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Nitrogen cycling in gliricidia (*Gliricidia sepium*) alley cropping in humid tropics

C.B. PANDEY* & R.B. RAI

Central Agricultural Research Institute, Post Box 181, Port Blair 744101, Andaman, India

Abstract: An experiment was conducted to evaluate the effect of method and time of application on the decomposition pattern of *Gliricidia* leaf manure and nitrogen release, mineralization and soil N pools, nitrogen uptake and shoot biomass and grain yield of maize in humid climate of South Andaman, India. Treatments included two methods (leaves being incorporated into soil vs. surface) and three times of application i.e. zero week after sowing (0 WAS), two week after sowing (2 WAS) and four week after sowing (4 WAS). Two additional treatments, urea (120 kg ha^{-1}, equal to the leaves) and control (no urea + no leaves) were also maintained to compute recovery of nitrogen from the leaves by the crop; and to know if the leaf manure could produce grain yield equal to that of equivalent urea. There was no effect of the method of application on the decomposition and release of nitrogen from the leaves, soil N mineralization, nitrogen uptake, shoot biomass and yield of the crop, but time of application affected these parameters significantly. Maximum 50% nitrogen was released quickly from the leaves within 15 days and remaining 48-49% gradually in 60 days. Rate of soil N mineralization, nitrogen uptake, shoot biomass and grain yield in maize were highest in 2 WAS and lowest in 4 WAS treatment. Recovery of nitrogen from the leaves was very low ranging from 4.5 to 9.3 kg ha^{-1}. The leaves could not produce yield in maize equal to that of equivalent urea. However, for synchronization of maximum release of N from *Gliricidia* leaves and its uptake by maize crop, the leaf manure should be applied two week after sowing.

Resumen: Se realizó un experimento para evaluar el efecto del método y el momento de aplicación sobre el patrón de descomposición de abono foliar de *Gliricida* y sobre la liberación de nitrógeno, la mineralización y los compartimientos de N en el suelo, la absorción de nitrógeno, la biomasa aérea, y el rendimiento de granos de maíz en condiciones de clima húmedo en Andamán del Sur, India. Los tratamientos incluyeron dos métodos (incorporación de las hojas en el suelo vs. colocación en la superficie) y tres tiempos de aplicación, i.e. cero semanas después de la siembra (0 WAS), dos semanas después de la siembra (2 WAS) y cuatro semanas después de la siembra (4 WAS). También se mantuvieron dos tratamientos adicionales, urea (120 kg ha^{-1}, igual a las hojas) y control (sin urea ni hojas) con el fin de cuantificar la recuperación de nitrógeno del abono foliar por el cultivo, y para averiguar si el abono foliar podría producir un rendimiento de grano igual al de su equivalente en urea. No se encontró ningún efecto del método de aplicación sobre la descomposición y liberación del nitrógeno de las hojas, la mineralización del N del suelo, la absorción de nitrógeno, la biomasa aérea y el rendimiento del cultivo, pero el tiempo de aplicación sí afectó estos parámetros significativamente. Un máximo de 50% de nitrógeno fue liberado rápidamente desde las hojas en los primeros 15 días y el 48-49% remanente se liberó gradualmente en 60 días. La tasa de mineralización del N del suelo, la absorción de nitrógeno, la biomasa aérea y el rendimiento de grano de maíz tuvieron sus máximos en el tratamiento 2 WAS y sus mínimos en el de 4 WAS.

* *Corresponding Author*; e-mail: cbpandey5@rediffmail.com

La recuperación de nitrógeno a partir de las hojas fue muy baja, fluctuando entre 4.5 y 9.3 kg ha^{-1}. Las hojas no pudieron producir un rendimiento de maíz igual al de su equivalente en urea. Sin embargo, para sincronizar la máxima liberación de N a partir de las hojas de *Gliricidia* y su absorción por el cultivo de maíz, el abono foliar tendría que ser aplicado dos semanas después de la siembra.

Resumo: Para avaliar o efeito do método e do tempo de aplicação no padrão de decomposição da folhada de *Gliricidia* bem como a libertação do azoto, mineralização e a armazenamento de N no solo, a absorção de azoto, a biomassa da rebentação e o rendimento de milho, foi conduzida uma investigação, em clima húmido no sul de Andaman, Índia, Os tratamentos incluíram dois métodos (folhas sendo incorporadas no solo a partir da superfície) e três tempos de aplicação i.e. zero semanas depois da sementeira (0 WAS), duas semanas depois da sementeira (2 WAS) e quatro semanas depois da sementeira (4 WAS). Dois tratamentos, ureia (120 kg ha^{-1} igual à das folhas) e controlo (sem ureia e sem folhas) foram também mantidos para calcular a recuperação do azoto das folhas pela cultura; e para saber se a adubação com as folhas podiam produzir um ganho em grãos de milho igual ao do equivalente em ureia. Verificou-se não ter havido efeito do método de aplicação na decomposição e libertação de azoto das folhas, na mineralização no solo e, na absorção do mesmo, na biomassa da rebentação e no rendimento da cultura; o tempo de aplicação, contudo, influenciou significativamente estes parâmetros. O máximo de 50% do azoto foi rapidamente libertado das folhas no período de 15 dias e os restantes 48-49% gradualmente em 60 dias. A taxa de mineralização e de absorção do N, da biomassa dos rebentos e rendimento em grãos de milho foram maiores com o tratamento 2 WAS e menores no tratamento 4 WAS. A recuperação do azoto das folhas foi muito lenta oscilando entre os 4,5 e os 9,3 kg ha^{-1}. As folhas não puderam produzir um rendimento igual ao do equivalente à ureia. Contudo, para sincronização da libertação máxima de N das folhas de *Gliricidia* e da sua absorção pela cultura de milho, o composto proveniente das folhas deve ser aplicado duas semanas depois da semeadura.

