

CHAPTER III
EFFECTS OF PEANUT AND OTHER LEGUMES AS GREEN
MANURES ON GROWTH AND YIELD OF SUGARCANE
PLANTED IN THE LATE RAINY SEASON

ABSTRACT

In Northeast Thailand planting a legume as a fallow crop between the plough-out of the final ratoon and the re-establishment of the next sugarcane crop has been recently practiced. Little research work has been conducted on the most appropriate legume species, their management, nitrogen contribution and impact on sugarcane growth and yield. The grain legume, peanut (*Arachis hypogaea* L.), three green manuring legumes, pigeonpea (*Cajanus cajan* (L.) Millsp.), jackbean (*Canavalia gladiata* (Jacq.) DC.), sunnhemp (*Crotalaria juncea*) and two local leguminous weeds, *Crotalaria striata* and hairy indigo (*Indigofera hirsuta* Harvey) were planted during the time gap in rainy season as N providers. N₂ fixing ability of these legumes was assessed using ¹⁵N dilution method. Nitrogen benefits from the decomposition of these legume residues to sugarcane were determined using high ¹⁵N enriched residues. Decomposition rates were determined using the litter bags buried in the field.

Total aboveground biomass ranged from 4 to 11 Mg ha⁻¹ and N content ranged from 59 to 150 kg ha⁻¹. Sunnhemp including fallen leaves produced the highest biomass. The legumes obtained a high proportion of their N requirements from N₂ fixation (61-81%) especially hairy indigo, jackbean and peanut without P and K fertilizers (80-81%). Jackbean decomposed fastest at 0-49 days after burying bag (DAB) ($kw = 0.0180 \text{ day}^{-1}$) whereas pigeonpea was the slowest ($kw = 0.0077 \text{ day}^{-1}$). During the second phase (77-358 DAB) *C. striata* decomposed fastest ($kw = 0.0068 \text{ day}^{-1}$), while pigeonpea was the slowest ($kw = 0.0042 \text{ day}^{-1}$). ¹⁵N recovery in sugarcane biomass at 180 days after planting (DAP) (late tillering and early elongation stages) from legume residues was 5.5, 9.0, 15.0 and 13.7% of ¹⁵N initially added, which was equivalent to 7.9, 10.5, 10.4 and 16.5 kg N ha⁻¹ under the applications of peanut, pigeonpea, jackbean and sunnhemp, respectively. The millable

cane yield was not significantly different among the different legume residues (94-105 Mg ha⁻¹). However, peanut residue applications with and without P and K fertilizers, jackbean and hairy indigo obtained significantly higher millable canes than unamended soil treatment and they were not significantly different from the application of mineral N fertilizer. Millable cane yields in all legume residue treatments were higher than in the weed treatments.



1. Introduction

Sugarcane production area in Thailand has fluctuated around 1 million hectares since 1992 with the production of 73 million Mg cane (Office of Agricultural Economics, 2007a). The Northeast is the main area of sugarcane production in Thailand. In this region, sugarcane is mostly grown in sandy soils at the late or end of rainy season to extend the age of harvesting and to reduce problem of weed infestation during rainy period. Sugarcane is usually harvested in the dry season leaving one rainy season free before establishing a new cane crop. During the rainy season, most farmers leave the land fallow with native vegetation. During fallow period, the land is ploughed 2-3 times to clear the land and to allow water to penetrate into deeper soil layer. New sugarcane crop is planted at the end of rainy season (October-December) using residual moisture for emergence. Half of the recommended rate of mineral fertilizers is applied at sugarcane planting. Occasionally, plant establishment is poor due to inadequate soil moisture that affects both shoot emergence and nutrient availability. The other half rate of fertilizers is applied as soon as the soil obtaining adequate soil moisture from the rain.

