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PROPAGATION AND MANAGEMENT OF *GLIRICIDIA SEPIUM* PLANTED FALLOWS IN SUB-HUMID EASTERN ZAMBIA

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SUMMARY

Gliricidia sepium features prominently as a soil replenishment tree in planted coppicing fallows in eastern Zambia. Its usual method of propagation, through nursery seedlings, is costly and may possibly hinder wider on-farm adoption. We compared fallows propagated by potted and bare root seedlings, direct seeding and stem cuttings, in terms of tree coppice biomass production, soil inorganic N availability and post-fallow maize yields under semi-arid conditions. We hypothesized that cutting fallows initially in May (off-season) would increase subsequent seasonal coppice biomass production as opposed to cutting them in November (at cropping). The tree survival and biomass order after two years was: potted = bare root > direct > cuttings. The post-fallow maize productivity sequence was: fertilized maize = potted = bare root > direct > cuttings = no-tree unfertilized controls, across seasons. However, farmers may prefer directly seeded fallows owing to their cost effectiveness. Soil inorganic N and maize yield were significantly higher in May-cut than in November-cut fallows. Preseason topsoil inorganic N and biomass N input correlated highly with maize yields. This implies that both parameters may be used to predict post-fallow crop yields.

INTRODUCTION

Soil degradation and nutrient depletion have become serious threats to agricultural productivity in southern Africa (Vanlauwe *et al.*, 2002). Decline of soil fertility due to continuous cultivation without using fertilizers is a major cause of low crop yields in sub-Saharan Africa (Sanchez and Logan, 1992). Short duration tree legume fallows (known as planted fallows) have been found to replenish soil fertility and increase subsequent crop yields on N limiting soils (Torquebiau and Kwesiga, 1996). *Sesbania sesban* (sesbania) has been the main focus of planted fallows in southern Africa, but the *Mesoplatys* beetle that defoliates sesbania, threatens to rob it of its known potential in agroforestry systems (Sileshi *et al.*, 2002). Moreover, sesbania does not coppice, and this means that sesbania fallows have to be re-established after two to three post-fallow crops. However, *Gliricidia sepium* has shown similar potential in restoration of soil fertility in eastern Zambia. *G. sepium* is used as a fallow species in maize-based systems, and in biomass transfer technology, where its foliage is used to support dry season vegetable production in ‘dambos’ (low lying wet areas bordering natural water

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systems) (Kuntashula *et al*., 2004). One of the important attributes of *G. sepium* is its capacity to re-grow (coppice) from the stump after being felled. This phenomenon ensures a continuous supply of residues as a nitrogen source for associated crops.

Easy propagation methods and management options for promising soil replenishment tree species are important and urgent needs in agroforestry development. The usual method of *G. sepium* fallow establishment using potted seedlings is expensive as farmers need to purchase polythene pots and to fill them with soil to raise seedlings. Farmers buy 10 000 pots for each hectare of fallow land, the recommended *G. sepium* fallow tree density. Ten thousand pots cost US$ 50, this alone is too costly for Zambian resource-poor farmers. Fresh *G. sepium* stem cuttings, used to stake trailing yams in Nigerian fields, are known to coppice profusely (Adejuwon and Adesina, 1990). Thus, we hypothesized that vegetative propagation could be used to by-pass the expenses incurred by farmers who raise seedlings in soil-filled polythene pots. Further, *G. sepium* can be raised by sowing seed in raised nursery beds without using polythene pots. However, labour is required for watering seedlings because nurseries are established in the dry season before the unimodal (seasonal) rains begin. Fallows are planted in November in the rainy season. *G. sepium* fallows can also be established by sowing seed directly in the fields. The advantage of direct sowing is that it bypasses labour and costs incurred in managing seedlings prior to field planting. It also bypasses water problems during the dry season, as it is rain fed.