Key words: Alley cropping, biomass accumulation, decomposition, *Gliricidia,* grain yield, mineralization, N uptake.

Introduction

Alley cropping system was started in the late twentieth century to improve/ remove crop rotation with an idea to replenish nutrients and cultivate cereals simultaneously on the same piece of land (Kang *et al.* 1981). The alley cropping involves hedgerows intercropping of food crops with fast growing shrub/tree species. The latter are preferably leguminous species because they contribute better to soil nitrogen and associated food crops due to biological N fixation (Amara *et al.* 1996). The hedgerows are periodically pruned to prevent shading and reduce competition with the companion crops (Kang *et al.* 1981). Prunings / leaves from the hedgerows are used for a number of purposes, an important one being as a source of nitrogen to the food crops. Out of the total amount of N present in the leaves / prunings, the fraction that is taken up by the crop is known as the nitrogen recovery value (Mafongoya & Nair 1997). Management of alley cropping system aims mainly to increase the nitrogen recovery rate from the prunings/leaves by the crops.

Though a large quantities of nitrogen can be harvested annually in the form of prunings/leaves in the alley cropping system, the nitrogen recovery rate by the associated crops has been found rather low, in the range of 10-30% (Giller & Cadisch 1995; Palm 1995). One of the reasons for such low values may be lack of synchrony between N demand by the crop and N release from the prunings/leaves (Mafongoya & Nair 1997; Myers *et al.* 1994; Swift 1987). Synchrony between the N release and its uptake by the crop depends upon the decomposition pattern, which in turn is influenced by the quality of the prunings, and time and mode of its application. Present experiment was carried out to study (1) the effect of time and method of application of leaf manure on shoot biomass and grain yield of maize; and to know also if the leaf manure could produce yield equal to that of equivalent urea, (2) the decomposition and nitrogen release pattern from *Gliricidia* leaves under different time and method of application, (3) the mineralization rate and mineral N pools in soil under the different time and method of application, and (4) the uptake of N, and recovery of nitrogen from the *Gliricidia* leaves by the maize crop under different method and time of application in humid climate of South Andaman, India.

Materials and methods

Study site

The study was conducted at a research farm of Central Agricultural Research Institute located at Sippighat, South Andaman (10°30′-13°42′N lat 92°14′-94°14′E long). The site lies 315 m above mean sea level. The study site is characterized with undulating hilly topography. Soil, not fully weathered, is entisol. Parent material is predominantly sandstone (NBBS LUP 1991). Soils are moderately deep owing to erosion, well drained, gravelly – sandy – loamy in texture, acidic in reaction and poor in nutrients (Table 1). The climate is equatorial humid tropical. Temperature varies from 23.1°C to 30.1°C being maximum in May and minimum in December. Average annual rainfall is 3000 mm, distributed over 8-9 months (May to Jan). Two months (March and April) are dry. Humidity ranging from 71% to 85% is maximum in September and minimum in February (Pandey *et al.* 2002).

Experimental designs and treatments

The experiment was carried out in one year old *Gliricidia* based alley cropping system. The system included 5 hedgerows and 4 alleys (space between alleys). The alleys were 4 m in width and 21 m in length. The hedgerows were pruned to 1 m to facilitate light in the alleys. The alleys were divided into twenty four 3x3 m plots. The plots were 50 cm away from the hedgerows, separated by 1 m deep root barrier.

Table 1. Characteristics of soil of the alley cropping system at South Andaman, India.