Legume green manure can be used to improve fallow practice. By this approach, soil fertility is improved *via* nutrient cycling. However, the potential benefit of green manures as a source of nutrients to succeeding crops can only be achieved if their decomposition and nutrient release patterns are known so that the synchrony of nutrient release with crop nutrient demand can be improved (Myers et al., 1994). Management options include selection of plant materials with different chemical composition (quality) and controlling the timing, quantity and form of application to the soil. Rapid N mineralization rates can be responsible for considerable N losses through leaching, denitrification or volatilization. In contrast, when N mineralization is very slow, low N availability can lead to poor crop growth (Myers et al., 1994). Knowledge of N mineralization patterns of green manure can be used to improve N use efficiency in cropping systems (Constantinides and Fownes, 1994a; Giller and Cadisch, 1997)

Positive residual effects of N₂ fixing legumes on subsequent crops in rotations have been reported (Giller and Wilson, 1991; Peoples et al., 1995). The successful

development of using legume green manure as N supplement mainly depends on biomass production and N tissue concentration based mostly on N₂ fixation. Legume residues eventually decompose and release N to meet sugarcane demand for N. There are numerous studies examining effects of legume rotations on growth of subsequent crops (McDonagh et al., 1993; Toomsan et al., 1993; Toomsan et al., 1995; Promsakha Na Sakonnakhon et al., 2005).

In the environmental conditions of the Northeast of Thailand, appropriate legumes should grow well under low inputs, be drought tolerant and have high N₂ fixing capacity. Pigeonpea, sunnhemp and jackbean are among the promising green manure legumes that were evaluated on soil fertility improvement (Jeranyama et al., 2000; Balckom and Reeves, 2005).

To measure the contribution of N derived from different legume species to subsequent cane crop as well as to determine its fate (i.e. measuring potential losses from the soil-plant system), it is necessary to use ¹⁵N-labelled materials. Studies on utilizing ¹⁵N-labelled sources indicated that legume residues contributed small to moderate amounts of N (varying from 4 to 25% of the N contained in the residues) to the crop in the first season (Ladd and Amato, 1986; Xu et al., 1993; Harris et al., 1994). Information on legume rotation with sugarcane in northeast Thailand is limited in many aspects, including suitable legume species and their contribution to sugarcane biomass production. The rotation of fallow legumes in crop production systems has been increasingly practiced in many places, e.g. in eastern Africa with maize production (Jama et al., 1998; Niang et al., 2002), and in southern Africa (Kwesiga and Coe, 1994).

Recovery of residue N by cereals was in the range of 10-30% for legume residues (C:N ratio 10-20) (Ladd et al., 1981; Ladd and Amato, 1986; Müller et al., 1988) and 5-15% for non-legume residues (C:N ratio 20-80) (Powlson et al., 1985; Wagger et al., 1985). The wide range of recoveries cannot only be attributed to C:N ratio of residues. Other important factors affecting residue decomposition and release of mineral N include the polyphenol and lignin contents of the plant material (Fox et al., 1990; Haynes, 1997), environmental conditions and soil management practice.

The N-use efficiency of residue-N by following crops is a particularly important consideration. Of the 30% ¹⁵N mineralized in the first season, 20% was lost

via leaching and denitrification (Haynes, 1997). The lack of synchrony between release of N from the residues and succeeding crop N demand resulted in the opportunity for significant losses of N. The main sink for N released from decomposable legume residues is normally the soil. For example, the percentage of residue N remaining in the soil was reported to be 27-46% by Müller et al. (1988), 71-77% by Ladd et al. (1981) and 62% by Ladd and Amato (1986).

The objectives of this experiment were :1) to evaluate biomass production, N accumulation and N_2 fixation of 6 potential legume species available in the northeastern Thailand, 2) to determine decomposition, N release of legume residues under sugarcane cultivation condition, 3) to evaluate the effect of residues of the 6 legumes on soil N availability under sugarcane cultivation, 4) to follow the fate of N in 4 legume species on their contribution to sugarcane and 5) to evaluate sugarcane growth and yield with green manure residue application as N supplement to mineral N fertilizer at planting.

