Netherlands Journal of Agricultural Science 48 (2000) 75-90

Soil organic matter and nitrogen transformation mediated by plant residues of different qualities in sandy acid upland and paddy soils

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Received 12 November 1999; accepted 18 February 2000

Abstract

Organic matter management is believed to solve many of the chemical and physical problems of coarse-textured, low fertility soils of Northeast Thailand. We tested the influence of different plant residues available in this area on soil C and N dynamics in upland (Oxic Paleustult) and lowland (Aeric Paleaquult) soils. Residues included groundnut (upland) or *Sesbania rostrata* stover (lowland), rice straw, *Tamarindus indica* and *Dipterocarpus tuberculatus* leaves applied at 10 t ha^{-1} (dry matter). For the former three residues additional application rates of 20 t ha^{-1} were included as well as a mixture (50:50) of groundnut/*Sesbania* – rice straw treatment. Groundnut stover and *Sesbania* had C/N ratios <28:1 and low lignin, and polyphenol contents whereas rice straw had the highest C/N ratio of 79:1. Dipterocarp and tamarind leaves were characterized by high lignin (>17%) and polyphenol (>4.5%) contents. These latter residues, despite slow decomposition, apparently resulted in only moderate soil C (<1 mm) build-up after one year due to the fact that a large proportion of their residues remained in particulate form (>1 mm). Thus the mixture of groundnut/*Sesbania* with straw was among those residue treatments that led to the highest soil C (<1 mm) build-up under both upland and lowland conditions.

Groundnut stover under upland condition resulted in immediate net N mineralisation but also an early decline in soil mineral N presumably due to leaching. By mixing groundnut or *Sesbania* with rice straw with a high C/N ratio residue N mineralisation could be delayed and prolonged, improving potentially the synchrony of N release and plant demand. Additions of dipterocarp and tamarind resulted in an initial N immobilization phase and net mineral N release remained low thereafter. Dynamics of microbial biomass N were closely related to N mineralisation and immobilization cycles in both upland and lowland experiments. Residue N concentration was the most significant factor controlling N release in both systems. While extractable polyphenols exhibited a significant influence on N release in upland conditions their effect was not evident in the lowland.

Keywords: soil C, mineral N, microbial biomass N, polyphenols, upland, lowland, paddy, groundnut, rice straw, *Arachis hypogeae, Sesbania rostrata, Oryza sativa, Dipterocarpus tuberculatus, Tamarindus indica*

Introduction

Upland and paddy soils of Northeast Thailand have high sand contents. They are highly weathered and continuous cropping has led to their low nutrient and low soil organic matter content (<1%). Organic matter management is believed to solve many chemical and physical problems of these soils including their low water holding and low buffering capacity as well as their low nutrient reserves. Although it is widely recognised that in sandy soils organic matter build up does not take place easily, some recent research in Northeast Thailand has shown that it is possible to improve soil organic matter content in land use systems that enable a continuous supply of organic inputs with minimum disturbance (Wu *et al.*, 1998). This has been shown for pastures in rotation with field crops (ley cropping system) where a few years under pastures led to build up of soil organic matter. Currently, the major land uses for agriculture in Northeast Thailand are paddy rice and upland field crops. These two systems have inherently different conditions for nutrient and soil organic matter dynamics. While paddy soils are periodically flooded and thus temporarily under anaerobic conditions, field crops, mainly cassava, sugar cane, and groundnuts, grown in upland soils are virtually continuously aerobic. These contrasting systems not only provide different conditions for organic matter decomposition but also for the type and amount of organic residues available.

Various types of organic residues can be obtained locally in Northeast Thailand. For lowland (paddy) systems they include rice straw, some green manures and tree leaf litters. For upland systems, potential organic inputs include residues from field crops, some green manures, pastures and tree leaf litters. Rice straw, which is in some cases burned, is available for both upland and lowland systems. The presence of scattered trees in both upland and paddy fields is not an uncommon characteristic of farming systems in Northeast Thailand. Trees play an important part in farmers livelihoods and farmers value tree litter as an important source of nutrients for crops. Farmers also have recognised the relative value of leaf litter from different tree species (Vityakon, 1993). The trees have a high potential for land-use development into 'agroforestry' systems providing both ecological services and a resource base for the Northeast rural people (Grandstaff *et al.*, 1986; Vityakon, 1993).

