CHAPTER V

EFFECTS OF TROPICAL LEGUME RESIDUES ON N DYNAMICS, CO_2 EVOLUTION, SUGARCANE GROWTH AND SOIL NUTRIENT CONTENTS

ABSTRACT

Northeastern Thailand is the main area of sugarcane production but its yield is rather low due to low soil fertility status which is considered to be one of the yield limiting factors. Integration of legume green manure into the farming systems can be a cheap alternative of alleviating low soil fertility and erosion problems. Residues of leguminous crops including peanut (*Arachis hypogaea* L.), pigeonpea (*Cajanus cajan* (L.) Millsp.), hairy indigo (*Indigofera hirsuta* Harvey) applied at 6.25 Mg ha^{-1} (low rate) and 12.5 Mg ha^{-1} (high rate) and jackbean (*Canavalia gladiata* (Jacq.) DC.), sunnhemp (*Crotalaria juncea* L.) and *Crotalaria striata* applied at low rate only were investigated for their contribution to soil mineral N dynamics, CO_2 evolution, nutrient contents and early growth of transplanted seedlings of sugarcane in a pot experiment. Mineral N application as $(NH_4)_2SO_4$ equivalent of 0 and 47 kg N ha^{-1} were control treatments.

It was found that these tropical legumes varied in their chemical characteristics and could be categorized into three groups using N concentration, C:N ratio, lignin and polyphenol concentrations. The high quality legumes were peanut and sunnhemp, the intermediate quality legumes were jackbean and *C. striata* and the low quality legumes were pigeonpea and hairy indigo. High quality legume residues resulted in high extractable mineral N, which resulted in higher sugarcane growth at 139 DAT. Peanut residue application resulted in the highest sugarcane biomass and followed by sunnhemp.

However, Peanut residue contributed the lowest CO_2 evolution while pigeonpea was the highest. Nutrient uptake in sugarcane biomass at 139 DAT indicated that the N and K were higher in peanut than other leguminous residues and N fertilizer application. Similarly, sunnhemp and peanut residue treated soils resulted

in higher uptake of Mg than those receiving other treatments. In addition, N, P, K and Mg uptake were higher in these treatments than the control treatment.

After harvest at 139 DAT, the application of legume residues resulted in higher soil organic matter especially with the application of pigeonpea.

1. Introduction

Thailand was the world's seventh largest sugar producer in 2006, i.e. 4.8 million Mg representing about 2.3 % of the world production. Sugarcane production area in Thailand fluctuated around 1 million hectares since 1992. The yield of cane per area was low, 58 Mg ha^{-1} (Office of Agricultural Economics, 2007a). The main production area in Thailand is in the Northeast which is characterized by low fertility sandy soils and erratic rainfall with long dry spells (Kamontum and Mongkolsawat, 2000).

Decline in yields commonly occurs under sugarcane cropping is due to high nutrient removal, lack of an adequate nutrient replenishment, inappropriate cultivation techniques, especially, burning of sugarcane fields either before or after harvesting. Hartemink and Wood (1998) and Vityakon et al. (2000) suggested that the decline in some nutrients for example, Ca (calcium) and Mg (magnesium) may be due to leaching and the decline in N (nitrogen) and P (phosphorus) levels is possibly linked to a decrease in organic matter which is commonly found in topsoil layers of the tropics.

Improved fallows with N_2 fixing leguminous green manures have been shown to enhance soil fertility rapidly (Smith et al., 1987; Sanchez, 1995). Green manure crops can increase cropping system sustainability by reducing soil erosion and ameliorating soil physical properties (MacRae and Mehuys, 1985; Smith et al., 1987; Blair et al., 2006), by increasing soil organic matter and fertility levels (Doran and Smith, 1987; Rao et al., 1995) and by increasing nutrient retention (Drinkwater et al., 1998; Staver and Brinsfield, 1998). Ambrosano et al. (2005) found that the efficiency use of nitrogen by corn was 30%, for the above-ground part of sunnhemp incorporated to a podzolic soil. Research on the effects of green manure on soil fertility has focused largely on the ability of green manure to supply N to succeeding crops (Ambrosano et al., 2005; Hemwong et al., 2009) while the potential of green manures to affect P and K fertility of succeeding crops has remained largely uninvestigated.

Biochemical characteristics of plant residue are used as indicators to predict residue decomposition and N mineralization. Some studies have shown that the initial residue N content (Frankenberger and Abdelmagid, 1985), lignin (Müller et al., 1988), polyphenols (Constantinides and Fownes, 1994a) and soluble C concentrations (Reinerstsen et al., 1984; Oglesby and Fownes, 1992; Kachaka, 1993) are useful indicators of residue quality. Beneficial effects of green manure legumes on crop growth depend on time of decomposition and subsequently nutrient release, to match with crop demand, that are regulated by the green manure's quantity and chemical quality and their nutrient contents.

Although some legume green manure crops are introduced for rotation in sugarcane cultivation in Northeast Thailand, there is limited information on their effect on sugarcane growth and soil fertility improvement. Pigeonpea is a common legume green manure used by some farmers with minor use of jackbean and sunnhemp. However, these herbaceous legume species serve the single purpose of improving soil fertility. However, they are not widely adopted especially by small farmers because they do not provide cash income. Dual-purpose legumes that produce both edible yield and high biomass such as peanut are more attractive because farmers can earn some extra income. Naturally occurring plants, such as hairy indigo (*Indigofera hirsuta* Harvey) and *C. striata* grow abundantly around farmers' fields. These two legumes have high biomass production and nutrient contents and should be good sources of green manure.

Soil can function as a net sink for sequestering atmospheric CO_2 through appropriate soil and crop management (Lal et al., 1995; Paustian et al., 1995). Several techniques have been developed to measure the decomposition rate of organic matter, however respiration continues to be the most popular method to measure microbial activity and substrate decomposition in soils (Zibilske, 1994).

The present study examined soil N dynamics and CO_2 evolution from soils planted with sugarcane as influenced by application of different legume residues and their rates of application compared to mineral N fertilizer and control treatments. Their effects on early growth of sugarcane and soil fertility were also measured using a pot experiment.

2. Materials and Methods

2.1 Soil

A pot experiment was conducted in the field under shelter of clear plastic sheet using 28 litre pots (32x35 cm : diameter x height) at the Field Crops Research Center (16° 15′ N and 102° 50′ E), Khon Kaen province, Northeast Thailand during April to August 2001. The soil used was classified as Yasothon series (Oxic Paleustults), loamy sand textured with high sand (86 %) and low clay (6 %) contents. Soil fertility was low with 4.9 g kg^{-1} organic C by the Walkley and Black method (Nelson and Sommers, 1982), 150 mg kg^{-1} total N by Kjeldahl method (Bremner and Mulvaney, 1982), pH 5.8 (1:5 w/v in water), and 5.64 $cmol_{(+)}$ kg^{-1} soil cation exchange capacity. Available P was 50 mg kg^{-1} (Bray II) and exchangeable K, Ca and Mg (in ammonium acetate pH 7) was 0.19, 0.72, and 0.32 $cmol_{(+)}$ kg^{-1} soil, respectively.