Another important issue is the time of cutting *G. sepium* fallow trees in a unimodal rainfall regime, to optimize tree coppice and maize production. Commonly, farmers have cut fallow trees in October at the end of the dry season. They would then cut and incorporate sprouts two to three more times during the cropping season. The N contribution of the October foliage materials is minimal, as most of it is senescent litter and hence poor in quality. In agroforestry, the term 'quality' refers to the biochemical composition (carbon, N, polyphenol, and lignin) of tree residues (Mafongoya and Nair, 1997). We hypothesized that cutting fallow trees or coppices in May (well before the wet season) would lead to higher production and proportion of younger and higher quality biomass. High quality biomass is one with high N (2.5–4 %), low lignin (< 15 %) and polyphenol (< 3 %) (Mafongoya and Nair, 1997). This study was aimed at testing *G. sepium* fallow establishment and management strategies and their effect on: (1) coppice biomass production (2) soil inorganic N dynamics and (3) post-fallow maize yields. The study sought to identify viable options for establishing and managing *G. sepium* (hereafter called gliricidia) fallows on resource-poor, smallholder farms in eastern and southern Africa.

MATERIALS AND METHODS

Site characteristics

The study was conducted at Msekera Research Station, Chipata, in eastern Zambia (13°39′S, 32°34′E; altitude 1020 m asl). The mean annual rainfall is 960 mm (range 887–1020 mm) occurring in a single season extending from November to April. The mean air temperatures vary between 23 and 28 °C in the hottest months (September and October) and between 15 and 18 °C in the coldest months (June and July). The topsoil (0–0.20 m) is sandy loam with 25 % clay, 17 % silt and 58 % sand, and a pH of 5.3 in 1 : 2.5 soil to water suspension. It is classified as a ferric Luvisol (FAO/UNESCO, 1988) with 10 g kg^{-1} organic C and 0.7 g kg^{-1} total N.

Experimental design and planting

The experiment was established in December 1998 on a site with a long history of continuous cultivation without inorganic fertilizer application. The experiment was a randomized complete block design with three replications of each treatment. These were four methods of establishing gliricidia fallows and three no-tree controls as follows: (1) potted seedlings; (2) bare root seedlings (seedlings raised on elevated nursery beds); (3) stem cuttings; (4) directly sown seed; (5) natural fallow (regrowth dominated by *Acanthospermum hispidum, Ageratum conyzoides, Bidens pilosa* and *Rhynchelytrum repens)*. Natural fallow is hereafter abbreviated as NF; (6) continuous maize (*Zea mays*) with recommended fertilizer applications (112 kg N, 18 kg P, and 17 kg K ha^{-1}) to each crop (this treatment is hereafter referred to as M + F); and (7) continuous maize monocropping without any fertilizer application (hereafter abbreviated as M − F). The main plot (10 m × 10 m) of each tree treatment was split into two equal plots (sub-plots) to cater for the two times of coppicing; trees or coppices were cut in either May (May-cut) or November (November-cut) before each cropping season. Each of the two cutting regimes was allotted at random to either sub-plot in each main plot tree treatment. Trees were planted in the field using five-week old seedlings in the case of the potted and bare root treatments. For vegetatively propagated fallows 0.50 m long stems cuttings, 10–20 mm in diameter, were pushed 0.20 m deep in the soil. Direct sowing of gliricidia seed in the field was carried out at the same time (December, 1998) as all the other treatments. Each main plot measured 10 m × 10 m and the tree spacing was 1 m × 1 m giving a population density of 10 000 trees ha^{-1}. Therefore, each sub-plot of tree treatments measured 10 m × 5 m. The entire experiment was tilled manually by hoeing at establishment, after initial soil sampling.

Above ground biomass and crop management

Trees were clear felled at ground level in May and November 2000 after 18 months and two years of growth respectively. Stumps and roots were left undisturbed. Tree aboveground biomass was separated into foliage (leaves + twigs) and wood (> 5 mm diameter) and the fresh weight of each component was taken. Wood biomass was removed for use as fuel wood. Sub-samples of leaves and twigs of each tree species and natural fallow vegetation were collected on a sub-plot or whole plot basis and oven dried at 70°C and wood at 105°C to constant moisture content. These data were used to estimate the dry weights on a plot basis. Fallow litter and foliage were incorporated in their respective plots at land preparation before cropping. Continuous maize, and post-fallow plots were hand sown with hybrid maize coded MM 604 (with 135–140 days to physiological maturity and a grain yield potential of 7–9 t ha^{-1}) at a spacing of 0.25 m within the rows and 1.0 m between the rows (40 000 plants ha^{-1})