It has long been recognised that organic residue decomposition and hence soil organic matter dynamics are a direct result of the physico-chemical environment (e.g. anaerobic vs. aerobic; soil structure) and the quality of the resource acting through their regulation of the decomposer community (Heal *et al.*, 1997). Non leguminous crop straws are of high C/N ratio compared to green manures (cover crops) or leguminous grain crop residues. Tree leaf residues widen the quality spectrum further by often having high lignin and polyphenol contents (Handayanto *et al.*, 1995). Studies on quality of leaf litter of tree species commonly found in the Northeast have shown that the C/N ratio is not an effective indicator of the litter decomposition and nutrient supply. Two of the six species studied had a relatively high C/N ratio, (*Tamarindus indica* 52, and *Irvingia malayana* 67) while two others had lower C/N ratios (raintree – *Samanea saman* 26 and *Xylia xylocarpa* 38), however the former group exhibited higher decomposition rates than the latter (Adulprasertsuk *et al.*, 1997). It has been suggested that decomposition rate, apart from N, is controlled by the composition of relatively resistant carbonaceous compounds, i.e. lignin and polyphenols. Polyphenols have been found to retard decomposition (Palm & Sanchez, 1991) and N mineralisation in tree legume leaf litter (Oglesby & Fownes, 1992) and prunings (Palm & Sanchez, 1991), and forage legume litter (Vallis & Jones, 1973). Handayanto *et al.* (1995) found that soluble polyphenols interfere directly with mineral N released from legume tree prunings under non-leaching conditions. However, under leaching conditions, the (lignin + polyphenols)/N ratio had the highest influence on N release. The transition from N immobilization to mineral N release is regulated through the soil microbial biomass by the ratio of available C to N substrates and environmental constraints (drought, flood) that affect the survival and effectiveness of the microbes. Although the microbial biomass constitutes only a small part of soil organic matter it has a relatively rapid turnover and hence has a considerable effect on N availability (Jenkinson & Ladd, 1981).

The objectives of this study were: 1) to test the effectiveness of different plant residues available in Northeast Thailand in contributing to the build-up of soil organic matter, 2) to investigate the effect of these residues on the dynamics of nitrogen transformations, and 3) to investigate their effect on size of microbial biomass (fast pool of soil organic matter turnover) in relation to N release in aerobic upland and periodically anaerobic lowland soils.

Materials and methods

Two field experiments were set up, in upland and lowland conditions in late March and late August 1995, respectively, at two sites in Khon Kaen, Northeast Thailand. The upland soil was very sandy while the lowland soil had more clay but both having low organic matter contents (Table 1). Both soil series together represent approximately 21 % of the soils in Northeast Thailand. Weather condition during the year of the experiments (i.e. upland experiment 23 March 1995 – 22 March 1996; lowland experiment 30 August 1995 – 30 August 1996) are shown in Figure 1.

Residue treatments

Both experiments had eight parallel organic residue treatments with single or mixed residue additions and in some cases two rates of applications (Table 2). Rice (*Oryza sativa*) straw, *Dipterocarpus tuberculatus* and *Tamarindus indica* residues were used in both upland and lowland experiments as they are potential resources for both systems. Organic residues were chopped to the size of approximately 5–10 cm length. Groundnut (*Arachis hypogeae*) stover consisted of whole shoots without the har-

Table 1. Soil classification and initial physical and chemical properties of topsoils (0–15 cm).

Classification/properties	Upland soil	Lowland soil
Soil taxonomy	Fine loamy siliceous isohyperthermic Oxic Paleustult	Clayey, mixed isohyperthermic Aeric Paleaquult
% Sand	93.4	78.5
% Silt	4.5	12.5
% Clay	2.1	9.0
Bulk density (g cm^{-3})	1.445	1.749
pH	5.50	5.18
Total N (%)	0.020	0.036
Bray II P (ppm)	47.2	16.8
Exchangeable K (cmol kg^{-1})	0.077	0.106
CEC (cmol kg^{-1})	3.53	5.14
Organic matter (%)	0.36	0.46

vestable component. *Sesbania* (*Sesbania rostrata*) residues included whole tops (stem + leaves) of two-month old plants with a stem diameter of approximately 1 cm. Tree residues included leaf litter (recently fallen leaves and petioles of *Dipterocarpus* and recently fallen leaves + small branches (ratio 7:1) in the case of *Tamarindus*.

Experimental design and statistical analysis

Plot size of both experiments was 4x4 m with 1 m path between plots. Plots were arranged in a randomized complete block design with 3 replications. Organic

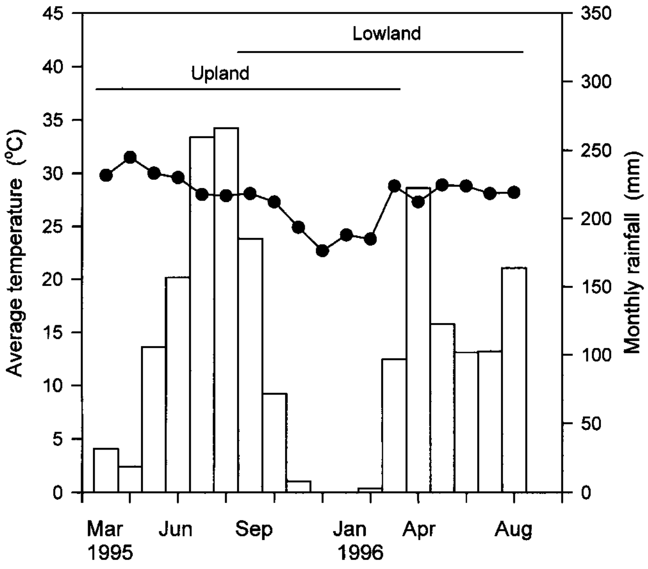

Figure 1. Climatic conditions (monthly rainfall (bars) and average temperature (•)) during the first year period of upland and lowland experiments (1995–1996).