Parameters	Value ± ISE
Texture (0-30 cm)	
Gravel (%)	23.77 ± 1.77
Fine sand (%)	73.01 ± 1.77
Silt (%)	2.18 ± 0.009
Clay (%)	1.04 ± 0.003
Bulk density (g cm^{-3})	1.12 ± 0.05
pH	5.92 ± 0.17
Total N (%)	0.055 ± 0.003
Total P (%)	0.002 ± 0.0002

The treatment included two methods (incorporated into the 0-15 cm soil vs. surface application) and three times of application (at the time of sowing, called zero week after sowing (0 WAS), two week after sowing (2 WAS) and four week after sowing (4 WAS) of *Gliricidia* leaves as organic manure (4 t ha^{-1}). Concentration of nitrogen in the leaves was 3% and C / N ratio 12.8. To compare the effect of the organic manure on the growth and grain yield of maize a treatment "Urea" (120 kg ha^{-1}) was also included. Urea was applied in two split doses as a common practice of fertilization. However, to measure the recovery of N by the maize crop from the leaves, one more treatment control (no urea + no leaves)was also maintained. The treatments were arranged in a completely randomized block design, replicated 3 times. *Gliricidia* leaves collected from the hedgerows of the alley cropping system during post monsoon were sun dried ($\leq$ 5% moisture) and stored in gunny bags. These sun-dried leaves were used for the experiment. Maize was sown in plots in June 2002 at 50 cm row to row distance and 50 cm within a row. Single super phosphate (100 kg ha^{-1}) and muriate of potash (80 kg ha^{-1}) were applied in all the treatments. Three random maize plants from each plot were harvested to ground level at 15, 30, 45 and 60 days after the sowing to measure the shoot biomass. The sample was brought to laboratory, dried to constant weight at 80°C and weighed. Dried samples were powdered in Wiley mill and sieved with 1 mm sieve for chemical analysis. Grain yield was measured at the crop maturity.

To measure the amount and pattern of nitrogen release 20 g of the sun dried leaves of *Gliricidia* were incorporated into a litterbag. Size of the litterbag was 20 x 20 cm. A set of 45 litterbags was placed into the soil (0-15 cm) and another set of 45 litterbags was placed on the soil surface for decomposition. Five litterbags were retrieved at 8 days interval. Adhered soil on the leaves were removed thoroughly with brush, dried at 80°C to constant weight and weighed. The samples were also powdered like the maize sample. Maize as well as leaf samples were analyzed for total N by the microkjeldahl method using auto N analyzer.

Soil samples (0-15 cm depth) were collected from 4 random places and composited for each treatment. Soil sampling was done on the sampling dates of the maize. After removing the surface organic materials and fine roots carefully, each composited field-moist soil sample was divided into two parts. One part was transported to the laboratory for determination of $NO_3^- - N$ and $NH_4^+ - N$. The other part was incubated *in situ* for estimation of N-mineralization rate. $NO_3^- - N$ was measured by a phenol disulphonic acid method and $NH_4^+ - N$ by a phenate method (Wetzel & Likens 1979).

Mineralization rate was measured by buried bag technique (Eno 1960). Three soil samples (each about 150 g) enclosed in polythene bags were buried at the 0-15 cm soil depth for a period of 15 days. $NO_3^- - N$ and $NH_4^+ - N$ were determined initially (at time zero) and after the recovery of buried bags. The increase in $NH_4^+ - N$ was considered as ammonification and the increase in $NO_3^- - N$ as the nitrification. The increases in the concentrations of $NH_4^+ - N$ + $NO_3^- - N$ during the field incubation were estimated as the net N – mineralization.

Maize N uptake was calculated by multiplying the maize N concentration by corresponding shoot biomass at each sampling date. Nitrogen releases from the leaves were calculated by subtracting residual N in the leaves at each sampling date from total N applied at the beginning of the experiment. Nitrogen recovery rate was calculated following Mafongoya & Nair (1997) as:

$$\text{Nitrogen recovery rate (\%)} = \frac{\text{N uptake of treatment} - \text{N uptake of control}}{\text{N initially applied}} \times 100$$

The data were subjected to analysis of variance using SPSS / PC+(1986) statistical package to test the significance of difference in the studied parameters due to the treatments. Treatments included two methods, three times of *Gliiricidia* leave application, urea, and no urea + no leaves and four dates of observations, replicated three times. LSD (P<0.05) was used to compare the means.

Results and discussion

Decomposition and N release from leaves

Percent weight loss and nitrogen concentration of leaves and their residues for both soil incorporated and surface applied condition are given in Fig. 1a & b. weight loss and N concentration did not differ due to the method of application of the leaves. Around 50% leaves were decomposed quickly in 15 days in both the conditions. Remaining leaves were decomposed at a little faster rate in the incorporated than that in