2.2 Experimental setup

Plant residues were obtained from legumes including one grain legume, peanut (*Arachis hypogaea* L.) cultivar Khon Kaen 60-3, three common green manure legumes; pigeonpea (*Cajanus cajan* (L.) Millsp.), jackbean (*Canavalia gladiata* (Jacq.) DC), and sunnhemp (*Crotalaria juncea* L.) and two local leguminous weeds; *Crotalaria striata* and hairy indigo (*Indigofera hirsuta* Harvey). They were grown in a field of the Research Centre from May until harvested in September 2000. Leaf litter was collected from the ground underneath the plants consisting mostly of senesced leaves. The residues of these legumes had different proportions of stem, leaf and leaf litter i.e. peanut 0.59:0.17:0.24, pigeonpea 0.54:0.23:0.23, sunnhemp 0.69:0.19:0.12, jackbean 0.53:0.18:0.29, *C. striata* 0.54:0.24:0.22 and hairy indigo 0.46:0.15:0.39. All residues were sun dried and cut to a length of approximate 1 cm. In April 4, 2001 plant residues and mineral fertilizer were thoroughly mixed at the rate equivalent to 6.25 Mg ha^{-1} with 32 kg dry soil according to the treatments. Three additional treatments of peanut, pigeonpea and hairy indigo residues receiving 12.5 Mg ha^{-1} residues were also included. Ammonium sulfate at the rate of 47 kg N ha^{-1} was added as mineral N fertilizer treatment. A pot without legume residues and without mineral N fertilizer was also added as a control treatment. All treatments received P_2O_5 and K_2O, both at 47 kg ha^{-1} as triple super phosphate and muriate of potash, respectively. In April 9, 2001, a one month old sugarcane seedling, 2-3 expanded leaves, was transferred to each pot. The treatments were arranged in a randomized complete block with 4 replications. Soil moisture was maintained at approximately 60% of field soil capacity by frequent weighing. To minimize damage to soil surface crust, a 50 cm pipe with drilled holes was driven into the soil then water was provided through the pipe. Two pots of blank soil were added as reference pots. The air temperature ranged from 16 to 37 ^{0}C (mainly day-night variation) during the experimental period.

Sugarcane was harvested on August 23, 2001 (139 DAT) and was separated into cane stalks, green and dry leaves, tops, roots and stools and weighed. A subsample of each plant parts was taken and dried at 65 °C to determine dry weight. All plant parts were ground and analyzed for nutrient contents. All green leaves were measured by an automatic area meter (Hayashi DenKo AAC-400, Tokyo, Japan). Calibrations were done by running a metal disc of known area (100 cm^2) through the machine. The leaf area index (LAI) was determined as the ratio of the leaf area and the pot area.

2.3 Chemical analysis of legume residues and sugarcane

Total C and N concentrations of residues were determined using an elemental analyzer (NA 1500, Carlo Erba, Milan, Italy). The acid detergent fiber (ADF) method was used for determination of lignin content (Van Soest et al., 1991). Total soluble polyphenols were determined by the Folin-Denis method using tannic acid as a standard (Anderson and Ingram, 1993). Phosphorus concentration of plants digested in HNO_3 and $HClO_4$ was determined by the ammonium molybdate method (Olsen and Sommers, 1982) and K, Ca and Mg by atomic absorption spectrophotometer. Total N in sugarcane was determined using the micro Kjedahl method (Nelson and Sommers, 1973), while P, K, Ca and Mg were determined using the same procedures as previously mentioned.

2.4 Soil sampling and analysis

Soils were sampled at 0-15 cm depth using a 2 cm diameter auger from 3 spots per pot at every sampling date and bulked. Soils were sampled at 15, 68, 85 and 133 DAT, and analyzed for chemical properties such as pH (1:5 soil:H_20), extractable P (Bray II), exchangeable K, Ca and Mg (ammonium acetate extraction at pH 7, atomic absorption spectrophotometer). Mineral N in soil (NH_4^++NO_3^-) was determined in 10 g of fresh soil samples immediately after sampling. The soil samples were extracted with 50 ml 1 N KCl, shaken, filtered and aliquots analyzed for NH_4^+-N and NO_3^--N calorimetrically using a flow injection analyzer (Tecator, 1984).

2.5 Determination of CO_2 evolution

Evolution of CO_2 was determined using the static chamber method with alkaline absorption (Anderson and Ingram, 1993). A one liter glass bottle having a diameter of 7.5 cm was pushed into soil surface to a depth of 2 cm in each pot to cover a 30 ml vial containing 10 ml of 1 N NaOH to absorbed CO_2 in the 44 cm^2 enclosed area . The bottle was covered with a paper bag to keep the bottle in dark condition and lower the air temperature. After 1-4 days the vials were collected and replaced with the new ones. To maintain adequate O_2 levels after the vial was collected, the bottle was left open for a few minutes. The trapped CO_2 was precipitated as carbonate with excess $BaCl_2$ and the excess NaOH was titrated with 1 N HCl. A glass bottle on a pot without plant residues and a glass bottle with 10 ml of 1 N NaOH in 30 ml vial closed tightly were used as controls. The measurement was performed continuously for 70 days after sugarcane seedlings were transferred into the pot.

The amount of CO_2 evolved was calculated using the following formula:

$$\text{C or } CO_2\ (\text{mg}) = (B-V)NE$$

Where: V = Volume (ml) of acid to titrate the base in the CO_2 collectors from the samples, B = Volume (ml) of acid to titrate the base in the CO_2 collectors from the control. N = the normality of the acid. E = equivalent weight. If results are expressed in terms of carbon, E = 6; if expressed as CO_2, E = 22.

C loss due to legume residue application was calculated as the difference between cumulative C loss from the residue application treatments and that from the control treatment. The rate constants of CO_2 evolution were estimated using a linear regression model

2.6 Statisical analysis

An ANOVA was performed on the data using the MSTAT C programme (MSTATC, 1990). Differences between means were compared by least significant difference (LSD) at $p \leq 0.05$. Correlation and regression between biomass production, nutrient contents and CO_2 evolution and initial residue chemical characteristics were performed on untransformed data at 139 DAT.

3. Results

3.1 Chemical characteristics of legume residues

Peanut residues were highest in N concentration (2.27%) and hence lowest in C:N ratio, (18:1) (Table 5.1). On the contrary, pigeonpea residues were lowest in N (1.13%) and C (40%) and highest in C:N ratio (35:1). Additionally, their ADF and lignin concentrations in pigeonpea residues were highest, 49.0 and 14.8%, respectively. Therefore, they were considered to be a low quality residue. Hairy indigo residues had higher N concentration (1.71%) than pigeonpea residues, However, their polyphenol concentration was the highest (2.49%) among the legume residues (0.98-1.88%). It also had high ADF and lignin concentrations (48 and 13.3%) and thus was also considered to be of low quality. Despite the high polyphenol concentration of 1.88%, sunnhemp residues were considered to be of high quality due to their high N concentration (1.93%), low C:N ratio (22:1) and lowest lignin concentration (8.2%). Jackbean residues were lowest in polyphenol (0.98%), and were fairly low in N (1.40%), but high in ADF (48.0%) and lignin concentration (11.3%).

Therefore they were considered to be of intermediate quality, i.e. between peanut and pigeonpea. *C. striata* residues contained high lignin but they had the lowest ADF concentration (34.0%), an intermediate C:N ratio (23:1) and N concentration (1.86%), and were thus considered to be of intermediate quality.