Table 2. Yearly additions of residues in the two experiments.

Treatment	Upland experiment	Rate (t DM $ha^{-1}yr^{-1}$)	Lowland experiment
1	No addition	0	No addition
2	Rice straw (low)	10	Rice straw (low)
3	Rice straw (high)	20	Rice straw (high)
4	Groundnut stover (low)	10	*Sesbania rostrata* (low)
5	Groundnut stover (high)	20	*Sesbania rostrata* (high)
6	Rice straw +Groundnut stover	10+10	Rice straw + Sesbania
7	*Dipterocarpus tuberculatus*	10	*Dipterocarpus tuberculatus*
8	*Tamarindus indica*	10	*Tamarindus indica*

residues were evenly distributed on soil surface and, then ploughed into the soil to 15 cm depth in March 1995 (upland) and August 1995 (lowland). Plots were kept weed free by periodic manual weeding. One-factor ANOVA was used to analyse the main effect of the treatments and standard error of the means (SE) and standard error of the difference (SED) were used for treatment comparisons.

Residue analysis

Total residue C and N were determined by dry combustion using a Roboprep automatic C/N analyzer (Europa Scientific). The acid-detergent fibre (ADF) and the acid detergent lignin (ADL) contents of plant materials were determined by the method of Goering and van Soest (1970). Polyphenols were extracted in hot (80 °C) 50% aqueous methanol (2 mg ml^{-1}) and determined colorimetrically using the Folin-Denis reagent with tannic acid as a standard (Anderson & Ingram, 1989).

Soil sampling and analysis

Soils were sampled before organic residue incorporation and at 2, 4, 8, 16, 26, and 52 weeks after incorporation. Soils in the upland experiment were sampled in a 2x2 m area in the center of the plot using a grid system which provided randomized sampling positions to avoid repeated samplings at the same position. In the lowland experiment a strip of 4×0.6 m was used as sampling area at each sampling time. Each successive sampling utilized an adjacent 4×0.6 m strip in order to avoid compacting wet soil in an area yet to be sampled. Soil was sampled from the 0–15 cm layer using sampling tubes (2.5 cm diameter) and augers and air dried. Ten auger samplings per plot were collected for the upland experiment and 4 for the lowland one. Total C determinations (Walkley & Black wet digestion) were done on air-dried soils after screening through a 1 mm mesh sieve. Measurements of soil bulk density were performed in alternate plots before incorporation of organic residues at the start of the experiments employing the undisturbed core sampling method (core size 4.5 cm diam. and 5 cm height). Sampling depths were 0–5, 5–10, and 10–15 cm. The particle size analysis was performed using the hydrometer method.

Microbial biomass N and mineral N

Microbial biomass N and mineral N were measured on fresh soil samples immediately after sampling. Microbial biomass N was determined by the chloroform fumigation-extraction technique (Amato & Ladd, 1988). Chloroform was washed and distilled before use to remove ethanol. After 36 hour fumigation the soil samples (10 g) were extracted with 50 ml of 1 M KCl. An unfumigated sample was extracted immediately after sampling. Microbial biomass N was determined by the ninhydrin-reactive N method and calculated as the difference between the fumigated minus the unfumigated sample (a k_N factor of 3.1 was applied in the calculation according to Amato & Ladd (1988)). Mineral N (NH_4^+ and NO_3^-) was measured in the extract of the unfumigated sample and determined colorimetrically using a flow injection analyser.

Results and discussion

Plant residue quality

Legume residues had appreciably higher N concentrations than rice and dipterocarp and hence lower C/N ratios (Table 3). Rice straw was particularly low in lignin thus its lignin/N ratio was similar to *Sesbania* despite its low N content. Tamarind and dipterocarp had high lignin and polyphenol contents. N and lignin concentrations of rice straw were about half those measured by Palm & Sanchez (1991, 1.13 and 6.2 % respectively) while polyphenols were higher (0.69 %). Slightly higher values of N (2.5 %) and polyphenols (3.7 %) but lower lignin (5.3 %) contents were recorded for leaf fractions of groundnut by Constantinides & Fownes (1994) however, the results presented herein included whole tops. N concentration of *Sesbania* shoots compared well with results of 1.7–2 % of McDonagh *et al.* (1993; 1996). However, the lignin content of whole plant tops was appreciably higher (27–30%). This is likely due to the older materials (3 months) used in their studies. Kachaka *et al.* (1993) found that lignin contents increased with pruning age in hedgerow trees. N concentration and C/N ratio of dipterocarp were similar to the results of Adulprasertsuk *et al.* (1997)

Table 3. Chemical quality characteristics of plant residues.

