia prunings applied at various times was assessed by regular sampling of the surface soil and analysis for soil mineral N. Soil samples were collected from the surface soil layer, 0–0.20 m deep. Mineral N was extracted from fresh soil with 100 ml of 2 M KCl extractant. Ammonium-N was determined in the extracts by the colorimetric method of Anderson and Ingram (1993). Nitrate-N was determined by cadmium reduction (Dorich and Nelson, 1984) and subsequent colorimetric analysis of nitrite.

Plant N determination

Maize samples (stover and grain) were collected at the time of harvesting. These were oven dried at 75 °C for 48 h and then finely ground. Sub-samples of 0.3 g were weighed into digestion tubes, and 2.5 ml of H_2SO_4-Se solution added. The mixture was left to stand overnight and then heated at 100 °C for 2 h. Afterwards, 3 ml of hydrogen peroxide were added and the samples were further heated at 330 °C until the solution turned colourless. The total N in the solution was determined by the colorimetric method (Terminghoff *et al*., 2000).

Substitution values

The response of maize to gliricidia N was compared with the response to inorganic N fertilizer (CAN) by the method of 'horizontal comparison'. Using the response curve to CAN, the amount of CAN-N required to obtain the same N uptake (N_U) for a gliricidia treatment was determined. The ratio of that value to the corresponding amount of applied gliricidia N is called the substitution value (SV). It is equivalent to the ratio of the recovery fractions of gliricidia N and CAN-N. The recovery fraction is the ratio of N_U to N applied. In the case where the response to CAN is linear, the recovery fraction of CAN-N (RF_i) is equal to the slope of the regression line. With the RFs obtained, the substitution value (SV) was calculated as follows:

$$SV = RF_o/RF_i \quad (1)$$

The subscripts o and i stand for organic and inorganic N. The substitution values were then substituted into the following equation to calculate the N fertilizer equivalent of the gliricidia prunings:

$$EF = SV \times N_{A,o} \quad (2)$$

where EF is the equivalent fertilizer rate, and N_A is the rate of N applied.

The RFs and SVs found for the six combinations of application times were subjected to multiple regression analysis to calculate the EFs and SVs for individual times of application.

Data analysis

The maize grain and N uptake data were subjected to two-way ANOVA (in randomized blocks) using GENSTAT version 5. The soil mineral N data were $\log_{10}$ (n + 1) transformed (Gomez and Gomez, 1984). Simple linear regression analysis was used to compare response parameters.

RESULTS

Mineral nitrogen in topsoil

Figure 2 depicts the variations of mineral N in the topsoil during the maize growing period following time of application of organic materials (the data plotted are the means across all the fertilizer treatments). Combinations of inorganic N fertilizer and organic materials gave higher mineral N in the topsoil than gliricidia prunings alone, but the increase was not large. After application of all the prunings in October (Treatment O), mineral N in the topsoil increased by up to 42 kg N ha^{-1} in December, but sharply declined in January. Split applications, OD, ODF and OD2F, increased mineral N in December, January and February. Late applications (DF) resulted in low N in the topsoil early in the season. Treatment ODF maintained mineral N at levels between 21 and 28 kg N ha^{-1} from December to March.

Maize grain and dry-matter yield

Gliricidia prunings and inorganic fertilizer significantly ($p < 0.01$) increased maize grain and dry-matter yields. The interaction between gliricidia prunings and inorganic fertilizer was not significant for either of the two yield parameters. Maize responded