Nutrient contents other than N, were also different among legume species. Variation of P concentration was moderate among the legume species. Jackbean residues contained the largest P concentration (0.36%) while pigeonpea residues were lowest in P (0.20%). Meanwhile, K and Ca concentrations varied widely (1.37-4.01% K and 0.32-1.40% Ca), K was lowest in pigeonpea and highest in peanut residues, while calcium was lowest in sunnhemp and *C. striata* and highest in peanut residues. The concentration of Mg was also highest in peanut residues (0.24%) but was lowest in pigeonpea residues (0.13%) (Table 5.1).

Table 5.1 Chemical concentration of legume residues (average of stalk, leaf and leaf litter).

Legume Residues	Concentration (%)									C:N
	N	C	ADF	PP	L	P	K	Ca	Mg	
Peanut	2.27	41	40	1.38	11.6	0.29	4.01	1.40	0.24	18:1
Pigeonpea	1.13	40	49	1.24	14.8	0.20	1.37	0.64	0.13	35:1
Hairy indigo	1.71	43	48	2.49	13.3	0.33	3.04	1.05	0.17	25:1
Sunnhemp	1.93	42	47	1.88	8.2	0.28	2.37	0.32	0.18	22:1
Jackbean	1.40	42	48	0.98	11.3	0.36	2.57	0.96	0.18	30:1
C. striata	1.86	43	34	1.41	13.6	0.22	3.57	0.32	0.21	23:1

N = nitrogen, C = carbon, ADF = acid detergent fiber, PP = total extractable polyphenol, L = lignin, P = phosphorus, K= potassium, Ca = calcium, Mg = magnesium.

3.2 Effect of legume residues on soil mineral N dynamics

Extractable mineral N contents in soil were the result of N mineralization minus sugarcane mineral N uptake. Initially (15-68 DAT) mineral N was elevated in all treatments but declined drastically thereafter to lower than 10 mg kg^{-1} at 84 DAT and lower than 1 mg kg^{-1} soil at 139 DAT (Figure 5.1).

At 15 DAT, application with mineral N fertilizer resulted in significantly highest extractable soil mineral N than the other treatments except sunnhemp. The application of sunnhemp and peanut residues obtained higher extractable soil mineral N than the other legume residues and the control treatments, although there were no significant differences. At 68 DAT, extractable mineral N reduced drastically with mineral N fertilizer and sunnhemp treatments. It was also found in the application of hairy indigo, jackbean, *C. striata* residue treatments at the application rate of 6.25 Mg ha^{-1}, and the control treatments, though in less extend. This result indicated that sugarcane uptake was higher than N release. The reduction of extractable soil mineral N did not occurred with the application of peanut and pigeonpea residues in both rates, indicating that N uptake of sugarcane was more or less equal to N release. In contrast to most legumes, application of hairy indigo residue at 12.5 Mg ha^{-1} resulted in higher extractable soil mineral N, indicating higher N releasing than the uptake (Figure 5.1).

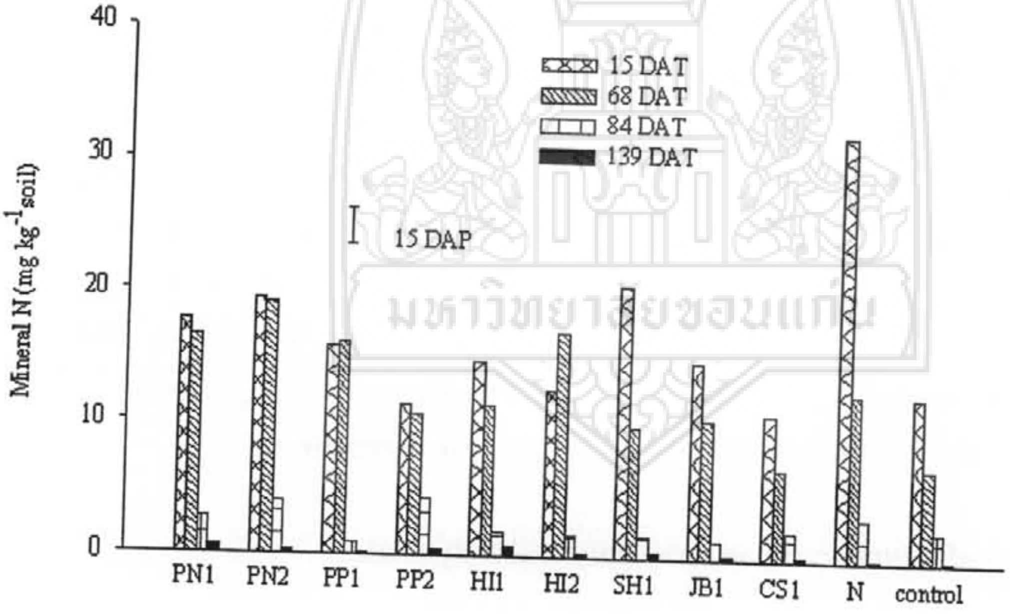

Figure 5.1 Extractable mineral N at 15, 68, 84 and 139 days after sugarcane seedling transplanting (DAT) as affected by species and rates of legume residues and mineral N fertilizer . Error bar indicates LSD at 0.01 level at 15 DAT, other dates were not significant difference.

PN = Peanut, PP = Pigeonpea, HI = Hairy Indigo, SH = Sunnhemp, JB = Jackbean
CS = *C. striata* and N = N 47 kg ha^{-1}. Rate of added residue 1 = 6.25 Mg ha^{-1} 2 = 12.5 Mg ha^{-1}.

The change in extractable soil mineral N from 15 to 68 DAT revealed effect of legume species and rate of application. Extractable mineral N with peanut and pigeonpea showed less change with dates but with increasing rate. This resulted in a slightly increase in the peanut residue treatment but a reduction in the pigeonpea residue treatment. Increasing rate of hairy indigo residue application resulted in lower extractable mineral N at 15 DAP but higher at 68 DAT, indicating no synchronize of N release (Figure 5.1).

3.3 Effect of legume residues on CO_2 evolution

In this study, three sources of CO_2 release were recognized i.e. 1) sugarcane root respiration, 2) legume residue decomposition and 3) indigenous soil organic matter decomposition (blank soil). Figure 5.2 and Table 5.2 clearly demonstrated that cumulative CO_2 evolution was lowest in the blank soil (without sugarcane plant and without residues) which accumulated 216 g m^{-2} at 70 DAT and the rate constant of CO_2 evolution (*Kc*) was 2.98 day^{-1}. Cumulative CO_2 evolution increased in the control pots, which contained sugarcane plants but without residues (564 g m^{-2}) and its *Kc* was 7.61 day^{-1}. Addition of mineral N fertilizer did not show a significant difference in the amount of cumulative CO_2 evolution, (588 g m^{-2}) compared to the control and the *Kc* was 7.73 day^{-1}.

Application of legume residues at the rate of 6.25 Mg ha^{-1} significantly increased CO_2 evolution and their *Kc* values compared to the control and mineral N fertilizer treatments, but CO_2 evolution was not significantly different among the legume species (775-832 g m^{-2}) at the end of the experiment. Although, *Kc* value was highest with *C. striata* residue application, it was not significantly different from the other legume residue treatments (10.12-11.07 day^{-1}). The amounts of CO_2 evolution in the higher rate treatments (880-944 g m^{-2}) were not significantly different from the lower rate ones. Although *Kc* values of pigeonpea and hairy indigo at higher residue application rate (12.76 and 12.63 day^{-1}, respectively) were significantly higher than those of the lower rate treatments, the peanut residue treatment only showed a tendency to increase (11.71 day^{-1}) (Figure 5.2 and Table 5.2).