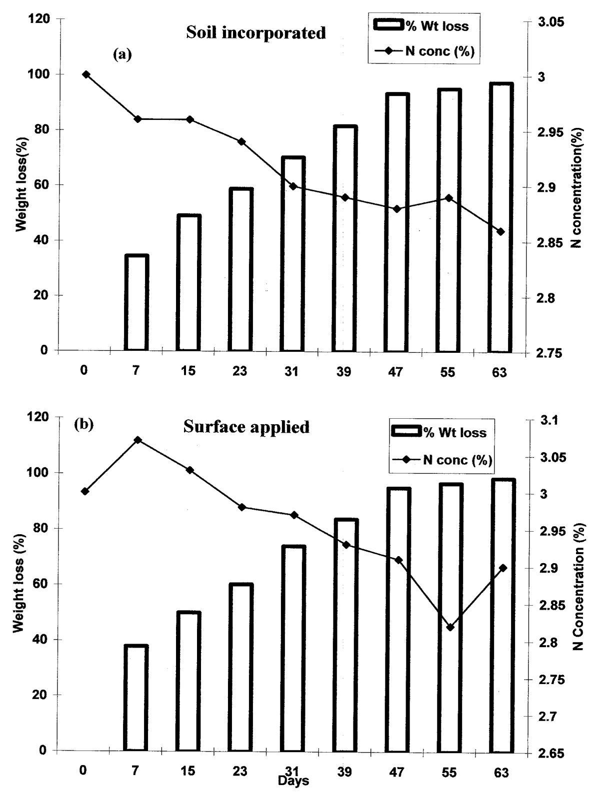

Fig. 1. Per cent weight loss and concentration of nitrogen of *Gliricidia* leaves (a) in the soil incorporated and (b) on surface applied condition in an alley cropping system in humid climate of South Andaman.

surface applied condition. At 30 days, decomposition in incorporated condition was 7% greater than that in surface condition. But, within two months maximum 98-99% leaves were decomposed in both the conditions.

Quick decomposition of the leaves may be attributed to high concentration of nitrogen (high quality) (Pandey *et al.* 2006). However, no difference in decomposition time owing to the method of application could be due to high humidity and rainfall, and optimum temperature. During the maize cropping season, high rainfall as well as humidity seem to have made the leaves wet. Whereas high intensity of rainfall could have mixed the leaves with soils by splashes and thereby ensured contact of the surface applied leaves with soil. Though data is lacking but it is most likely that the surface applied leaves could have provided stable temperature, and soil moisture at the leaves: soil interface and thereby provided suitable breeding ground to microorganism similar to that found inside the soil. In sharp contrast to the humid climate of our study, decomposition and nitrogen release rates differed due to the method of application in semi-arid (Mafongoya & Nair 1997) and temperate climate (Bross *et al.* 1995). Direct release of nitrogen from the leaves without immobilization in our study, seem to have occurred due to high concentration of nitrogen. Mafongoya & Nair (1997) argued that the method of placement might have a less significant effect on decomposition and N release rates when organic matters are of better quality (higher N). Lehmann *et al.* (1995) also observed no net N immobilization during the decomposition of *Gliricidia* leaves in a sub-humid climate of West Africa.

Amount of nitrogen released from the leaves under the different treatments is given in Table 2. Release of nitrogen was maximum (52%) within 15 days in 0 WAS treatment that declined with time and was lowest (7%) at 60 days. However, in 2 WAS treatment the release was slow in the beginning, but it was 2.8 times greater at 60 days compared to that in 0 WAS treatment. In both 0 WAS and 2 WAS treatments, the amount of nitrogen released from the leaves in incorporated condition was similar to that in surface applied condition. In 4 WAS treatment no release of nitrogen occurred in the beginning for the first 15 days as the leaves were applied quite late.

Mineralization and inorganic nitrogen pool in soil

Concentrations of $NO_3^- - N$, $NH_4^+ - N$ and mineral N in the different treatments are given in Fig. 2. The $NO_3^- - N$, $NH_4^+ - N$ and mineral N differed due to the method (P<0.0001) and time of application (P<0.0001) and their interaction (P<0.0001). In 0 WAS treatment $NO_3^- - N$ was high in the beginning until 45 days but declined thereafter and was lowest at 60 days. However, in 2 WAS treatment, NO_3-N pool size was lower at 15 days in the beginning, but it was 11 to 24 % higher across the rest of the sampling dates compared to that in 0 WAS. In 4 WAS treatment, $NO_3^- - N$ pool increased from 30 days and was quite close to that in 2 WAS treatment at the later dates. In the control plots $NO_3^- - N$ was lowest of all the treatments across the sampling dates. The $NH_4^+ - N$ in 0 WAS treatment was high in the beginning until 30 days that declined thereafter and was lowest at 60 days. Pattern of variation in the pool sizes of $NH_4^+ - N$ across the sampling dates in 2 WAS was similar to that in 0 WAS, but it increased unlike 0 WAS up to 45 days and declined thereafter. In 4 WAS treatment $NH_4^+ - N$ increased quite late from 30 days, however, it persisted for a longer period of time compared to that in 0 WAS and 2 WAS treatment. Like the leaf treated plots, in urea treated plot also $NH_4^+ - N$

Table 2. N release from the leaves under two methods of leaves application at different times at South Andaman, India.

Times of leaves application	N release (kg ha^{-1})									
	Surface					Incorporated				
	15 days	30 days	45 days	60 days	Total	15 days	30 days	45 days	60 days	Total
0 WAS	60.44	21.22	27.66	7.97	117.29	60.3	27.73	24.11	6.64	118.78
2 WAS	18.44	46.50	26.72	22.22	113.88	19.0	46.27	27.84	22.62	115.73
4 WAS	NA	36.88	32.55	58.81	91.36	NA	40.12	23.49	34.01	97.62

WAS denotes “week after sowing.”