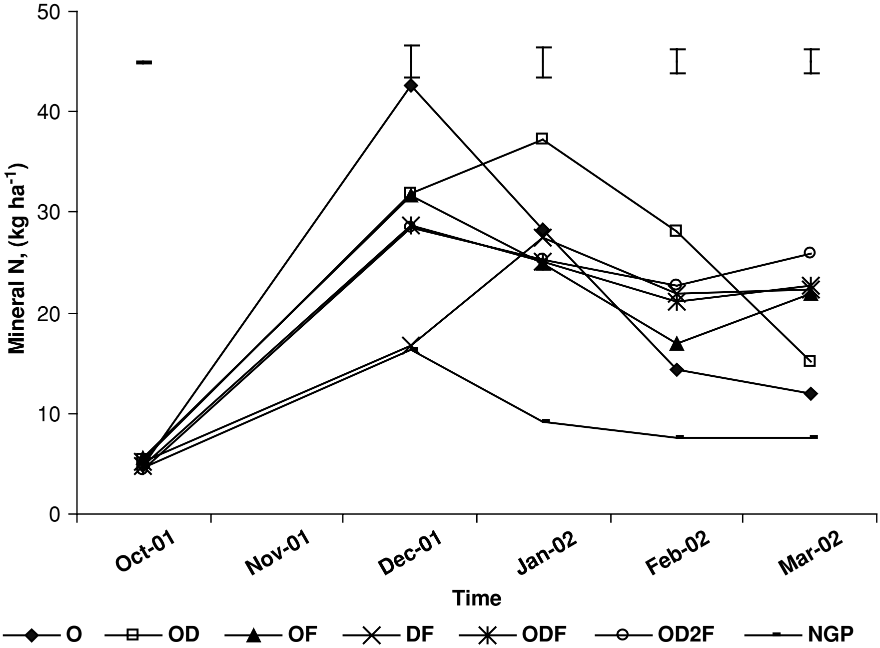

Figure 2. Effect of gliricidia prunings applied at various times on mineral N present in the soil surface layer (0–0.2 m) during the maize growing period. The bars represent *s.e.d.* at 5% for the means of the treatments at each sampling time. See text for definition of treatments.

significantly ($p < 0.01$) to inorganic fertilizer application; the grain yield continued to increase with increasing rates of inorganic fertilizer. Maize grain yield values varied ($p < 0.01$) with the time of application of the gliricidia prunings, ranging between 1.7 and 2.3 t ha^{-1} in treatments that received either all or at least a part of the prunings in October (Table 1). Treatment DF yielded less, 1.3 t ha^{-1}. Combining gliricidia prunings with 24 or 48 kg ha^{-1} N inorganic fertilizer increased mean grain yields by 43 and 75 %, respectively, over gliricidia prunings alone.

The total above ground dry-matter yield was 4.9 t ha^{-1} in treatment O and 2.7 t ha^{-1} in treatment DF. The addition of inorganic fertilizer at the rates of 24 and 48 kg N ha^{-1} increased the mean total dry-matter yields by 36 % and 72 % over the prunings alone.

N uptake by maize

Inorganic fertilizer and time of application of prunings significantly ($p < 0.01$) affected N uptake. No interaction was found between inorganic fertilizer and gliricidia prunings. Table 2 presents total N uptake by the maize crop, this being the sum of the N content in the above ground parts of the maize plant (stover, rachis and grain). The addition of 24 and 48 kg N ha^{-1} as inorganic fertilizer increased average N uptake by 20 and 39 kg ha^{-1}, respectively. N uptake was lowest (32 kg N ha^{-1}) when gliricidia prunings alone were split applied in December and February (DF), and highest (61 kg N ha^{-1}) in treatments O and OD2F.

Table 1. Grain yield and total dry-matter (grain + stover) yield (t ha^{-1}) of maize fertilized with inorganic fertilizer and/or gliricidia prunings (split) applied in October (O), December (D) and February (F).