Residues	C (%)	N (%)	C/N	L[1] (%)	L/N	Pp[2] (%)	Pp/N	(L+Pp)/N
Rice straw	39	0.49	79	3.6	7.4	1.48	3.02	10.4
Groundnut	39	1.73	23	9.9	5.7	1.57	0.91	6.6
Sesbania	42	1.50	28	11.1	7.4	0.88	0.59	8.0
Dipterocarp	42	0.68	62	24.9	36.6	4.98	7.32	43.9
Tamarind	42	1.23	31	16.9	13.7	4.61	3.75	17.5

[1] Lignin
[2] Polyphenol

while lower %N (0.89 %) and higher C/N (52) were found for tamarind by the same researchers. Dipterocarp and tamarind leaf residues can be ranked as low quality litters due to their relatively high C/N ratio, high lignin, and polyphenol contents. Rice straw can be classified into an intermediate quality category due to its high C/N but it does not have high lignin and polyphenols as compared to dipterocarp and tamarind. The high-quality residues were groundnut stover and *Sesbania* with low C/N, low lignin, and polyphenols contents.

Total soil organic carbon build-up

Upland

Where no plant residues were added to the soil, ongoing oxidation of soil organic matter (SOM) had significantly reduced soil C by approximately 855 kg C ha^{-1} yr^{-1} in the top 15 cm compared to the organic matter content at the start of the experiment (Table 4). One year after organic residue incorporation, the three treatments containing groundnut stover resulted in the highest soil C build-up (as compared to the treatment with no residue addition, Table 4). Surprisingly, adding dipterocarp residues with their high lignin and polyphenol contents apparently resulted in significantly lower soil C contents at the end of year 1 than most other plant residues. This was due to the fact that a large proportion of its residues remained still in large (>2 mm) particulate forms and were thus not included in the soil analysis which consisted of the <1 mm sieved fraction only. In general, less than 20% of the applied C in the residues was recovered in the total soil carbon fraction (< 1 mm) with exception of the groundnut low application rate treatment in which > 30% was recovered (Table 4).

Soil C build-up in the soil exhibited a significant correlation with two of the residue qualities, i.e. a positive correlation with %N and a negative correlation with C/N (Table 5). As soil C values were obtained from sieved soil they reflected the C

Table 4. Carbon recovery in upland soil (0–15 cm, particles <1mm) one year after residue application.

Plant residues	Application rate (t ha^{-1} year^{-1})	C content at the end of Year 1 (t ha^{-1})[1,2]	Net C increase (t ha^{-1} year^{-1})[3,4]	C increase (% C applied in residues)[4]
No OM addition	0	3.66±0.19[4]	0	0
Rice straw (low)	10	3.98±0.11	0.31±0.11	8.0±2.9
Rice straw (high)	20	4.37±0.25	0.70±0.16	9.0±2.0
Groundnut stover (low)	10	4.96±0.53	1.29±0.37	32.9±9.6
Groundnut stover (high)	20	4.93±0.32	1.27±0.19	16.1±2.5
Rice straw + groundnut	10+10	5.05±0.33	1.38±0.25	17.7±3.2
Dipterocarp	10	4.08±0.27	0.42±0.16	10.0±3.8
Tamarind	10	4.48±0.15	0.82±0.05	19.5±1.3

[1] Bulk density value used was 1.45 g cm^{-3}.

[2] C content at the start of the experiment = 4.52 ± 0.11[4] t ha^{-1}.

[3] Net C increase = C in residue treatment – C in the control (no addition)

[4] Values preceded by ± are SE.

Tabel 5. Correlation coefficients relating soil total C build-up in soil particles <1 mm to chemical characteristics of plant residues under upland and lowland conditions at the end of year 1 (n=12).

	Para-meters[1]	%C	%N	C/N	%L[2]	L/N	%Pp[2]	Pp/N	(L-Pp)/N
Upland	r	–0.11	0.66	–0.62	–0.06	–0.30	–0.16	–0.45	–0.33
	(*P*)	(0.734)	(0.020)	(0.032)	(0.860)	(0.337)	(0.61)	(0.147)	(0.298)
Lowland	r	0.12	0.052	–0.07	0.11	0.08	0.08	0.05	0.08
	(*P*)	(0.717)	(0.872)	(0.832)	(0.734)	(0.808)	(0.799)	(0.870)	(0.816)

[1] r = correlation coefficient
(*P*) = probability value
[2] L = lignin; Pp = polyphenols

associated with soil particles less than 1 mm in size. Thus residues with higher N and lower C/N, which often decompose more rapidly, apparently accumulated more soil C when excluding the undecomposed litter fraction >1mm. On the other hand, litter of size larger than 2 mm at the end of year two exhibited a significant positive correlation with lignin, lignin/N, polyphenols, and polyphenols/N (results not presented; litter fraction of year 1 accidentally lost).