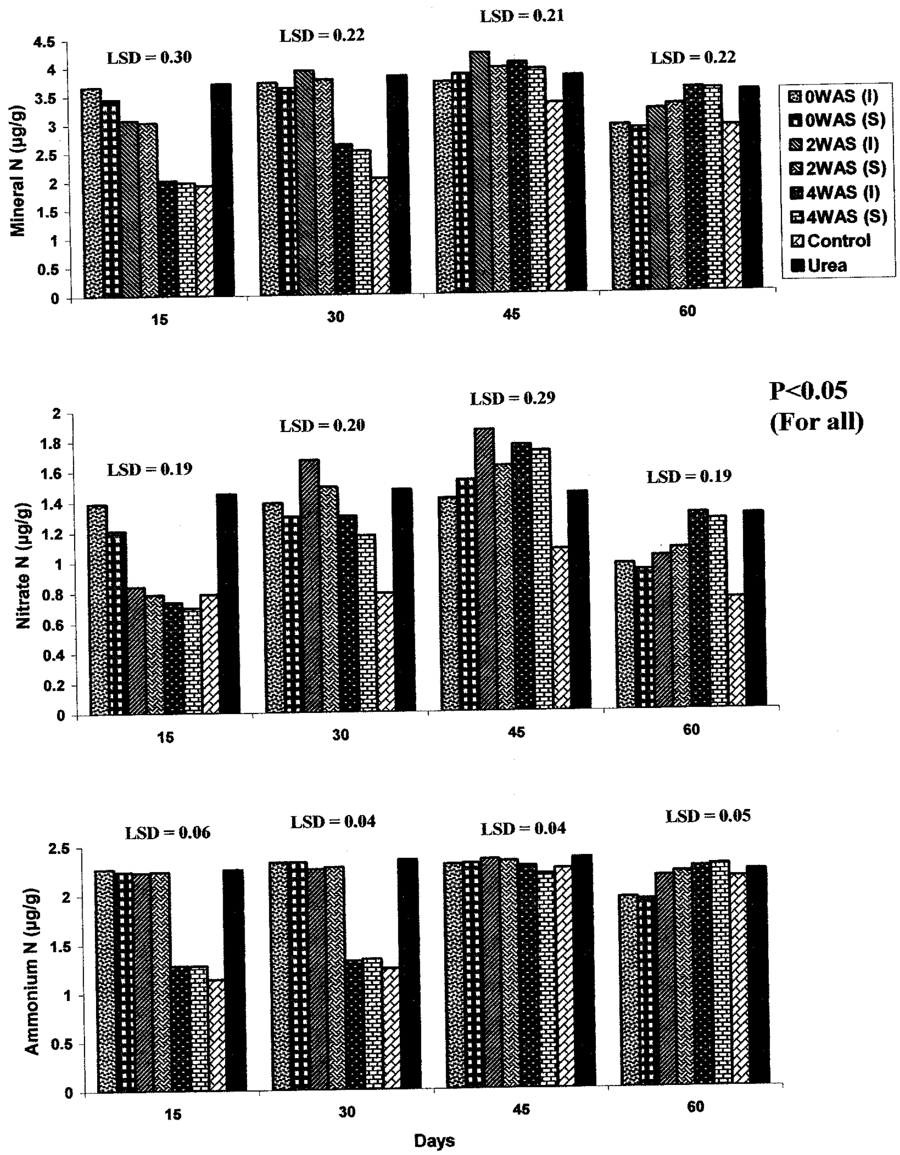

Fig. 2. Ammonium N, nitrate N and mineral N pool sizes in soil under 0 WAS, 2 WAS, 4 WAS, urea and control treatments in soil incorporated (1) and surface applied (S) condition in an alley cropping system in humid climate of South Andaman.

was greater than that of $NO_3^- - N$. Urea is converted first to ammonium N that is oxidized to $NO_3^- - N$ (Campbell 1995). The $NH_4^+ - N$ formation was faster than that of its oxidation due perhaps to continuous excessive rainfall during the experiment. John *et al.* (1992) also reported similar pattern in soil nitrate and mineral N in an organic manuring with cowpea to rice experiment at Laguna, Philippines.