on 12 December each year. Fertilizer was applied only to the fertilized control plots at rates of 20 kg N, 18 kg P, and 17 kg K ha^{-1} using Compound-D at sowing and 92 kg N ha^{-1} using urea, four weeks after sowing (WAS). Continuous (controls) and post-fallow maize plots were cultivated by hand-hoes before cropping and weeded thrice during the cropping season. Coppices in post-fallow maize plots, were harvested and incorporated (thrice for May-cut and twice for November-cut fallows) by ridging during weeding. Tree and natural fallow treatments were not weeded in the fallow phase. Maize was harvested at physiological maturity, 140 days after sowing. Maize grain yield was determined on an oven dry weight basis using net plots of 6 m × 6 m area in the control plots and net plots of 6 m × 3 m area in the sub-plots.

Soil N dynamics

Pre-season soil samples (0–0.20 m) were taken in all plots in October 2000 and October 2001. This was before the rainy season, when the continuously cropped controls were bare. Soil samples were taken using a 42-mm diameter metal sampler, in a grid pattern from 20 positions in the centre 49 m^2 of each control plot and from 10 positions in the centre 24.5 m^2 of each sub-plot. The samples were bulked and immediately analysed for ammonium (NH_4^+) and nitrate (NO_3^-) ions (hereafter, collectively termed as inorganic N). Ammonium was determined by the salicylate-hypochlorite colorimetric method (Anderson and Ingram, 1993). Nitrate plus nitrite (NO_2^-) were collectively determined by cadmium reduction (Dorich and Nelson, 1984). No attempt was made to separate NO_3^- and NO_2^-. Nitrite concentration was probably relatively small compared to NO_3^-, and the values are reported as NO_3^-.

Foliage N analysis

The total N content of gliricidia foliage was determined by the methodology described by Anderson and Ingram (1993). Gliricidia foliage N concentration (3.3 %) was similar across treatments and times of cutting or coppicing, and a constant value has therefore been used in all calculations.

Data analyses

All data were subjected to analysis of variance (ANOVA) using the generalized linear model (PLOC GLM) of the SAS system (SAS Institute, 1996). Standard error of the difference (*sed*) was used to separate treatment means in the case of a significant *F*-test at $p \leq 0.05$. The survival data were transformed to arcsine before analysis. Simple linear regressions and correlations were used to determine the relationship between inorganic N, biomass N and maize grain yield. Individual plot data were used for regression and correlations.

RESULTS

Tree survival, biomass and N yield

Gliricidia fallows established by potted and bare root seedlings had the highest survival (90–100 %). Tree survival in directly sown gliricidia fallows was 56 % and

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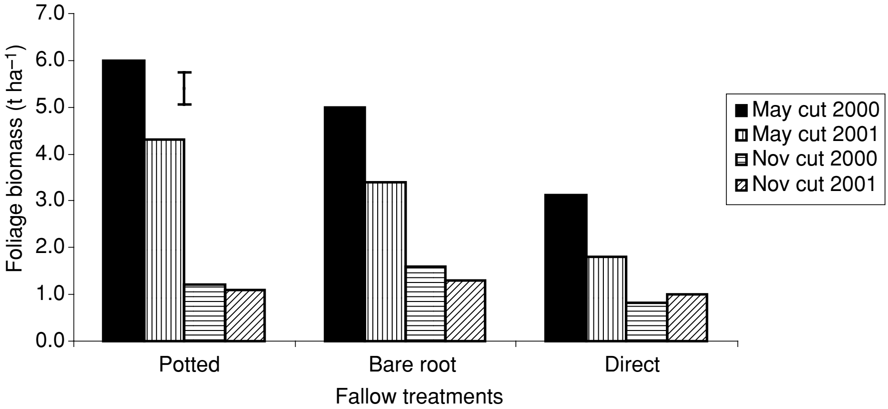

Figure 1. Seasonal total *G. sepium* foliage biomass production as affected by mode of fallow establishment and management in 2001 and 2002 at Msekera, Zambia. Bar represents *sed* = 0.79.