Lowland

In contrast to the upland system there was no significant loss of soil C in the control treatment (no OM added) after one year (Table 6). This was probably due to accumulation of organic materials from surroundings during flooding. One year after residue incorporation only *Sesbania* treatments at the high application rate (20 t ha^{-1}) resulted in significant soil C build-up in the soil fraction <1 mm (Table 6). The high rice straw treatment led to similar soil C contents but high variation resulted in

Table 6. Carbon recovery in lowland soil (0–15 cm, particles < 1 mm) one year after residue application.

Plant residue treatment	Application rate (t ha^{-1} year^{-1})	C content at the end of Year I (t ha^{-1})[1,2,4]	Net C increase (t ha^{-1}year^{-1})[3,4]	C increase (% C applied in residues)[4]
No OM addition	0	7.28±1.53	0	0
Rice straw (low)	10	7.27±2.15	ns	ns
Rice straw (high)	20	8.30±0.97	ns	ns
Sesbania (low)	10	7.62±2.45	ns	ns
Sesbania (high)	20	8.13±0.66	0.85±0.67	10.2±8.0
Rice straw + sesbania	10+10	8.55±0.46	1.28±0.64	15.9±7.9
Dipterocarp	10	7.78±0.22	ns	ns
Tamarind	10	7.70±1.32	ns	ns

[1] Bulk density value used was 1.75 g cm^{-3}.
[2] C content at the start of the experiment = 6.88 ± 0.71[4] t ha^{-1}.
[3] Net C increase = C in residue treatment – C in the control (no residue application)
[4] Values preceded by ± are SE.
ns = non-significant statistically.

a statistically non significant effect (p>0.05). The residue recoveries varied between 10–16% of the applied residue C for the high rate *Sesbania* and rice-*Sesbania* mixture treatments, respectively. Among the low application rate treatments the ranking in soil C content was dipterocarp, tamarind, *Sesbania* and rice. This ranking followed closely the lignin content of the materials with dipterocarp having the highest lignin content and rice the lowest. It is known that lignin is little degraded under anaerobic conditions (Zeikus (1980) as cited by Becker *et al.* (1994)) although the correlation was not significant in our experiment. In contrast to the upland experiment, none of the correlations of soil C with chemical characteristics of plant residues were significant (Table 5).

Nitrogen transformations

Upland

Initially (first 5 weeks after residue incorporation) N immobilisation occurred in treatments that received low-intermediate quality residues, e.g. rice straw (high C/N) and dipterocarp or tamarind (high lignin and polyphenols, Figure 2). However, residue treatments containing groundnut stover did not have such an initial N immobi-

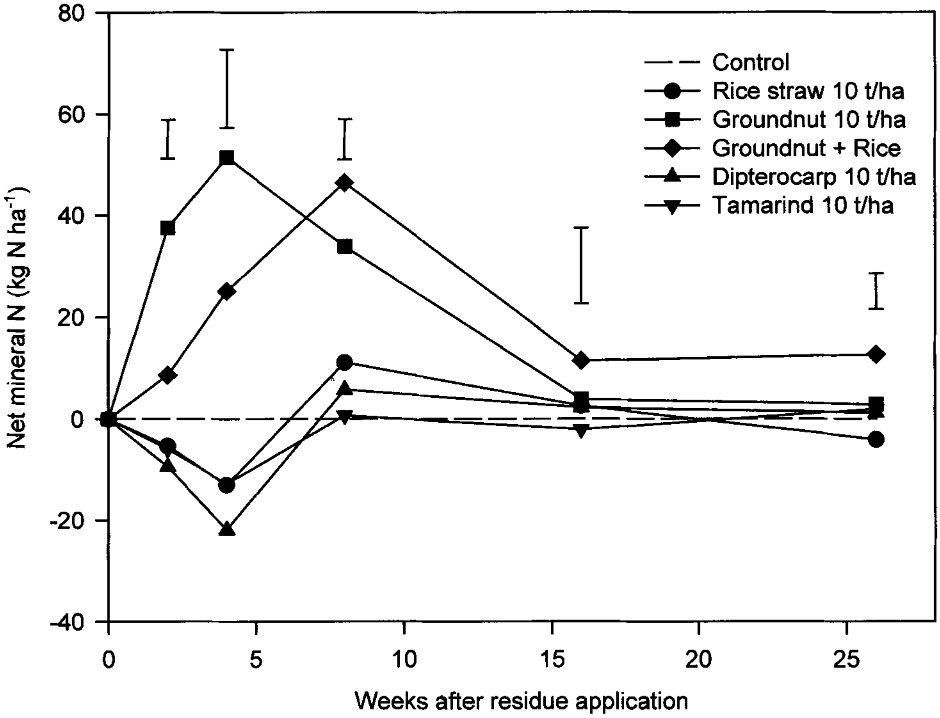

Figure 2. Net amount of mineral N produced by different organic residues under upland condition. Vertical bars represent SED.