2. Materials and Methods

2.1 Experimental site

The experiments were conducted in the experimental field of Khon Kaen Field Crops Research Center ($16^{\circ} 15' N$ and $102^{\circ} 50' E$), Khon Kaen, Thailand. The climate is savanna with bimodal pattern of rainfall. All experiments were conducted on a typical soil of this region, i.e., well-drained loamy sand (Yasothon series, Oxic Paleustults). Soil texture (at 0-15 cm depth) was classified as loamy sand with high sand (86 %), low silt (8 %) and clay (6 %) contents. Soil fertility (at 0-15 cm depth) 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 $5.64 \text{ cmol}_{(+) } \text{ kg}^{-1}$ soil cation exchange capacity. Available P was 50 mg kg^{-1} (Bray II) and exchangeable K, Ca and Mg (in ammonium acetate pH 7) were 0.19, 0.72, and $0.32 \text{ cmol}_{(+) } \text{ kg}^{-1}$ soil, respectively.

2.2 Experimental set up

The legumes used in this experiment comprised of a grain legume, i.e. peanut (*Arachis hypogaea* L.) cultivar Khon Kaen 60-3 (KK60-3); three green manuring legumes, included pigeonpea (*Cajanus cajan* (L.) Millsp.), jackbean (*Canavalia gladiata* (Jacq.) DC.) and sunnhemp (*Crotalaria juncea* L.) and two local leguminous weeds, included crotalaria (*Crotalaria striata*) and hairy indigo (*Indigofera hirsuta* Harvey). All the legumes were sown in May 2000 with row spacing of 40 cm. Peanut, jackbean and sunnhemp were planted (2 plants hill⁻¹) with 20 cm spacing between hill. Pigeonpea, *C. striata* and hairy indigo seeds were drilled and after germination, the seedlings were thinned to the spacing of 10 cm for pigeonpea and 5 cm for *C. striata* and hairy indigo. This resulted in the population of 125,000-250,000 plants ha⁻¹ in 12 x 8 m plots, which were arranged randomly in blocks with four replicates. The 6 legumes were not applied with any fertilizers. Peanut adding with P₂O₅ and K₂O at the rate of 56.25 and 37.50 kg ha⁻¹ as triple super phosphate and muriate of potash was additional treatment. Peanut was limed at the rate of 625 kg ha⁻¹. Only one weeding was performed at approximately 1 month after the legumes were sown. Local weeds were allowed to grow freely in the four plots to be used as control treatments. Yield and biomass production of aboveground parts of the legumes were determined in September 2000.

2.3 Nitrogen (N₂) fixation of the legumes

Nitrogen (N₂) fixations were evaluated using the ¹⁵N isotope dilution method (Witty, 1983) with a non-nodulating peanut (referred as nonnod-peanut) which was the non-fixing reference plant, obtained from ICRISAT, Hyderabad, India. A microplot, 1.2 x 1.2 m, was set up at one end of each legume plot. The soil in the microplot was labeled using the solution of (¹⁵NH₄)₂SO₄ with an enrichment of 10% atom ¹⁵N excess. The N was applied at 10 kg N ha⁻¹, and mixed with glucose as a carbon source at the rate which gave the solution C:N ratio of 10:1, then all the mixture were incorporated to 15 cm depth. The field was left for 8 days before legume sowing to allow applied N to be immobilized by the soil microorganisms so reducing the rate of release of

labeled N (Giller and Witty, 1987). Nonnod-peanuts were planted in the same size of plots as the other legumes and similar microplots were set. Legumes were harvested from the area of 0.4x0.8 m from the inside rows. Plant materials were harvested and subsampled for oven drying at 65 °C, ground and analyzed for ¹⁵N enrichment using a Europa Scientific mass spectrometer based on the assumption that the non-fixing reference plant takes up a similar proportion of soil N and fertilizer-¹⁵N as the fixing plant. The proportion of N derived from the atmosphere can be calculated through the following equation (McAuliffe et al., 1958):

$$\% \text{ N}_2 \text{ fixation} = \left[1 - \frac{\text{atom\% } ^{15}\text{N excess of fixing legume}}{\text{atom\% } ^{15}\text{N excess of non - fixing reference plant}} \right] \times 100$$

Where atom% ¹⁵N excess = atom% ¹⁵N the legume – 0.3663 (natural ¹⁵N abundance of atmospheric N₂). Harvested area was 0.4 x 0.8 m for the legumes and the reference non-nod peanut. All biological materials were analyzed for ¹⁵N.