Table 1. Seasonal total foliage biomass N input (kg ha^{-1}) as affected by treatment and management strategy in 2000 and 2001 at Msekera, Zambia.

	Time of initial fallow tree or coppice cutting date			
Treatment	May 2000	November 2000	May 2001	November 2001
Potted	198	41	146	37
Bare root	167	53	116	44
Direct	103	27	61	34
sed		7.8		

30 % in fallows established by stem cuttings after two years of growth in November 2000. The *sed* for tree survival data was 8.3 %. Since fallow establishment and hence, biomass yield from stem cuttings, was poor, the data for the stem cuttings treatment are not presented in either Figure 1 or Table 1.

Overall, the highest ($p < 0.05$) biomass production was obtained from potted and bare root treatments when fallow trees or post-fallow coppices were first cut in May. The May-cutting (coppicing) strategy gave a higher ($p < 0.05$) biomass input than the November-coppicing. For instance, at the end of the fallow period, in May and November 2000 respectively, gliricidia established from potted seedlings had produced 6.0 t ha^{-1} of seasonal cumulative foliage re-sprout biomass from May-cut plots, and only 1.0 t ha^{-1} from November-cut plots. In 2001, the corresponding yields were 4.0 and 1.0 t ha^{-1}. By comparison bare root and direct seeding treatments cut in May 2000 and 2001, yielded 5.0 and 3.5 t ha^{-1}, and 3.0 and 2.0 t ha^{-1} respectively (Figure 1). In contrast, yields from the November-cut were always much less, ranging from 0.5 to 1.5 t ha^{-1} across treatments. These results show that cutting fallow trees or post-fallow coppices initially in May increased ($p < 0.05$) seasonal gliricidia biomass production potential compared to the usual November-cutting strategy.

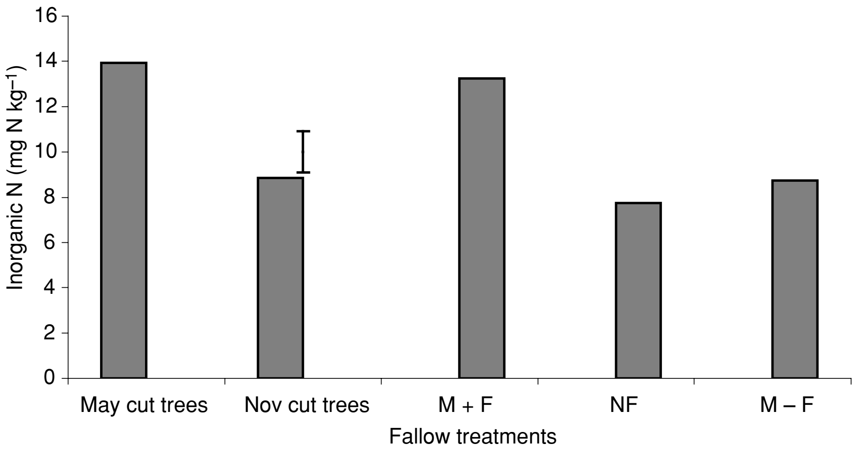

Figure 2. Overall topsoil (0–0.20 m) total inorganic N as affected by time of fallow cutting in October 2000 at Msekera, Zambia. Bar represent *sed* = 1.82; M + F = continuous maize (*Zea mays*) with recommended fertilizer applications (112 kg N, 18 kg P, and 17 kg K ha^{-1}) per crop; M − F = continuous maize monocropping without fertilizer; NF = natural fallow.

The May harvested tree foliage N content was consistently higher (60–200 kg ha^{-1}) than that of the November harvest (30–50 kg ha^{-1}) across all treatments ($p < 0.05$; Table 1). Gliricidia fallows established from potted seedlings yielded more foliage N (150–200 kg ha^{-1}) than either fallows established from bare root seedlings (115–170 kg ha^{-1}) or directly sown seed (60–100 kg ha^{-1}) for May-cut in both seasons. Foliage biomass N, in the November-cut fallows was higher in potted and bare root treatments (40–50 kg ha^{-1}) than in the directly planted treatment (27 kg ha^{-1}) at the end of the fallow in 2000. However, there were no differences between treatments in N yields in 2001 for fallows cut in November ($p > 0.05$; Table 1). In addition, treatments did not vary between seasons when the initial cut was in November.