CAN-N (kg ha^{-1})	0	24	48	Mean
		Maize grain yield (t ha^{-1})		
NGP†	0.62	1.22	2.03	1.29
DF	1.29	1.51	2.30	1.70
OF	1.68	2.53	3.22	2.48
OD	2.01	2.88	3.46	2.78
ODF	2.06	3.00	3.34	2.80
O	2.23	3.06	3.82	3.04
OD2F	2.30	3.29	3.51	3.03
Mean	1.74	2.50	3.10	2.45
s.e.d. TOA‡		0.202		
CAN-N§		0.132		
TOA × CAN-N		0.350		
		Total dry-matter yield (t ha^{-1})		
NGP†	1.55	2.55	4.23	2.77
DF.	2.67	3.33	5.03	3.67
OF	3.41	4.87	6.48	4.92
OD	4.06	5.48	6.95	5.50
ODF	4.18	5.56	6.93	5.56
O	4.93	6.57	7.88	6.46
OD2F	4.65	6.30	7.40	6.12
Mean	3.64	4.95	6.41	5.00
s.e.d. TOA‡		0.221		
CAN-N§		0.145		
TOA × CAN-N		0.383		

† NGP: No gliricidia prunings.
‡ TOA: Time of application.
§ CAN-N: Inorganic N fertilizer (Calcium ammonium nitrate).

Table 2. Nitrogen uptake by maize (grain and stover) fertilized with gliricidia prunings applied at various times during the season and/or with inorganic fertilizer.

	Nitrogen uptake (kg ha^{-1})			
CAN-N (kg N ha^{-1})	0	24	48	Mean
Time of application				
NGP	18.4	35.9	54.5	36.28
DF	32.3	42.7	65.9	46.95
OF	44.2	66.3	84.3	64.93
OD	48.7	67.4	94.2	70.10
ODF	52.1	81.2	94.1	75.82
O	61.3	81.3	101.4	81.32
OD2F	60.6	82.0	98.6	80.40
Mean	48.93	68.69	87.55	68.39
s.e.d. TOA		2.132		
CAN-N		1.396		
TOA × CAN-N		3.694		

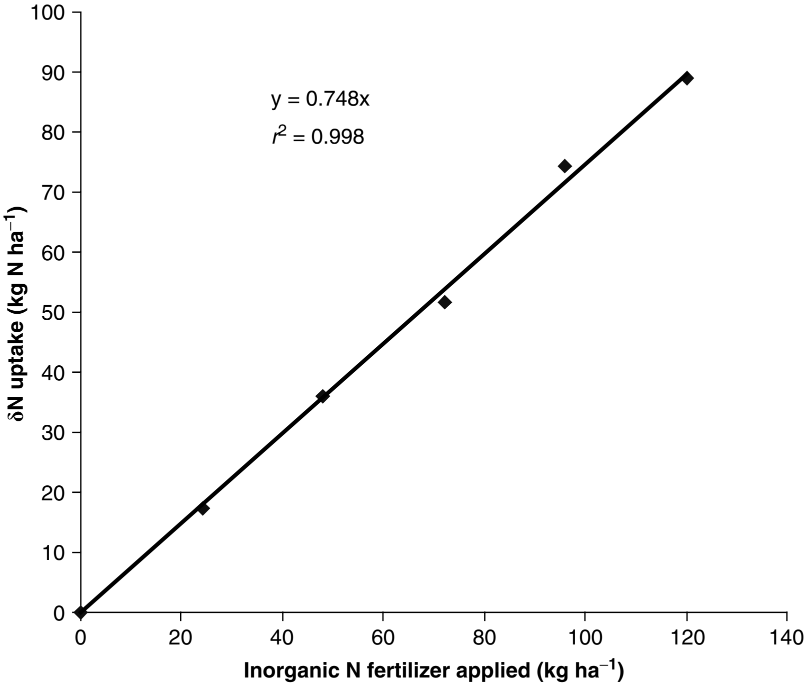

Figure 3. Relationship between delta N uptake by maize and inorganic N fertilizer applied.

Table 3. Recovery fractions (RF), substitution values (SV) and equivalent rates of fertilizer (EF) N for 87 kg N $^{-1}$ in gliricidia prunings, as affected by the time of application.