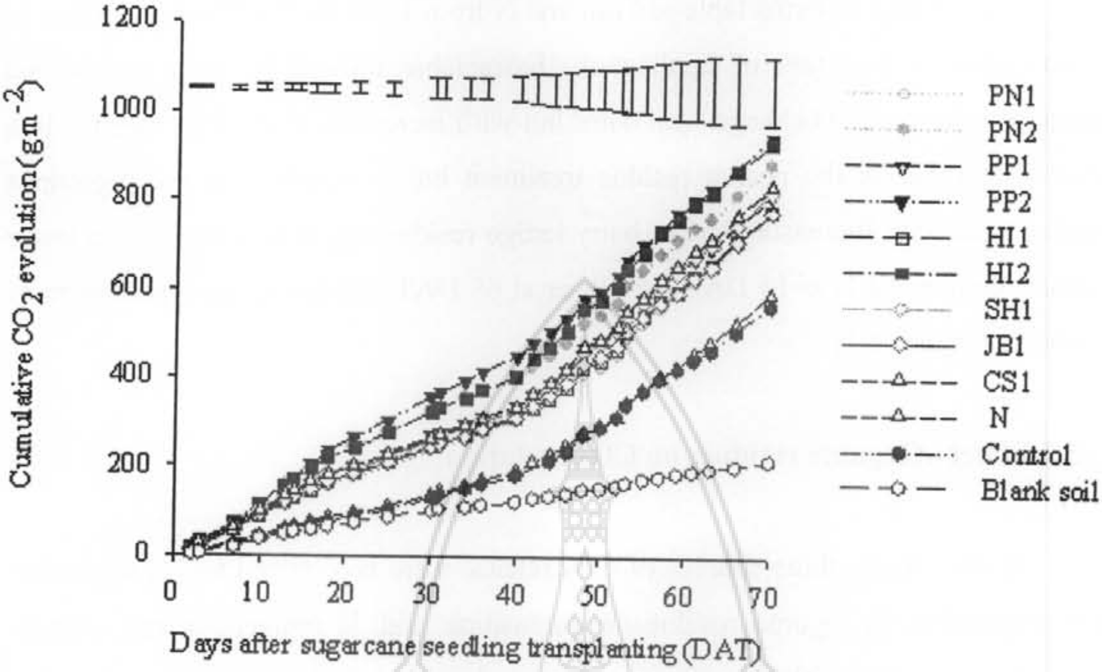

Figure 5.2 Cumulative CO_2 evolution as affected by species and rates of legume residues and mineral N fertilizer. Error bars indicate LSD at 0.01 level.

PN = Peanut, PP = Pigeonpea, HI = Hairy Indigo, SH = Sunnhemp, JB = Jackbean CS = *C. striata* and N = N 47 kg ha^{-1}. Rate of residue application 1 = 6.25 Mg ha^{-1} 2 = 12.5 Mg ha^{-1}

Percentage of C loss was calculated under the assumption that underground activities were similar among the treatments as root biomass of sugarcane was not significantly different among the treatments (Table 5.3) and the soil used in this study was taken from the same field. Therefore, net C loss due to legume residue application was calculated as the difference between cumulative C loss from the residue application treatments and that from the control treatment. Percentage of C loss showed significant differences among the treatments up to 50 DAT (Figure 5.3). At 50 DAT, Cumulative C loss from initial C added of the peanut residue treatment was significantly lower (11.67%) than those of pigeonpea, *C. striata* and sunnhemp residue treatments (15.9-16.9%) at the application rate 6.25 Mg ha^{-1}. It had also the lowest rate constant of percentage C loss (*Kc*) (0.22% day^{-1}). Even though the *Kc* values of C loss were highest with the application of pigeonpea and *C. striata* (0.32 and 0.31% day^{-1}, respectively), they were not significantly different from the other legume species (0.22-0.27 day^{-1}). Increasing residue application rate to 12.5 Mg ha^{-1}, C loss in all three legume residue treatments was reduced (11.67-16.92% vs 10.77-13.23%). However, there were no significant differences in *Kc* of %C loss values among the legume species or application rates (Figure 5.3 and Table 5.2).

Table 5.2 Linear daily rate constant *(Kc)* of cumulative CO_2 evolution and the percentage of C loss (% initially added) from the soil planted with sugarcane as affected by species and rates of legume residues and mineral N fertilizer.

Legume residues	Added rates ($Mg\ ha^{-1}$)	*Kc* of CO_2 evolution (day^{-1})	*Kc* of % C loss[1] (day^{-1})
Peanut	6.25	10.12	0.22
Pigeonpea	6.25	10.93	0.32
Hairy indigo	6.25	10.23	0.23
Sunnhemp	6.25	10.80	0.27
Jackbean	6.25	10.23	0.27
C. striata	6.25	11.07	0.31
Peanut	12.50	11.71	0.21
Pigeonpea	12.50	12.76	0.23
Hairy indigo	12.50	12.63	0.25
Fertilizer N	0.047	7.73	
Control	0	7.61	
Blank soil	0	2.98	
F-test[2]		**	ns
$LSD_{0.05}$		1.70	0.14
CV(%)		11	33

[1] $$\%C\ loss = \frac{(C\ evolution\ from\ treatments - C\ evolution\ from\ control\ soil)*100}{initial\ C\ added}$$

[2] F-test ns= not significantly different $p>0.05$, ** = significantly different at $p<0.01$.

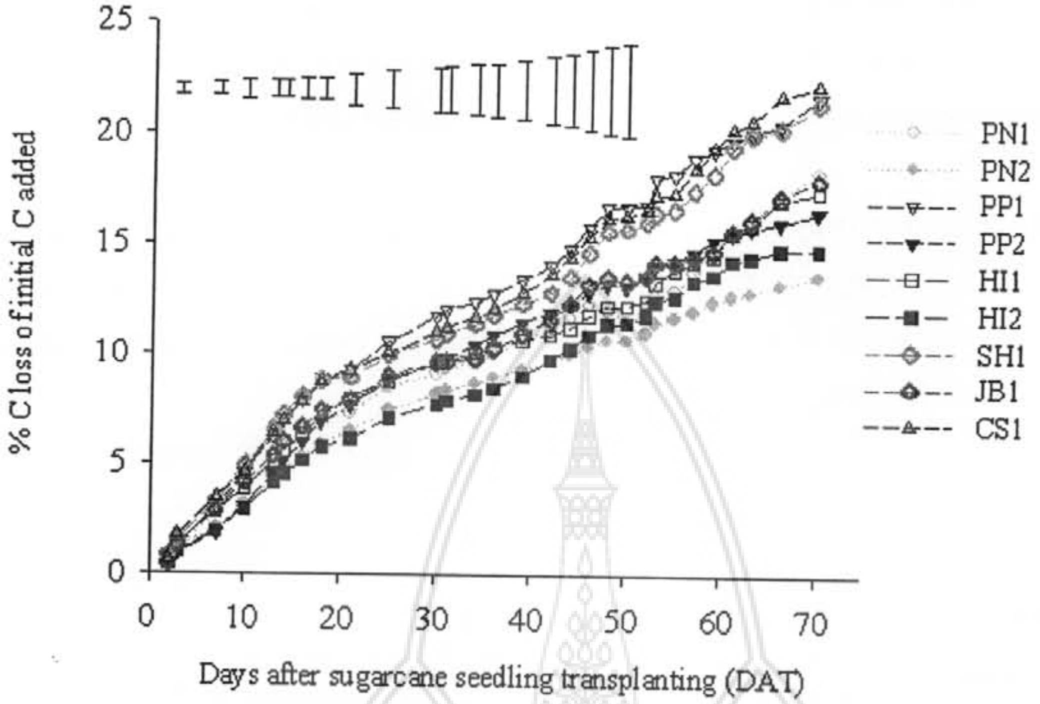

Figure 5.3 Temporal pattern of C loss of initially added as affected by species and rates of legume residues and mineral N fertilizer. Error bars indicate LSD at 0.05 level.