Topsoil N dynamics

Topsoil (0–0.20 m) inorganic N, measured in October 2000 in planted tree fallow systems initially cut in May 2000, was the highest and statistically similar to the no-tree fertilized maize (M + F) plots. The tree fallows initially cut in November 2000 were similar to the no-tree unfertilized controls, M − F and natural fallow (NF). The results were based on the bulked N data of all tree systems representing each of the two respective times of cutting, compared with the controls from the October 2000 soil sampling (Figure 2).

Maize grain yield

In both seasons, potted and bare root treatments produced similar maize grain yields to the no-tree fertilized control (M + F). Maize grain yields from potted treatments were approximately 4 t ha^{-1} in both seasons, while bare root treatment yielded 4 t ha^{-1} in 2001 and 3.6 t ha^{-1} in 2002. These were both significantly higher than the yields from fallows established by direct sowing (3.1 t ha^{-1} in 2001 and 2.8 t ha^{-1} in 2002).

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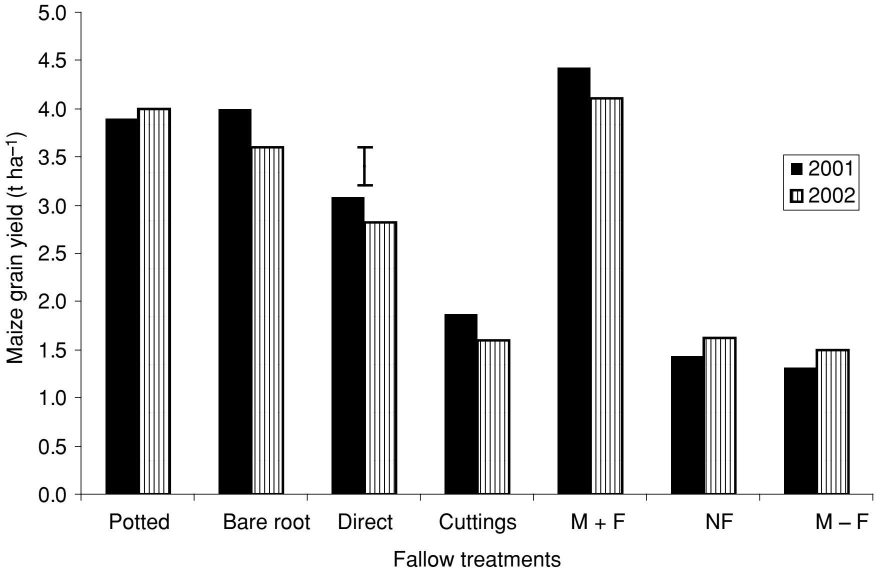

Figure 3. Maize grain yield in 2001 and 2002 as affected by method of fallow establishment at Msekera, Zambia. Bar represent *sed* = 0.40; treatments as in Figure 2.

However, in both seasons, the direct sown gliricidia fallows yielded more maize grain than the two no-tree unfertilized controls (NF and M − F) with ≤ 1.6 t ha^{-1}. Fallows established by stem cuttings (with 1.9 t ha^{-1} in 2001 and 1.6 t ha^{-1} in 2002) had no advantage over the no-tree unfertilized (NF and M − F) controls in either season (Figure 3).

When data from individual tree treatments were bulked and viewed in terms of management strategy (time of initial tree biomass harvest), maize grain yields from fallows cut initially in May and the fertilized maize (M + F) plots were similar. The May-cut regime and the fertilized (M + F) plots produced the highest grain yields, followed by that of the fallows initially cut in November, which produced more grain than the no-tree unfertilized (NF and M − F) controls (Figure 4). The May-cut regime and the fertilized (M + F) plots produced between 4 and 4.5 t ha^{-1}, the November–cut fallows produced at least 2.9 t ha^{-1} in both seasons, which was higher than the 1.3 to 1.6 t ha^{-1} range from the no-tree unfertilized (NF and M − F) controls.