lisation phase but yielded net N mineralisation immediately after they were incorporated. Peak mineral N in the groundnut treatment occurred four weeks after residue incorporation and the amount mineralised corresponded to 29% of the N initially added in the stover. On the other hand, peak N mineralisation of groundnut + rice straw was delayed to week 8 and the respective amount released was only 20% of the N initially added. These results demonstrate that, by mixing high C/N ratio residues (i.e. rice straw) with high-quality residues (i.e. groundnut stover), we can manipulate the temporal pattern of N release to better suit plant's need. This is the core idea of the 'synchrony' concept. Quemada & Cabrera (1995) found a similar interaction when incubating mixtures of leaves and stems of wheat. They attributed the retarded N mineralisation to the high soluble C content of the wheat stems causing an enhanced microbial immobilisation of N. Handayanto *et al.* (1997) demonstrated that by including residues with a high active polyphenol content in the mixture N release and N utilization of the higher quality residue can be reduced due to the protein binding capacity of the polyphenols. Following the peak mineral N appearances, there was a rapid decline of mineral N after week 8 indicating severe losses of N. These losses are likely to be due to leaching as rainfall after the week 8 sampling on May 22,1995 increased dramatically (Figure1). Dipterocarp, tamarind and rice straw did not significantly contribute to the net mineral N pool (Figure 2) even after the end of the N immobilisation phase after week 8. This was associated with their high C/N ratios, and/or with high lignin and polyphenol content which resulted in a strong N immobilisation or slow decomposition. While the input of N from tamarind amounted to 123 kg N ha^{-1}, no apparent positive contribution to the soil mineral N pool was evident (Figure 2).

Tissue N concentration showed a positive correlation with mineral N during the 2 periods which covered the first 4 weeks of decomposition (Table 7). The C/N ratio had a negative correlation with mineral N during the first 2 weeks of decomposition, however as decomposition proceeded further the correlation became non significant. Lignin and lignin/N ratio did not exhibit a significant correlation with mineral N. On

Table 7. Correlation coefficients relating amounts of soil mineral N (NH_4^+ + NO_3^-–N) to chemical characteristics of plant residues under upland (n=12) and lowland (n=36) conditions.

Period	Parameters[1]	%C	%N	C/N	%L	L/N	%Pp	Pp/N	(L-Pp)/N
Upland									
Week 0–2	r	0.52	0.79	–0.62	–0.33	–0.51	–0.57	–0.72	–0.55
	(*P*)	(0.090)	(0.002)	(0.031)	(0.292)	(0.087)	(0.052)	(0.008)	(0.063)
Week 2–4	r	–0.38	0.58	–0.47	–0.29	–0.43	–0.43	–0.57	–0.46
	(*P*)	(0.219)	(0.047)	(0.126)	(0.367)	(0.158)	(0.165)	(0.054)	(0.134)
Lowland									
Week 0–8	r	0.49	0.88	–0.84	0.17	–0.17	0.01	–0.38	–0.20
	(*P*)	(0.179)	(0.002)	(0.004)	(0.665)	(0.669)	(0.977)	(0.310)	(0.607)

[1] r = correlation coefficient
(*P*) = probability value

the other hand, polyphenols and polyphenols/N ratio had a significant negative influence on N mineralisation especially during the first 2 weeks of decomposition. This suggested that polyphenols interacted directly with decomposing plant residues. Polyphenols are known to bind with proteins and thus inhibit N release (Handayanto *et al.*, 1995). Although in our case the polyphenol/N ratio appeared to be a good predictor of N release it was not better than %N on its own. Thus no additional improvements in predicting N release were gained by combining polyphenols with the N term.

Lowland

Under lowland conditions, the first peak of mineral N occurred at four weeks during which the paddies were flooded and thus decomposition proceeded under anaerobic conditions (Figure 3). After week 4 the soil gradually dried out and mineral N disappeared. It is generally found that N mineralisation is higher under anaerobic conditions than aerobic conditions, e.g. Gale & Gilmour (1988), Ono (1989; 1991). The second peak of mineral N occurred at 26 weeks after residue incorporation which was likely due to the remineralisation of microbial biomass N (see Figure 5). The sesbania-rice straw mixture, while having a slightly reduced N release during the