Time of application	RF	SV	EF
	Calculated with equations 1 and 2		
DF	0.16	0.21	18
OF	0.30	0.40	35
OD	0.35	0.47	41
ODF	0.39	0.52	45
O	0.49	0.65	57
OD2F	0.36	0.48	56
CAN	0.75	–	–
	By multiple linear regression analysis		
October	0.50	0.66	57
December	0.23	0.32	28
February	0.15	0.20	17

N recovery fractions and substitution values

The recovery fraction of the inorganic fertilizer was determined from the slope (0.75, *s.e.* 0.0187) of the linear regression of delta N uptake by maize and the inorganic N applied (Figure 3). Table 3 presents the recovery fractions and substitution values of gliricidia prunings at various times of application. The recovery fraction was three times greater in treatment O than in DF. Recovery fractions for split applications were less than for the single application in October. Substitution values ranged from 0.21 (for DF) to 0.65 (for O), and those calculated for single applications ranged from 0.66 (in O) to 0.20 (in F). The application rates of inorganic fertilizer N equivalent to 3 t of prunings, providing 87 kg organic N ha^{-1}, varied between 57 and 17 kg N ha^{-1}.

DISCUSSION

Soil mineral N

Application of gliricidia prunings in October substantially increased mineral N in the topsoil by December. Split applications of prunings in October and December maintained the levels of mineral N at high levels for two months longer than a single application. Mineral N declined rapidly in treatment O, probably as a result of uptake by the crop and leaching to depths below 0.20 m. Ikerra *et al*. (1999) reported similar trends in a mixed intercropping of gliricidia with maize; they found a peak of mineral N in December followed by a sharp decrease in January. Mugendi *et al*. (1999) and Cobo *et al*. (2002) also found that mineral N declined 2–4 weeks after peak N mineralization.

N uptake by maize

The early release of mineral N from the prunings applied in October might have been in synchrony with the N demand by maize, resulting in high N uptake and grain yield. The low N uptake and low maize yield in the DF treatment suggests that N released late in the season was in asynchrony with the N demand by maize.

Increases in mineral N availability in the soil surface extended over a longer period in treatments OD and ODF than in treatment O (Figure 2). Nevertheless, treatments OD and ODF did not result in higher maize grain yields and N uptake than treatment O. With split applications about half or a third of the organic N was applied at the beginning of the season. This resulted in less N being released early in the season than when all 87 kg N ha^{-1} was applied in October. The treatments with split applications had more N remaining in the topsoil at the end of the growing season than those receiving inorganic fertilizer alone (Figure 2). The maize crop might not have benefited from the mineral N available in the topsoil late in the season.

Maize N uptake is explained better by mineral N levels in the top 0.20 m of soil in December than by soil mineral N in January and later, as revealed by the linear regression coefficients of determination of 0.73, 0.32, 0.29 and 0.15 (Table 4). This finding is in consistent with the high correlations of maize grain yield with pre-season N reported by Ikerra *et al*. (1999). Combining gliricidia prunings with inorganic fertilizer at rates of 24 and 48 kg N ha^{-1} improved the coefficient of determination, especially for the relationship between maize grain yield and soil mineral N sampled in January. As inorganic fertilizer had been applied in December, this improvement is another indication that the presence of N early in the season was beneficial for maize growth.

Table 4. The coefficient of determination of the linear regression relating N uptake by maize and mineral N assessed in the topsoil, 0–0.20 m, at various times during the growing season.

Time of N assessment	Gliricidia alone	Gliricidia +24 kg N ha^{-1}	Gliricidia +48 kg N ha^{-1}	Mean
December	0.73	0.70	0.70	0.71
January	0.32	0.49	0.64	0.48
February	0.29	0.25	0.30	0.28
March	0.15	0.11	0.19	0.15
Mean	0.37	0.38	0.46	