PN = Peanut, PP = Pigeonpea, HI = Hairy Indigo, SH = Sunnhemp, JB = Jackbean
CS = *C. striata* and N = 47 kg N ha^{-1}.
Rate of residue application 1 = 6.25 Mg ha^{-1} 2 = 12.5 Mg ha^{-1}.

3.4 Effect of legume residues on sugarcane growth

At 139 DAT, sugarcane growth was in the tillering and elongation stages. The application of different legume residues resulted in increased growth of sugarcane and was higher with the double rate of residue application (Table 5.3). Total sugarcane biomass of the treatments, with legume residue application, were in the range of 254-331 g pot^{-1} and were significantly higher than that of the control. The treatment with N fertilizer application gave 239 g pot^{-1} total biomass of sugarcane and was noticeably lower than other residue application treatments, except the pigeonpea and hairy indigo residues that were applied at the rate of 6.25 Mg ha^{-1} (Table 5.3). Among treatments of 6.25 Mg ha^{-1} residue application, peanut and sunnhemp, both good quality residues gave the highest total biomass of sugarcane. The higher rate of residue application resulted in significantly higher total sugarcane biomass (282-331 g pot^{-1}) than the mineral N (239 g pot^{-1}) and control (229 g pot^{-1}) treatments. However, there were no significant differences in total sugarcane biomass among the three legume residue treatments applied at 12.5 Mg ha^{-1} (Table 5. 3).

Cane dry weight was significantly increased with the application of peanut, sunnhemp and *C. striata* residues at 6.25 Mg ha^{-1} (113-116 g pot^{-1}) compared to the control treatment (88 g pot^{-1}) but was not significantly different from the mineral N fertilizer treatment (101 g pot^{-1}) (Table 5.3). Increasing residue rate of peanut, and hairy indigo to 12.5 Mg ha^{-1} significantly increased cane biomass compared to that of mineral N fertilizer and control treatments. No significant difference in cane dry weight was observed among legume species at both application rates.

Table 5.3 Sugarcane biomass dry weight and their growth parameters at 139 days after sugarcane seedling transplanting (DAT) as affected by species and rates of legume residues and mineral N fertilizer.

Legume residues	Added rates (Mg ha^{-1})	Biomass dw (g pot^{-1})				Cane dia. (cm)	Cane height (cm)	Cane no.	Leaf No.	Leaf area index
		Total	Cane	Leaf	Below ground					
Peanut	6.25	295	113	94	90	2.41	111	1.25	6.75	3.53
Pigeonpea	6.25	256	103	89	68	2.49	98	1.50	6.75	3.30
Hairy indigo	6.25	254	100	85	69	2.35	101	1.25	7.00	3.29
Sunnhemp	6.25	289	114	93	83	2.52	110	1.50	7.00	3.72
Jackbean	6.25	271	102	82	86	2.44	108	1.00	6.50	3.42
C. striata	6.25	277	116	85	76	2.44	115	1.00	6.50	3.88
Peanut	12.50	331	124	111	97	2.51	104	1.50	8.00	4.62
Pigeonpea	12.50	282	112	92	78	2.48	110	1.00	7.00	4.06
Hairy indigo	12.50	298	125	91	82	2.60	117	1.25	7.75	4.03
N fertilizer	0.047	239	101	83	72	2.23	89	1.25	7.50	4.09
Control	0	229	88	73	68	2.40	92	1.00	5.75	2.96
F-test[1]		**	*	**	ns	ns	**	ns	*	*
LSD$_{0.05}$		30.2	20.9	13.4	21.1	2.39	13.1	0.57	1.21	0.84
CV(%)		7.6	13.2	10.5	18.5	6.77	8.6	31.40	12.08	15.57

[1] F-test ns= not significantly different $p>0.05$, * = significantly different at $p<0.05$, ** = significantly different at $p<0.01$.

All legume residue applications had no effect on the below ground dry weight, cane diameter and cane number. However, the treatment of peanut at the rate of 12.5 Mg ha^{-1} produced the highest leaf biomass (111 g pot^{-1}). This was the only treatment that was significantly higher than the N fertilizer application. While cane height, only the *C. striata* with 6.25 Mg ha^{-1} and hairy indigo (12.5 Mg ha^{-1}) were the tallest (115 and 117 cm) among the rest. Moreover, both treatments were significantly different from the control treatment. The leaf number and leaf area in every treatment were not different among the residue application treatments and the N fertilizer treatment but it was different from the control (Table 5.3).

3.5 Nutrient contents in sugarcane biomass

Nitrogen content of total sugarcane biomass was highest with the application of peanut residues at the rate of 12.5 Mg ha^{-1}(1,257 mg N pot^{-1}) which was significantly higher than the rest of the treatments (702-954 mg N pot^{-1}) (Table 5.4). Peanut residue application at the rate of 6.25 Mg ha^{-1} still had the highest N content of sugarcane biomass (939 mg N pot^{-1}) which was however not significantly different from the other legume residue treatments (812-929 mg N pot^{-1}). Increasing rate of application to 12.5 Mg ha^{-1} the peanut treatment showed a significant increase in N content from that applied at the rate of 6.25 Mg ha^{-1} while pigeonpea and hairy indigo residue treatments only showed a tendency to increased N contents (954 and 947 mg N pot^{-1}, respectively). N content was lowest in the control treatment (702 mg N pot^{-1}).

Application of mineral N fertilizer resulted in the highest Ca content which was not significantly different from the treatments that received peanut residues at the rate of 12.5 Mg ha^{-1} and sunnhemp at the rate of 6.25 Mg ha^{-1}. Ca contents in the rest of treatments were not significantly different from that of the control treatment (Table 5.4).

The application of peanut residues at the rate of 12.5 Mg ha^{-1} resulted in the highest Mg content (558 mg Mg pot^{-1}) which was significantly higher than those of other treatments with the same application rate. Among the legume species application at the rate of 6.25 Mg ha^{-1}, the sunnhemp treatment was the highest in Mg content (489 mg Mg pot^{-1}) which was significantly different from the pigeonpea and hairy indigo residue application. Increasing the rate of legume residue application significantly increased Mg content only in the peanut residue treatment. The lowest Mg content was observed in the control treatment (Table 5.4).

Table 5.4 Nutrient contents in sugarcane biomass at 139 days after sugarcane seedling transplanting (DAT) as affected by species and rates of legume residues and mineral N fertilizer.