Nitrification rates in soil in the different treatments are given in Fig. 3. Nitrification and ammonification rates in the soils varied due to the time of application (P<0.0001). But, their variations did not differ due to the methods of application. It indicated that the method of application did not affect the mineralization in the soil. Nitrification increased quickly after application of the *Gliricidia* leaves in all the treatments. It was maximum in the beginning in the 0 WAS treatment, but declined after 30 days and was lowest at 60 days after application of the leaves. On the contrary in 2 WAS treatment, nitrification was lowest in the beginning and increased with time and was 24 to 77% higher at 45 days and 60 days respectively compared to that in 0 WAS treatment. In 4 WAS treatment, nitrification was 17 to 35% lower compared to that in 2 WAS treatment. Lowest nitrification rate (0.05 to 0.08 μg g^{-1} day^{-1}) was observed in the control and highest (0.01 to 0.17 μg g^{-1} day^{-1}) in urea treatment (Fig. 3). Like nitrification, ammonification was higher in the beginning and declined with the time in the 0 WAS treatment. However, in 2 WAS treatment ammonification was lower in the beginning at 15 days, but at 30, 45 and 60 days it was 22, 15 and 60% higher than that in 0 WAS treatment. Contrary to that of nitrification, ammonification was lower in urea treatment compared to that in the leaf manuring treatments at almost all the sampling dates. Pattern of soil N mineralization was similar to that of the nitrification and ammonification in the soil. Soil N mineralization was 9 % to 64% higher in 2 WAS compared to that in 0 WAS treatment across the observation dates. In 4 WAS treatment nitrogen mineralization until 15 days in the beginning was at par to that in control, but on the later dates it increased from 21 to 69%. In urea treated plots soil N mineralization was though nearly equal to that in the leaf manuring treatments, but it was relatively more homogeneous.

Quick soil N mineralization in the leaf manuring treatments may be attributed to high concentration of nitrogen in the leaves, low C/N ratio, high soil-moisture, high temperature and high humidity (De Datta 1995). Clement *et al.* (1995) and Haslam (1981) reported that a high tissue N concentration in green manures increased early N mineralization. Wong & Nortcliff (1995) are of the view that net mineralization occurs when nitrogen content of the plant material is more than 1.7%. However, Browaldh (1995) argued that C/N ratios <20-25 are generally required for net mineralization of the organic material. Frankenberger & Abdelmajid (1985) also found C/N ratio or the N concentration important in determining the rate of mineralization. Most of the decomposition models have been described by single exponential decay functions indicating that decomposition proceeds at maximum rates immediately after incorporation (Wieder & Lang 1982). According to Clement *et al.* (1995) plant residue N mineralization rate was related to a number of factors, the most important being the positive effect of N concentration. Lignin + polyphenol / N ratio, tannin / nitrogen, lignin / nitrogen and carbon / nitrogen are organic matter quality factors which affect residue N mineralization. Though in our experiment most of the quality parameters are not estimated, but Clement *et al.* (1995) reported lignin 103 g kg^{-1}, cellulose 133 g kg^{-1}, polyphenol 30 g kg^{-1} and tannin 3.3 g kg^{-1} in *Gliricidia* leaves. They are of the view that early N mineralization occurs due to higher tissue N concentration. However, high

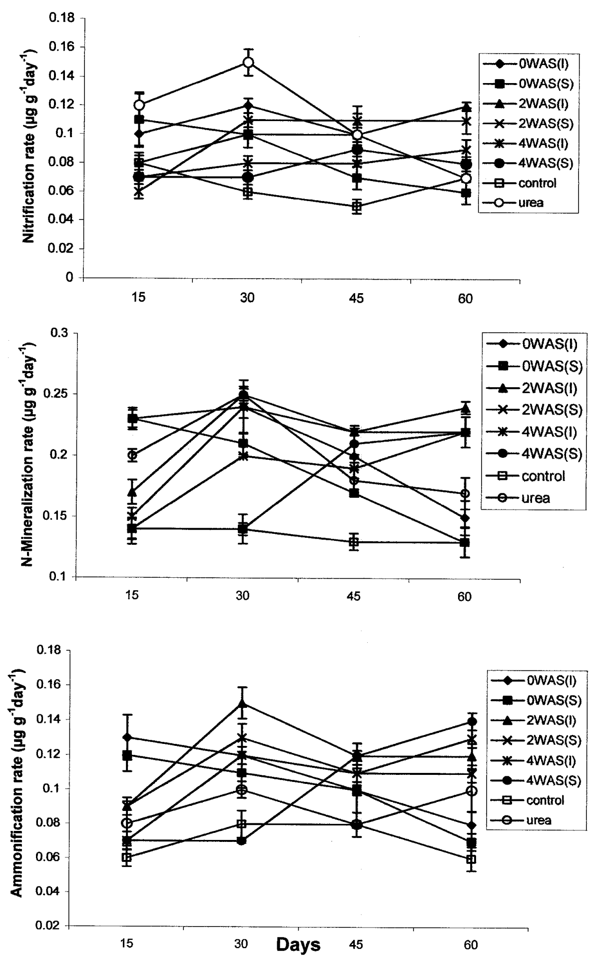

Fig. 3. Ammonification, nitrification and N mineralization rates in soils under 0 WAS, 2 WAS, 4 WAS, urea and control treatments in soil incorporated (1) and surface applied (S) condition in an alley cropping system in humid climate of South Andaman. Bars represent ± ISE.

concentration of lignin (Fox *et al.* 1990) or polyphenols (Palm & Sanchez 1991) have a little inhibitory effect on immediate net mineralization of plant N. Tannin is reported to precipitate proteins (Haslam 1981) including bacterial exoenzymes which help organic matter decomposition.