The high recovery fraction for inorganic fertilizer (Table 3) points to conditions conducive to uptake which are ascribed to low and rather uniform distribution of the rainfall throughout the growing season (Figure 1); this minimized leaching of N beyond the root zone of the maize. These conditions also explain why a recovery fraction of 0.49 was obtained in the experiment, when 3 t ha^{-1} gliricidia prunings were applied in October (about four weeks before planting); this value is 1.8 times the recovery fraction of 0.27 reported by Mafongoya *et al*. (1997a) for *Calliandra calothyrsus* prunings applied at planting (46.5 kg N ha^{-1} extra uptake by 5 t ha^{-1} prunings with 3.83 % N). The recovery fraction was highest when all the prunings were applied in October, followed by split applications with at least the first application made in October. Quite often, low N recoveries (less than 0.30) have been reported for gliricidia prunings under field conditions (Giller and Cadisch, 1995). Our study, based on one year's results only, indicates that the application of prunings four weeks before planting can increase N recovery to 0.40–0.50.

Split applications of gliricidia

In general, split applications of organic materials reduced the recovery of N. Mafongoya *et al*. (1997a) also found that split applications of calliandra prunings reduced N recovery fractions from 0.27 when applied at planting to 0.16 when split with 50 % at planting and the remainder at two weeks after planting, and to 0.12 when the second application was made at four weeks after planting. Testing the effects of split applications of cattle slurry and inorganic N fertilizer on maize silage production in the Netherlands, Schröder (1998) found that slurry reduced maize dry-matter yields in experiments that received low rainfall. By contrast, yields were increased in experiments that experienced excess rainfall at the beginning of the season. Split applications of inorganic N fertilizer had small positive effects on the maize dry-matter yield. According to Schröder (1998) excessive rainfall at the beginning of the season favoured a positive response to split applications of inorganic fertilizer.

In a synthesis of trials in the humid tropics of Suriname, Boxman and Janssen (1990) concluded that splitting inorganic fertilizer applications into two or three at planting, and four and seven weeks after planting, resulted in higher maize yields provided the first application was relatively large. Differences in the effects of split application of organic materials and inorganic fertilizer on maize yields could be explained by the fact that inorganic fertilizer N is in plant-available form from the time of application whereas for organic materials there is a time lag while organic N is converted into available N through the process of mineralization. Also in split applications, the portions applied later in the season have too little time for mineralization to meet with crop demand. Mineralization of gliricidia-N was not affected by the time of application as long as there was sufficient soil moisture; however, late application means that a large part of the mineral N is released too late for plant uptake. Evidently, split applications resulted in asynchrony.

Method of application

Generally, maize N uptake is higher when prunings are incorporated than when they are surface applied (Ezenwa and Alasiri, 1991; Mafongoya *et al*., 1997c). This could in part explain the high N recovery fractions obtained in this experiment, and the low N recovery fractions in those experiments where the prunings are surface applied. Surface application of prunings before planting could expose the prunings to further drying and hence loss of quality (Mafongoya *et al*., 1997b). This implies that the method of application used in this study, incorporation on the ridge thus concentrating the nutrients where most of the maize roots grew, probably also contributed to the relatively high N recovery.

CONCLUSIONS

The results clearly show that N uptake and the grain yield of maize are highest when gliricidia prunings are applied in October before planting. Evidently, to obtain high maize yields and N uptake, sufficient amounts of mineral N have to be in the topsoil early in the growing season. The substitution values of gliricidia prunings decreased with time of application in the order October > December > February. Mineral N availability in the topsoil was prolonged, but N uptake by the crop was lower when the prunings were split.

A combination of inorganic N and gliricidia prunings increased N uptake and maize grain yields over the gliricidia prunings alone but the effect of inorganic fertilizer was only additive. The addition of gliricidia prunings was exclusively a fertilizer N effect and no additional effects from the organic materials were found.

Our first hypothesis that split applications of gliricidia prunings can prolong mineral N in the topsoil was confirmed, but our second hypothesis that this would increase nutrient use efficiency was not valid. Based on the results of one field experiment with relatively low rainfall, a single application of prunings some weeks before planting is recommended, with evenly distributed rainfall, but this recommendation might not be applicable under high rainfall conditions.

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