Regression analysis between maize grain yield and pre-season total topsoil inorganic-N indicated that the latter accounted for 57 % ($r = 0.77$) of the variation in maize yield ($p < 0.05$; Figure 5). The relationship between seasonal foliage biomass N input and maize grain yield was similar and consistently highly positive in both seasons. Foliage biomass N input accounted for 62 % ($r = 0.78$) of the grain yield increase in 2000 and similarly, 53 % ($r = 0.72$) in 2001 ($p < 0.001$; Figures 6a and b). Seasonal N input implies the amount of N added to the system through tree foliage application. It was calculated by multiplying foliage N concentration by the biomass added at each time of coppicing in a season.

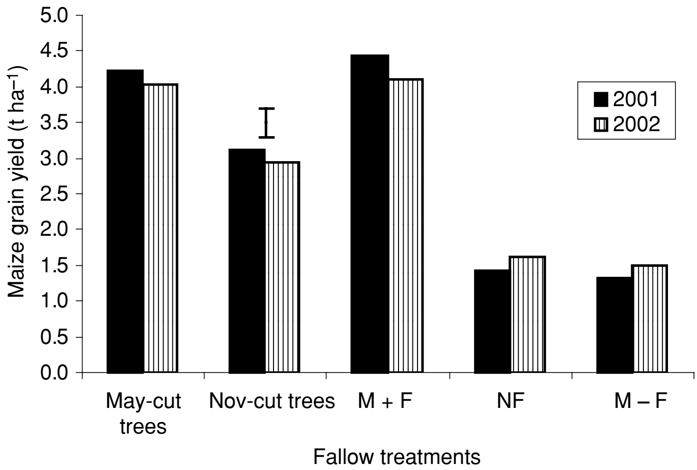

Figure 4. Maize grain yield under planted tree systems as affected by management (time of tree cutting) in 2001 and 2002, Msekera, Zambia. Bar represent *sed* = 0.40; treatments as in Figure 2.

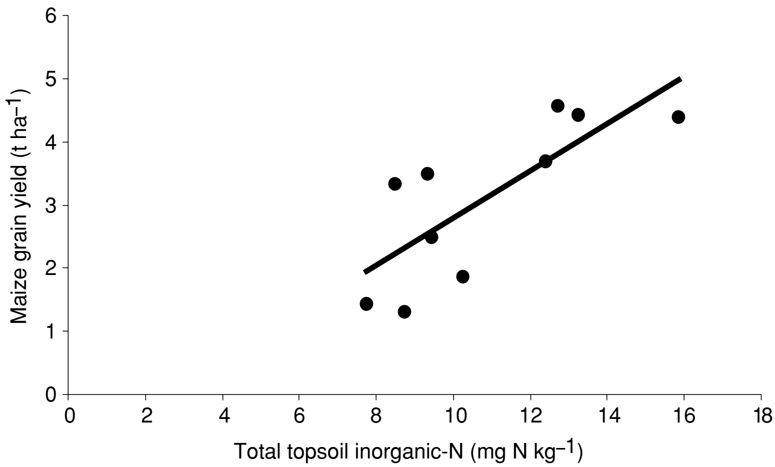

Figure 5. Relationship between pre-season (October 2000) total inorganic-N (0–0.20 m soil profile) and first post-fallow grain yield at Msekera, Zambia. Fitted line: $y = -1.0(1.18) + 0.38(0.106)x$, $r^2 = 0.57$; $n = 10$ ($p \leq 0.05$).