Decline in N mineralization after 45 days in our leaf manuring experiment could be due to immobilization (Fig. 1 a & b). Karen & Fownes (1992) also observed immobilization between 8 to 12 weeks in a green manuring with seven legume tree leaves. Based on visual observation they reported that late immobilization in organic manuring occurred because of the colonization of organic materials by lignin degrading fungi. High tannin content may cause N immobilization and could limit the N mineralization percentage (Clement *et al.* 1995).

Nitrogen uptake and biomass production

ANOVA results indicated that method of application of the leaves did not affect the shoot biomass as well as yield of maize at all the observation dates (Table 3). But, time of application affected the parameters ($P<0.001$). Peak shoot biomass of the maize at 60 days was maximum in the plot applied with leaves at 2 WAS. Interestingly the peak shoot biomass in the plots applied with the leaves at 2 WAS were equal to that applied with urea. In the beginning for 15 days, shoot biomass in the treatment 0 WAS and urea was nearly equal, but with the passage of time biomass accumulation in the crop in the 0 WAS treatment declined and finely at 60 days it was 15% lower than that of urea. Leaves application at 4 WAS was not much effective to the biomass accumulation as it produced lowest amount of shoot biomass among the treatments. Like the shoot biomass, grain yield of maize was highest in 2 WAS and lowest in 4 WAS treatment.

In 0 WAS treatment nitrogen release from the leaves (>50 %) and nitrification rate in soil were high within 15 days which triggered the growth in the crop, but failed to sustain it at par to urea because the amount as well as the rate declined on the later dates. Maximum N demand and rapid growth phase in maize is reported to occur between 6 to 9 week after sowing (Mafongoya & Nair 1997). When the leaves are applied at 2 WAS, maximum N is released after 15 days that continued up to the grain filling; and high nitrification rate persisted for later dates that translated comparatively greater grain production. It indicates that if *Gliricidia* leaves are applied to maize at 2 WAS, N release synchronizes greater with the nitrogen demand of the crop compared to that applied at 0 WAS. However, when it is applied at 4 WAS the released N did not synchronize with the crop's demand and therefore did not register its impact on its growth and yield.

The leaves applied at both 0 WAS and 2 WAS supported shoot biomass accumulation in maize to nearly equal amount up to 30 days (Table 3). However, the leaves applied at 2 WAS supported comparatively greater accumulation thereafter.

Table 3. Shoot biomass (kg ha^{-1}) of maize in a *Gliricidia* based alley-cropping system under two methods of leaves application (incorporated into soil denoted with I and surface application, denoted with S) at different times at South Andaman, India.

Time of leaves application	Shoot biomass (kg ha^{-1})								Grain yield (t ha^{-1})	
	15 days		30 days		45 days		60 days			
	I	S	I	S	I	S	I	S	I	S
0 WAS	147^{a}	104^{a}	242^{a}	225^{a}	484^{a}	465^{a}	1348^{a}	1295^{a}	5.01^{a}	4.98^{a}
2 WAS	76^{b}	87^{b}	235^{a}	217^{a}	678^{b}	626^{b}	1588^{b}	1579^{b}	5.52^{b}	5.38^{a}
4 WAS	42^{c}	44^{c}	133^{b}	113^{b}	518^{c}	438^{c}	1183^{c}	1088^{c}	2.04^{c}	2.12^{b}
Control	43^{c}	43^{c}	56^{c}	56^{c}	276^{d}	276^{d}	680^{d}	680^{d}	1.94^{d}	1.94^{c}
Urea	150^{a}	150^{a}	271^{d}	271^{d}	669^{b}	669^{b}	1561^{b}	1561^{b}	6.28^{e}	6.28^{d}
LSD (P<0.05)	16.98		33.46		85.42		58.39		0.79	

Values in a column with different superscript are significantly different at $P < 0.05$.
WAS denotes "week after sowing."
LSD ($P < 0.05$) compares means of a parameter in rows

Compared to 0 WAS, shoot biomass in 2 WAS treatment was 36% greater at 45 days and 19% greater at 60 days of the crop. However, biomass accumulation in maize in urea-applied plots was always greater than that of the leaves applied plots. Like the shoot biomass, grain yield in 2 WAS treatment was 8 to 10% greater than that in 0 WAS treatment but 12 to 14% lower from that in urea treated plots.

Equal amount of shoot biomass in 0 WAS and 2 WAS treatments for 30 days could be due to similar amount of nitrogen uptake (Table 4). Up to 30 days there was no difference in the uptake of N in 0 WAS and 2 WAS treatments probably due to similar amount of its release. However, at peak growth stage (60 days) N release in 0 WAS treatment declined substantially which failed to support the crop to carry out the growth. The leaves applied contained nitrogen equal to that of urea and most of the N was released within the cropping season, but N uptake in the leaves applied plots were not equal to that applied with urea most likely because the urea was applied in split doses. It may also be attributed to lack of synchrony between N demand by the crop and N release from the leaves (Myers *et al.* 1994; Swift 1987). The differences in N uptake explain why grain yield in 2 WAS treatment was lower than that in urea treated plots though the peak shoot biomass was equal. Kang *et al.* (1981) reported that efficiency of maize crop in the utilization of nitrogen yield of *Leucaena* prunings was low compared to nitrogen fertilizer in humid climate at Ibadan, South Nigeria. They further observed that the prunings were, however, when removed from the plots, a significant yield reduction in maize

Table 4. Nitrogen uptake (kg ha^{-1}) by maize crop in a *Gliricidia* based alley-cropping system under two methods of leaves application (incorporated into soil; denoted with I and surface application; denoted with S) at different times at South Andaman, India.