Legume residues	Added rates (Mg ha^{-1})	Nutrients content (mg pot^{-1})				
		N	P	K	Ca	Mg
Peanut	6.25	939	332	2,127	334	451
Pigeonpea	6.25	847	315	1,736	329	411
Hairy indigo	6.25	821	307	1,765	304	409
Sunnhemp	6.25	929	331	1,590	356	489
Jackbean	6.25	862	291	1,466	327	434
C. striata	6.25	812	308	1,864	268	426
Peanut	12.50	1,257	370	2,127	390	558
Pigeonpea	12.50	954	362	1,998	291	446
Hairy indigo	12.50	947	382	2,452	242	441
Fertilizer N	0.047	882	260	895	458	416
Control	0	702	260	1,105	321	365
F-test[\1]		**	**	**	*	**
LSD $_{0.05}$		175	43	359	104	76
CV(%)		13	9	14	22	12

[\1] F-test * = significantly different at $p<0.05$, ** = significantly different at $p<0.01$.

Nutrient contents were not significantly different among the legume residue treatments at the same rate of application. Thus, the average effect of the rates of application on various nutrient contents was presented in Figure 5.4 and Table 5.5. Potassium content in sugarcane were strongly increased to the rates of residue application and followed by N. The other nutrient contents, Mg, P and Ca showed low response to increasing rates of residue application.

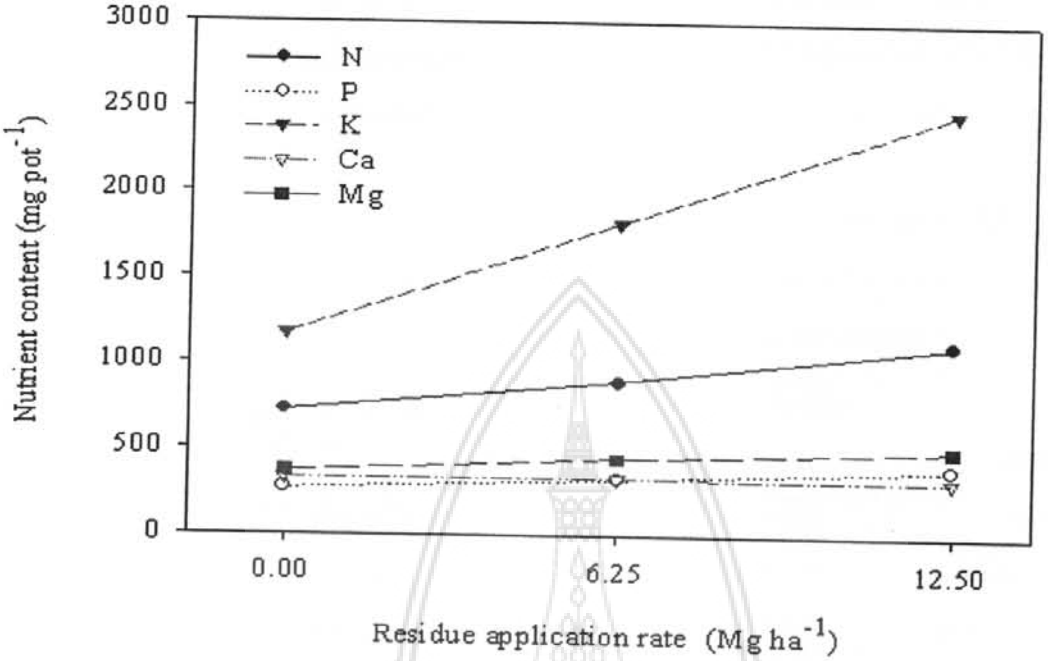

Figure 5.4 Nutrient contents of total sugarcane biomass at 139 days after sugarcane seedling transplanting (DAT) as affected by rates of legume residue application.

Table 5.5 Regression equations of nutrient contents in total sugarcane biomass (y) as affected by species and rates of legume residues application (x) at 139 days after sugarcane seedling transplanting (DAT).

Nutrients	Equation	R^2\1
N	y =713+31x	0.994*
P	y = 263+10x	0.997*
K	y = 1172 +104x	0.999**
Ca	y = 329-0.95x	0.940^{ns}
Mg	y = 370+10x	0.990*

\1 R^2 = Coefficient of determination

ns= not significantly different at $p>0.05$, * = significantly different at $p<0.05$,

** = significantly different at $p<0.01$.

3.6 Effect of adding legume residues on soil fertility

Application of legume residues significantly raised soil pH at 15 and 84 DAT but not at 139 DAT compared to those of the control and mineral N fertilizer treatments (Figure 5.5). However, the rate of legume residue application did not show significant differences on soil pH of all sampling dates. The mineral N fertilizer treatment resulted in lower soil pH than that of the control treatment. It was significantly lower than those receiving legume residues at most sampling dates, except at harvesting which pH values of all treatments were not different (Figure 5.5).

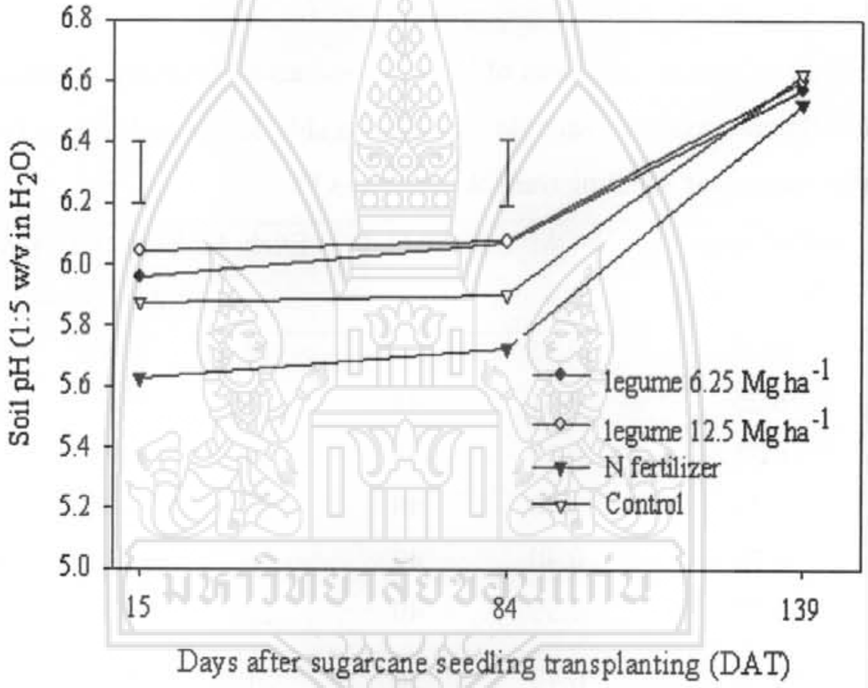

Figure 5.5 Soil pH at 15, 84 and 139 days after sugarcane seedling transplanting (DAT) as affected by rates of legume residue and mineral N fertilizer application. Error bars indicate LSD at 0.01 level.

At the end of the experiment (139 DAT), soil organic matter was highest with the application of pigeonpea residues (0.42%) at the rate of 12.5 Mg ha^{-1} which was not significantly different from most legume residue treatments at both application rates, except the application of peanut residue at 6.25 Mg ha^{-1}. Soil organic matter was significantly higher with the application of legume residues compared to the control treatment except with the application of peanut residues at 6.25 Mg ha^{-1}. (Table 5. 6).

At harvest, available P remaining in the soil was highest in the control treatment, although it was not significantly different from most legume residue treatments and was significantly lowest with the mineral N treatment (Table 5.6). Similarly, exchangeable Mg was not significantly different among legume species and rates of application. However, increasing rate of residue application had a tendency to increase available P. Exchangeable K and Ca were not significantly different among treatments.