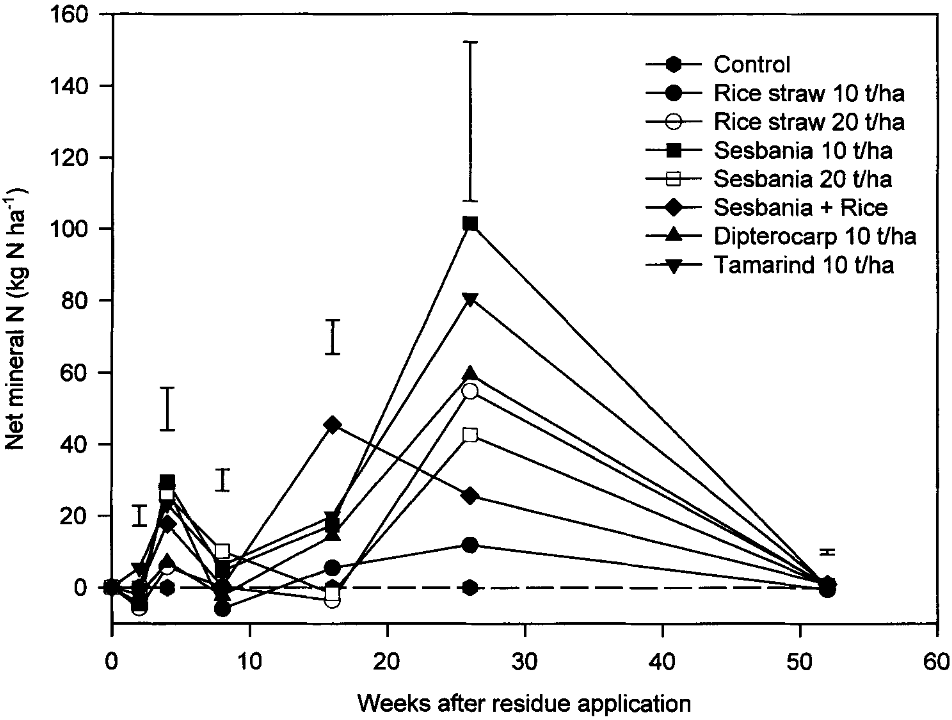

Figure 3. Net amount of mineral N produced by different organic residues under lowland condition. Vertical bars represent SED.

anaerobic phase compared to sesbania alone, exhibited the fastest remineralisation during the aerobic phase. Similarly, Becker & Ladha (1997) found that the N mineralisation rate of a sesbania-rice straw mixture was delayed compared to the sesbania alone treatment and concluded it was in better synchrony with rice N demand.

As in the upland soils, residue %N and C/N exhibited significant positive and negative correlations respectively with soil mineral N. However different from the upland, extractable polyphenols did not appear to influence mineral N release from the residues (Table 7). Becker *et al.* (1994) also did not find an impact of polyphenols on N mineralisation in flooded soils. They suggested that the dilution of the water-soluble polyphenols in flooded water retarded and diminished their reaction with N compounds. Toomsan *et al.* (2000) found also no significant effect of polyphenols on pre-rice green manure N recovery by rice but including the (lignin+polyphenol)/N ratio improved the prediction of residue N assimilation.

Microbial biomass N in relation to N transformations

Upland

Microbial biomass N was highest in the rice + groundnut mixed treatment (Figure 4). This was probably the combined result of the large amount of available C (from

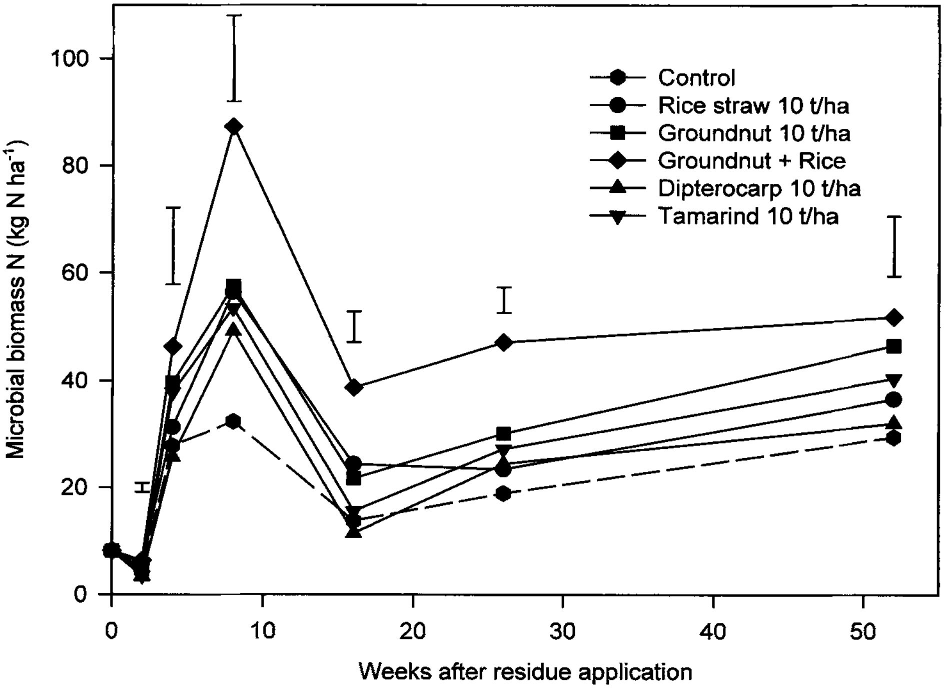

Figure 4. Dynamics of microbial biomass N as affected by different organic residues under upland condition.Vertical bars represent SED.

rice straw and groundnut stover; application 20 t DM/ha) as well as the immobilisation of N readily available from groundnut stover. This combined effect resulted in the delayed N mineralisation observed with the rice + groundnut mixed treatment as compared to the groundnut stover alone treatment (Figure 2). The amount of residue N immobilised in the microbial biomass (approx. 54 kg N ha^{-1}) corresponded to 24 % of the N initially added in the combined residues. The total amount of N recovered in microbial biomass and mineral N at 8 weeks after residue incorporation amounted to 44% of the N initially added in the mixture. No significant differences among the other residue treatments were observed.