Time of leaves application	N uptake (kg ha^{-1})							
	15 days		30 days		45 days		60 days	
	I	S	I	S	I	S	I	S
0 WAS	1.56^a	1.06^a	2.57^a	2.30^a	5.13^a	4.74^a	14.29^a	13.21^a
2 WAS	0.80^b	0.88^a	2.46^a	2.19^a	7.11^b	6.33^a	16.75^b	15.95^b
4 WAS	0.42^c	0.44^b	1.34^b	1.13^b	5.23^c	4.42^c	11.95^c	10.91^c
Control	0.34^c	0.34^b	0.45^c	0.45^c	2,21^d	2.21^d	5.44^d	5.44^d
Urea	1.84^d	1.84^c	3.33^d	3.33^d	7.00^b	7.00^e	19.20^e	19.20^e
LSD (P<0.05)	0.22		0.34		0.89		1.14	

Values in a column with different superscript are significantly different at P < 0.05.
WAS denotes "week after sowing."
LSD (P < 0.05) compares means of a parameter in rows

Table 5. Nitrogen recovery (kg ha^{-1}) by maize in a *Gliricidia* based alley-cropping system under two methods of leaves application (incorporation into soil; denoted with I and surface application; denoted with S) at different times at South Andaman, India.

Time of leaves application	N recovery (kg ha^{-1})							
	15 days		30 days		45 days		60 days	
	I	S	I	S	I	S	I	S
0 WAS	1.00^a	0.59^a	1.75^a	1.53^a	2.41^a	2.09^a	7.29^a	6.39^a
2 WAS	0.38^b	0.44^a	1.66^a	1.44^a	4.04^b	3.40^b	9.31^b	8.66^b
4 WAS	0.06^c	0.08^b	0.74^b	0.57^b	2.49^c	1.82^c	5.36^c	4.50^c
Urea	1.23^d	1.23^c	2.37^c	2.37^c	3.95^b	3.95^b	11.33^d	11.33^d
LSD (P<0.05)	0.20		0.40		0.90		0.13	

Values in a column with different superscript are significantly different at P < 0.05.
WAS denotes "week after sowing."
LSD (P < 0.05) compares means of a parameter in rows

crop occurred. In our study concentration of nitrogen in maize plant in the urea treated plot was 16-23% greater than that in the leaf manuring treatments.

N recovery by the maize crop differed due to the time of application of the leaves for all the observation dates (P<0.001). The nitrogen recovery was highest in the plot applied at 2 WAS (Table 5). N recovery from the leaves was nearly equal to that in the plots applied at 0 WAS and 2 WAS until 30 days, but increased later on and at 45 days the recovery was 63 to 68% higher in the 2 WAS treatment compared to that in 0 WAS. The recovery of nitrogen in 2 WAS treatment reached almost equal to that in urea treated plot. However, finally maximum recovery occurred in the urea followed by 2 WAS treatment. Nitrogen recovery in 4 WAS treatment was lowest among all the treatments.

Low nitrogen recovery (4 to 8%) from the applied leaves by the maize crop in our study could be due to its high immobilization in microbial biomass and, high run-off and leaching losses. Palm (1995), Giller & Cadisch (1995) reported that maximum 20% of the N released from tree prunings or litter is taken up by the current crops. Much of the remaining part (40% to 80%) of the applied organic N is incorporated into soil organic matter (Haggar *et al.* 1993). Gravelly- sandy-loamy soils of our study site seem to have caused heavy leaching loss. Runoff loss from the site is found 12 to 22 t ha^{-1} under different landuses (Pandey & Venkatesh 2003), which is expected to export a reasonably good amount of nitrogen from the soil.

Conclusions

Our study concludes that *Gliricidia* leaves decompose quickly and release maximum nitrogen within 15 days and the remaining part in two months in both surface applied as well as soil incorporated conditions. It increases mineralization and mineral N pools in soil, but the rate of mineralization as well as the amount of nitrogen pools are maximum in 2 WAS and lowest in 4 WAS treatment. It seems the rate of mineralization and nitrogen uptake synchronize best in 2 WAS treatment that facilitate higher grain yield compared to that in 0 WAS and 4 WAS treatments. Recovery of nitrogen from the *Gliricidia* leaves by the maize crop was in general low, but highest recovery occurred in 2 WAS treatment. These suggest that *Gliricidia* leaves should be applied as organic manure after 2 WAS with either of the two methods for maximum shoot biomass and grain production.

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