Table 5.6 Effects of species and rates of legume residues and mineral N fertilizer on soil organic matter, available P, exchangeable K, Ca and Mg at 139 days after sugarcane seedling transplanting (DAT).

Legumes	Added rates (Mg ha^{-1})	OM %	Avail. P	Exch. K	Exch. Ca	Exch. Mg
			----------------------	----mg kg^{-1}----	----------------	
Peanut	6.25	0.35	47	16	160	14.6
Pigeonpea	6.25	0.41	48	15	158	13.7
Hairy indigo	6.25	0.37	48	36	109	12.2
Sunnhemp	6.25	0.40	49	20	164	13.6
Jackbean	6.25	0.40	49	16	188	13.9
C. striata	6.25	0.39	49	22	159	13.4
Peanut	12.50	0.40	50	21	187	17.0
Pigeonpea	12.50	0.42	47	17	182	14.6
Hairy indigo	12.50	0.41	51	18	195	15.5
Fertilizer N	0.047	0.35	41	28	130	10.8
Control	0	0.34	53	21	143	16.7
F-test\1		*	*	ns	ns	**
$LSD_{0.05}$		0.053	4.91			2.91
CV(%)		9.5	7.0	67	23	14

\1F-test ns = not significantly different $p>0.05$, * = significantly different at $p<0.05$,
** = significantly different at $p<0.01$.

4. Discussion

4.1 Effect of legume residues and rates of application on N dynamics in soil and sugarcane growth and nutrient uptake

Extractable mineral N from soil was the sum of soil and legume residue mineralization that remained after sugarcane uptake. At 15 DAT, N uptake by sugarcane was still low and N was assumed to be absorbed at the same amount in all treatments. Some legume species showed extractable N lower than control indicating N immobilization. The critical N content required for immediate net mineralization of N to occur was reported at 1.73% and the critical C:N ratio was 20 (Frankenberger and Abdelmagid, 1985). Heal et al. (1997) suggested that net mineralization would occur at a C:N ratio of 25:1. In our study, peanut, sunnhemp and *C. striata* had N content over 1.73% but only peanut had a C:N ratio below 20. It was thus expected that the N mineralization from peanut would benefit early growth of sugarcane. A fast N release of peanut residues in upland conditions in similarly poor sandy soils of Northeast of Thailand had been also reported (Vityakon et al., 2000; Promsakha Na Sakonnakhon et al., 2005; Hemwong et al., 2008). They also found an early decline of mineral N as indication of leaching losses (Vityakon et al., 2000; Promsakha Na Sakonnakhon et al., 2005). Vityakon et al. (2000) reported that the peak of soil mineral N in the peanut residue treatment occurred at 4 weeks after residue incorporation and the amount mineralized corresponded to 29% of the N initially added. In our experiment early reduction of mineral N did not occur with peanut and pigeonpea but with the rest of legume species especially sunnhemp at 68 DAT. However, because of a high coefficient of variation (%CV), there was no significant difference in extractable N among legume species of all dates of soil samplings.

The three different patterns of changes in extractable mineral N of the three legume species also found by Thippayarugs et al.(2008). They incubated the same material of legume residues under laboratory conditions and found that only the mixture of stalk, leaf and leaf litter of peanut showed net N mineralization throughout the 133 days period. On the other hand, the mixture of pigeonpea showed N immobilization throughout the incubation time, while the mixture of hairy indigo showed N immobilization up to 63 days before net N mineralization occurred. They, therefore, concluded that the decreasing order of legume decomposition and N release was peanut>hairy indigo>pigeonpea. The different effect between studies might be due to differences in plant chemical characteristics, however, no correlations between different chemical characteristics and mineral N was observed in this study. This might be due to the interfering effects of some intermediate products that occurred during residue decomposition on plant nutrient uptake. Meanwhile, the extractable mineral N reported in this study was the amount remaining after some of it had been absorbed by the plants. Peanut residues were high quality regarding their decomposition and N release. It has high N, low lignin, and ADF contents, therefore net N mineralization occurred immediately after application. Increasing rate of application of peanut residues resulted in slightly increased in extractable soil mineral N. Pigeonpea residues, in contrast, had low N content but were high in lignin and ADF contents. High rate of pigeonpea (12.5 Mg ha^{-1}) showed reduction in soil mineral N. Such a result may have occurred from higher uptake of sugarcane that resulted in higher sugarcane yield or might have been a far more retarded effect in N mineralization, as mineral N in soil was used more for decomposition of the higher amount of residues. Hairy indigo quality was also considered as low, even though it had intermediate N content and rather high in ADF and lignin but had extremely high in polyphenol content (Table 5.1). Increasing rates of application affected the amount of extractable mineral N, which was slightly increased with peanut residues, but markedly reduced with pigeonpea residues at 15, 68 and 84 DAT while application of hairy indigo resulted in a reduction of extractable mineral N at 15 DAT but markedly increased at 68 DAT.

Nitrogen dynamics in soil showed a significant effect on growth of sugarcane. The peanut residue treatment resulted in the highest sugarcane biomass production. In contrast pigeonpea and hairy indigo residue application resulted in the lowest biomass production, as their mineral N levels were lower than that of peanut and might not be synchronized with sugarcane demand. In this experiment, sugarcane seedlings were transplanted and they were ready for immediate nutrient uptakes. Thus, earlier N release from residues might be of more benefit than slower release. In the actual sugarcane planting under field conditions, legume residues are recommended to be incorporated at least 2 weeks prior to sugarcane planting. Therefore, N released early might be lost from the system, and, hence, not beneficial for sugarcane growth. Positive effects of peanut on subsequent crop yield were shown in previous studies in the same soil type as our present work (McDonagh et al., 1993; Toomsan et al., 1995; Toomsan et al., 2000; Promsakha Na Sakonnakhon et al., 2005). Hemwong et al. (2008) showed a rapid decomposition and N release of peanut residues that resulted in increased sugarcane tillering. Sunnhemp was fairly high in N content as well as polyphenol but was lowest in lignin (Table 5.1) which may have led to the second highest sugarcane biomass following the peanut. In our case sunnhemp showed a rapid release of N and the remaining of mineral N at 68 DAT was rather low compared to the peanut (which still maintained a high level of extractable mineral N). A sharp reduction of mineral N was also found with the mineral N fertilizer treatment which may have been the cause of lower sugarcane biomass under this treatment compared to the peanut and sunnhemp treatments.

However, there were some studies which showed advantages of sunnhemp over mineral N fertilizer treatment on sugarcane productivity, especially at early stages of growth (Perin et al., 2006). Ambrosano et al. (2005) found a higher N percentage of sugarcane derived from sunnhemp in sugarcane leaves at the early sampling (8 months) than from mineral N treatment. This indicated the importance of the presence of an organic source for initial nitrogen nutrition of sugarcane. They also showed higher sugarcane biomass and higher cumulative N under sunnhemp than ammonium sulfate application in an early stage (8-15 month). However, at harvest (18 months) the ammonium sulfate was superior to the sunnhemp. Ambrosano (1995) reported the N used efficiency of sugarcane from sunnhemp incorporation to be 30%, while Mascarenhas et al. (1994) (cited by Ambrosano et al., 2005) provided evidence of the positive effect of sunnhemp green manure treatments in sugarcane, with higher productivity than with the application of 40 kg ha^{-1} mineral N to the soil.