Lowland

The measured microbial biomass flush during the flooded phase (anaerobic) was small (Figure 5). However, as the soil started to dry out the microbial biomass N increased strongly. This was likely due to increased aeration and presence of large amounts of carbonaceous substrates, such as semi-decomposed organic acids, that led to the increase in microbial biomass. The microbial biomass N reached its peak at 8 weeks after residue incorporation. This was mirrored by a strong immobilisation of mineral N at the same time (Figure 3). The N mineralisation surge at week 26

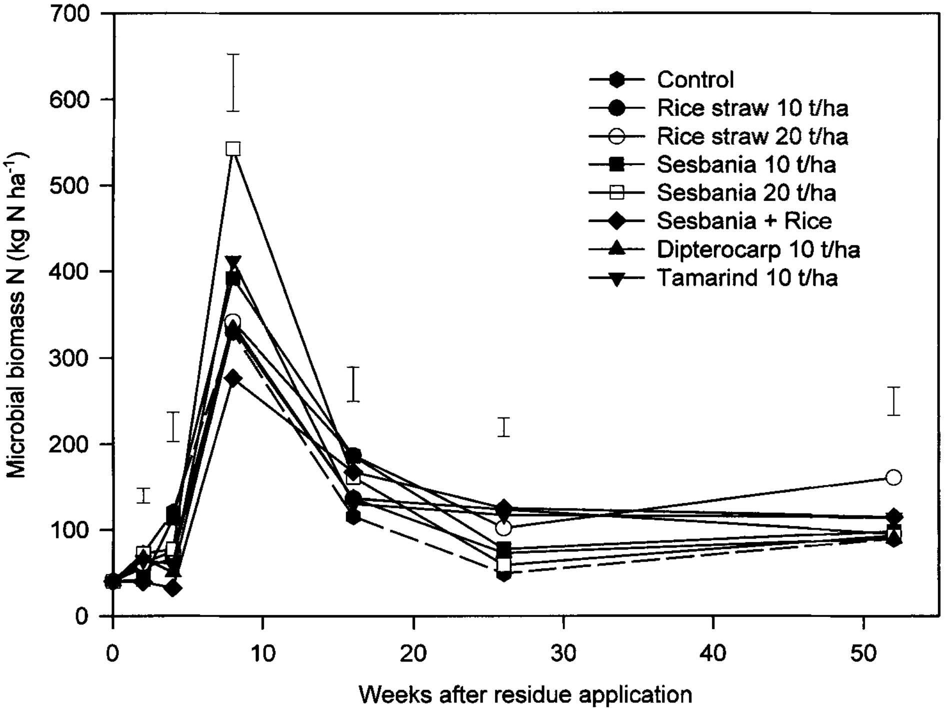

Figure 5. Dynamics of microbial biomass N as affected by different organic residues under lowland condition. Vertical bars represent SED.

(Figure 3) corresponded to the previous rapid decline of the microbial biomass N (Figure 5).

Upland versus lowland

The paddy soil was richer in organic matter than the upland soil. This was likely due to its heavier texture which is more favourable for organic matter retention and protection. Nitrogen mineralisation was affected by aeration. Higher net N mineralisation was found under lowland than under upland conditions (Figures 2 and 3) but this was associated with the remobilisation of N after the anaerobic phase. On the other hand, N immobilisation was negligible under flooded lowland as compared to the upland condition. Microbial biomass N was generally higher in the lowland soil which was in agreement with the higher organic matter and higher N mineralisation in the lowland soils.

Manipulation of N release

The individual residues locally available in Northeast Thailand cannot provide optimal N release patterns for the requirement of crops. High quality residue, i.e. groundnut stover, under upland aerobic conditions resulted in immediate net N mineralisation but also an early decline in soil mineral N indicating a high potential for leaching losses. Additions of lignin- and polyphenol-rich dipterocarp and tamarind residues resulted in an initial N immobilisation phase as well as no significant contribution to the mineral N pool after the immobilisation phase. On the other hand, by mixing high C/N ratio residues, like rice straw, with groundnut or sesbania the N mineralisation could be delayed in both upland and lowland systems and hence potentially improving the synchrony of residue N release with plant N demand. The delay of net N mineralisation was associated with an increased N immobilisation in microbial biomass (Figure 4) due to an excess of available C in rice straw added to the groundnut. Additionally, the mineral N was sustained at relatively higher levels until the end of the measurement period potentially improving the N supply during the crop grain filling phase.

Acknowledgements

The research sites belong to Agriculture and Cooperatives Provincial Office, Khon Kaen and Northeastern Regional Agricultural Extension Office (Ministry of Agriculture and Cooperative). Jon Fear of Wye College provided his skillful chemical analyses of the plant residues. We are grateful for their cooperation. We thank the European Union Science and Technology for Developing Countries programme for financial assistance (contract TS3*–CT94–0261).

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