DISCUSSION

Incorporating N rich materials, such as, gliricidia foliage into cropping systems is known to increase topsoil inorganic N and yields of associated crops (Mafongoya and Nair, 1997 and Sing *et al.*, 2001). This was evident in the planted tree systems with high seasonal foliage biomass. Such systems recorded post-fallow maize grain yields that were significantly higher than the no-tree unfertilized controls (NF and M − F). Similarly, Torquebiau and Kwesiga (1996) reported that two years of planted sesbania fallow resulted in an average maize grain yield of 4.5 t ha^{-1}, representing at least 200 % relative increase over the natural fallow which produced less than

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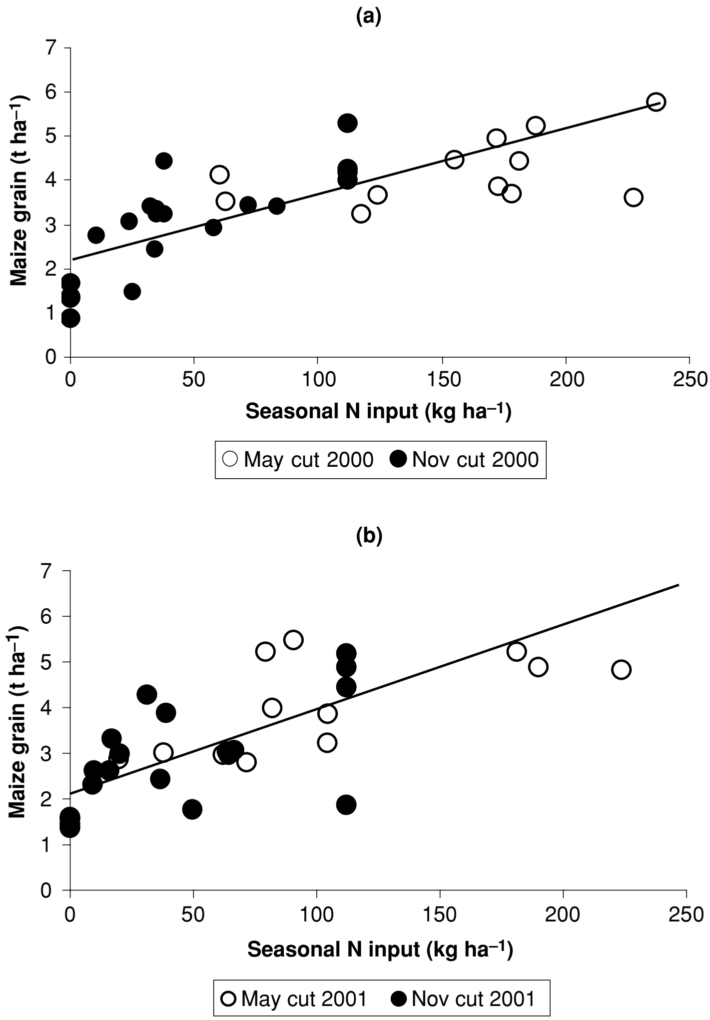

Figure 6. Relationship between seasonal N input and associated maize grain yield in (a) 2000 and (b) 2001 at Msekera, Zambia. Fitted linear equations; 2000: $y = 2.15(0.201) + 0.015(0.0019)x$, $r^2 = 0.62$; $n = 40$ ($p \leq 0.001$) and 2001; $y = 2.12(0.222) + 0.017(0.0025)x$, $r^2 = 0.53$; $n = 40$ ($p \leq 0.001$).

1.5 t ha^{-1}. The increase in grain yield could be due to litter addition, biological N fixation and enhanced mineralization (Agyare *et al*., 2002; Rao *et al*., 1999). Fallows initially cut in May were superior to those cut in November in terms of post-fallow seasonal foliage biomass production (hence biomass N yield), pre-season soil inorganic N levels, and subsequent maize yield. Since both pre-season inorganic and biomass N (input) individually accounted for over 50 % of the maize yield variance, it confirms that significant soil N deficiencies were limiting grain yields. The results imply that soil with more N would lead to higher crop yield response (as N is limiting). Pre-season soil inorganic N has been used in semi-arid agriculture to predict maize yields as it represents readily available initial soil N (Danhke and Johnson, 1990). In this experiment biomass N input was equally and strongly correlated with maize productivity ($r = 0.78$) despite being in the organic (unmineralized) form. Gliricidia foliage is of a very high quality (high N content 3.3 % and presumably low C : N ratio) so that, N was probably readily released (Snapp *et al.*, 1998) producing the high correlation to grain yield. Karim *et al.*, (1993) found a linear correlation (r^2 = 0.61) between total gliricidia biomass N applied and the subsequent soil inorganic N content, and that gliricidia's half-life was 20–30 days. Half-life in this context implies the time it takes for a decomposing plant residue to release half its N content. Similarly, Mafongoya and Nair (1997) reported that 96 % of the applied gliricidia foliage decomposed within the cropping season.