The high amount of extractable mineral N available at an early stage of sugarcane growth (68 DAT) under the high quality residues was too early for sugarcane demand which was still low as root development was not at the stage to effectively up take the high amount of N, consequently N leaching was likely although the soil depth was only approximately 30 cm in our experiment. However, sugarcane roots would be able to use the leached N at later stages when sugarcane roots penetrated deeper.

Similar to the sugarcane biomass, nutrient uptake of N, K and Mg was also highest under the peanut residues. Among all the residues investigated, Ca uptake was also highest in peanut. Peanut appears to be superior to other legume green manures and also mineral fertilizer. Muraoka et al.(2002) found that green manures provided better mineral N utilization, particularly in sidedressing applications, in sugarcane row resulting in an efficient use of the N source up to 79%.

4.2 Effect of legume residues on CO_2 evolution

Measurement of CO_2 evolution provides an early indicator of soil C level when there is a change in organic C due to management practice. It can be detected within a short period of time (Fortin et al., 1996; Grant, 1997). Application of mineral fertilizer to sugarcane plants resulted in higher CO_2 evolution than the blank soil (without sugarcane plants) from approximately 30 DAT onward indicating that majority of CO_2 evolution came from root activity. Mineral N fertilizer addition did not show any effects on CO_2 evolution comparing to the control treatment. This result implied that the N fertilizer did not affect root and microorganism activities in soil. Rochette and Gregorich (1998) and Amos et al. (2005) also reported that N fertilizer had little effect on CO_2 evolution. Nitrogen fertilization increased CO_2 flux compared to no N fertilization only in 2 out of 17 measurements. Application of various legume residues in our study, significantly increased CO_2 evolution compared to the control and mineral N fertilizer treatments. Parkin and Kaspar (2003) suggested that the CO_2 evolution from soil to the atmosphere is the primary mechanism of soil C loss, however, it was shown in the study on planted soil that the distinguishing between root and residue induced CO_2 loss is rather obscure.

4.3 Effect of legume residues on soil chemical properties

After sugarcane harvesting, soil was measured for chemical properties. Legume residues were likely to increase soil pH while mineral N fertilizer significantly decreased it. Nitrogen fertilizers have been frequently reported to lower soil pH. Hartemink and Wood (1998) reported soil pH reduction in many sugarcane plantations and suggested that it was the result of enhanced acidity through acid input from ammonium-N fertilizers. However, higher soil pH accompanying the addition of legume residues was also reported by Tang and Yu (1999). They reported soil pH increased up to 2 units after incubation and suggested that the magnitude of pH change depended largely on the concentration of organic anions in the legume residues, initial soil pH and the degree of residue decomposition. However, a number of incubation studies using widely different types of organic materials and soils under various experimental conditions showed that the addition of plant materials was able to increase or decrease or did not affect soil pH (Pocknee and Sumner, 1997). Calcium-containing low weight organic molecules were shown to play a major role in alleviating soil acidity (Pocknee and Sumner, 1997). It is suggested by Meda et al. (2001) that low molecular weight organic acids are released into the soil from plant residues and cause great effect on acid soil chemistry, increasing soil pH and exchangeable Ca, Mg, and K and decreasing Al.

It was found in this study that the soil organic matter contents were higher in almost all legume residue treatments comparing to the control and mineral N treatments, (with the exception of those of the peanut). However, increasing the rate of legume residues application showed no significant difference of soil organic matter content to the lower rate.

Cherr et al. (2006a) suggested that the small increase in soil organic matter with residue application was due to the fact that the experimental periods of green manures were short (2-5 years). Moreover, the long-term potential of green manure in increasing soil organic matter is limited, especially in low yielding green manures grown in the same field. In our study we used not only a closed system, but also a cut-and-carry system, with no leaching which enabled us to obtain high biomass application rates therefore soil organic matter increase was higher than in an open system (field condition).

The use of legume green manures has a potential to substitute chemical N fertilizer in partly or totally at early growth of sugarcane. In this study, the effect of legume residue application on sugarcane growth could be seen at 139 DAT. However, the mineral N data indicated that it was exhausted since 84 DAT and a second N fertilizer application might be needed. The information obtained in this study is a useful guideline in further study for N recommendation.

Phosphorus and Mg in soil were lower in legume application treatments than the control treatment but higher than with mineral N application. This may indicate non-adequate nutrient supply for sugarcane growth with both the legume residues and mineral N fertilizer. Nutrient interactions i.e.NxP, NxK, are known to influence yield and quality of cane. Balanced N+K fertilization has been emphasized by Ingram and Hilton (1986) to maximize the efficient use of inputs. Thomas and Scot (1990) observed that N fertilization resulted in increased P and K uptake. It is likely that N addition stimulated growth of roots and shoots and, hence increased the area for nutrient uptake. This might be a result of lower soil P and K compared to the control treatment.

To successfully manage the use of green manures as an N source for subsequent crops, some knowledge on green manure biomass production, decomposition and N release patterns are necessary. These are site-specific. Management of green manure for full benefit to associated crops may be manipulated through quality of residues, planting and incorporation time, and tillage to better synchronize nutrient release with crop demand. Age of harvested plant affects decomposition and nutrient release rates. In our condition, rainy season is in the fallow period so green manures can be established and has to serve as soil surface covering (4-5 months). Peanut is not only a cash crop, but also covers soil surface rapidly. In addition, all peanut plant parts showed more superior chemical characteristics than the other legume species for N release as presented in Thippayarugs et al. (2008). Early N release of peanut was highly beneficial to transplanted seedlings of sugarcane in this study. However, it may not necessarily be beneficial under field conditions when incorporated 2-3 weeks prior to sugarcane planting (employing non-presprouted cane which needs at least 15 days for shoot emergence.) In this case manipulation of green manure quality may be needed. Peanut residues may be mixed with pigeonpea residues or hairy indigo to delay N release of peanut as shown by Vityakon et al. (2000) that mixed peanut residues with rice straw which enable the delay of N release. Gathumbi et al. (2002) suggested that mixing legume species may have superior potential in replenishing soil fertility and reduce the risk of failure in establishment or productivity. This suggestion helps improving the use of peanut-based systems efficiently since peanut cropping area is rather limited due to high labour cost. Furthermore, the mixing of peanut and pigeonpea or hairy indigo could expand the area under green manure crops.

5. Conclusions

Use of legume green manure, especially peanut, has been proved in this study to be superior to the use of chemical N fertilizer alone for sugarcane biomass production. The high rates (12.5 Mg ha^{-1}) of some legumes investigated were not advantageous to the lower rate as far as sugarcane biomass is concerned. The higher sugarcane growth under the peanut green manure was attributable to higher nutrient uptake, notable N, K, Mg and Ca. Effective nutrient uptake by sugarcane resulted from synchrony between nutrient release from the green manure and crop demand. Our study showed that peanut and to a lesser extent sunnhemp, could release N rapidly enough for the demand of sugarcane seedlings, while the other legume residues did not release N rapidly due to their differences in chemical quality. Chemical quality of organic residues played a prominent role in regulating their rate of decomposition and nutrient release. In contrast to the high quality residues, like the peanut, the low quality residues, like the pigeonpeas in our study, release N much more slowly. In addition, double the rate of pigeon pea and hairy indigo application led to higher N immobilization relative to the low rate resulting in lower available soil mineral N to sugarcane crop. Application of legume residues not only increased soil mineral N but also increased soil organic matter. This was found to be particularly so in low quality residues like the pigeonpea which is beneficial for the soil component of the production system in the long run.

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