The greater biomass N production in the May-cut regime was due to greater coppice biomass growth and coppicing frequency as compared with the November-cut. Fallows initially cut in November, were coppiced twice during the cropping season as compared with thrice for those initially cut in May. Additionally, the May-cut strategy, seems to encourage vigorous coppicing of younger and richer material before cropping (in November) while most of the material in the November-cut is senescent (dry litter) and of low quality. November-cut fallows were dominated by fallen leaf litter and had scant fresh live (high quality) leaves, while the fallows cut earlier in May, had a heavy canopy of fresh leaves. Fallen litter is of poor quality, because most of its elemental nutrients translocate to younger plant parts before leaf-fall (Mafongoya and Nair, 1997).

In conclusion, larger tree coppice production and input in the May-cut fallows could imply more N cycled to maize representing a larger net N input to the system from biological nitrogen fixation and subsoil N capture processes by trees than from November-cut fallows (Mekonnen *et al.*, 1997).

The overall tree and maize performance as affected by the fallow establishment method was in the order: potted = bare root >direct seeding> cuttings. Survival in fallows established by cuttings was 30 % after two years of growth and < 1 % after one post-fallow crop, hence associated maize grain yields were always statistically the same as the no-tree unfertilized controls. Survival of stem cuttings was low probably because of a two-week dry spell following field planting. However, Kuntashula (personal communication) reported 90 % gliricidia cuttings survival under wet conditions in the dambos of eastern Zambia. Similarly, Budelman (1990) recorded profuse coppicing of gliricidia poles used as supports for yam in the humid conditions of the Ivory Coast. Therefore, we cannot rule out the potential of propagating gliricidia fallows by cuttings, especially in the humid tropics, and in isolated semiarid areas where water is not limiting. The method may not be advisable for drier locations such as Msekera because of poor tree establishment and survival. Moreover, this method may also present labour constraints where harvesting and transportation of fresh cuttings are involved.

Farmers may wish to consider, adopting potted and bare root seedlings for fallow establishment based on maize yields alone. However, inputs (polythene pots for seedlings), labour and management (watering seedlings before the rainy season) costs may hinder wide adoption among resource-poor, smallholder farmers. This leaves us with the direct seeding method as a viable alternative for gliricidia fallow establishment. Despite maize yields being lower than in the potted and bare root treatments, directly seeded fallows, present a promising way of escaping from labour and management costs associated with the other methods. In semiarid areas of Zambia, nurseries can only be established in dambos where irrigation water is present in the dry season. The upland, rainfed fields to where the seedlings are later transplanted are far from dambos. After a cost benefit analysis, Swinkels *et al*., (1997), concluded that the net benefits from tree fallows are highly sensitive to fallow establishment costs, but that costs can be reduced by direct seeding and relay cropping.

CONCLUSION

The test site (Msekera) is deficient in soil N. Pre-season soil inorganic N is used for predicting crop yield in semi-arid, temperate agricultural systems where chemical N fertilizers are used. However, our results indicate that, seasonal foliage N input is also positively correlated to maize grain in gliricidia planted coppicing fallows. Farmers who initially cut fallow trees or post-fallow coppices in May will harvest larger maize grain yields than those that are cut in November. However, this would imply additional labour as coppice cutting frequency is higher in May-cut, than in November-cut fallows. Gliricidia fallows established by potted and bare root seedlings produced higher maize grain yields than the other establishment methods. Directly seeded fallows may be more attractive for adoption by farmers than fallows established by all the other methods because of the lower costs involved. Gliricidia cuttings had poor establishment and survival probably because of poor and erratic rain distribution. Establishing fallows by cuttings may not be advisable in upland fields in semi-arid eastern Zambia. Apart from the agronomic data so far gathered, a financial analysis is needed to determine reliably, which of the gliricidia establishment and management options is economically viable. Such research is under way (on farmers' fields) in our programme.

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