2.4 Decomposition and fate of mineral N in soil of the legumes

Legume residue decomposition was evaluated in a sugarcane field, using 20x20 cm nylon bags with 2 mm mesh size. Combination of air-dried stalks and green leaves was weighed equivalent to the average of dry matter production of each legume or weeds in the field. Twenty-five bags were buried between the second and third row of sugarcane crop at 5 cm depth. One bag of each treatment was randomly retrieved every 1 or 2 week. The damaged bags caused by insects, such as termite, were discarded and only intact bags were used. The remaining plant residues in the litterbags were water-cleansed, oven-dried at 65°C, and weighed. They were ground to pass through a 0.5 mm mesh size sieve. To minimize the effects of soil contamination, ash correction was performed using 0.5-1.0 g of ground samples burnt in a furnace at 550°C for 5.5 hours and ash content determined.

Decomposition and N release were evaluated through assessment of dry weight and N losses from the retrieved residues. The percentage of dry weight and N remaining relative to the initial amount added were calculated as follow:

$$XR(\%) = (X_t/X_o) \times 100,$$

Where XR is the percent weight or N remaining, X_t is the dry weight or N content at each sampling time and X_o is the initial weight or N value.

In order to describe of changing trends, treatment means of dry weight and nutrients remaining were regressed over time using a single exponential decay model (Wieder and Lang, 1982). This model is described by the following equation:

$$XR_t = 100. \exp^{-kt}$$

where XR_t is the dry weight or N remaining at time t and the slope k , the decomposition or N release rate constant.

2.5 Effects of legume residues on growth and yield of succeeding sugarcane

The design of the experiment was randomized complete block with 11 treatments and 4 replications. There were six preceding legume residue treatments and one added treatment with peanut residues grown with P and K fertilizer application. There were four control treatments, including, unamended treatment (weed removed, bare soil), weed treatment (weed incorporation or weed), weed removed with N fertilizer application at 47 kg N ha^{-1} as $(\text{NH}_4)_2\text{SO}_4$ (bare soil+N), weed incorporation with 47 kg N ha^{-1} as $(\text{NH}_4)_2\text{SO}_4$ (weed+N).

After harvesting, legume residues were cut into lengths of approximately 5-10 cm, and applied back to the plots that were already prepared for sugarcane planting. The plots were rotor-tilled to mix legume residues thoroughly into the soil to a depth of 10-15 cm. Two weeks after the incorporation, October 2000, sugarcane cultivar Uthong 1 was planted in the furrow about 30 cm depths with a spacing between the furrows of 1.2 m. Two cuttings, each with 2 buds were laid 50 cm apart in the furrows. Before laying the cuttings, chemical fertilizers according to the treatments were spread at the bottom of the furrows. The furrows were covered with a thin layer of soil, 10 cm thick. At the time of planting when the soil was very dry, supplementary water was provided in the planted furrows to ensure a successful emergence of shoots

and survival through the dry period. All treatments received basal fertilizers of 47 kg ha⁻¹ of P₂O₅ and K₂O (0-47-47) as triple super phosphate and muriate of potash before laying sugarcane cuttings at planting. The same rates of chemical fertilizers of N, P₂O₅ and K₂O (47-47-47) were applied in all plots again in June 2001. The plot size was 12.0x8.0 m and harvesting area was 8.0x 6.0 m.

Growth of sugarcane was evaluated 3 times, 1) March 24-29, 2001 (151 DAP) 2) August 6-10, 2001 (285 DAP) and 3) at harvest January 14-29, 2002 (443 DAP). At the first and second samplings, six hills of sugarcanes, were randomly taken from the inner border rows on both sides. Meanwhile the third sampling, materials were randomly picked from the harvesting area. Cane and the rest of the biomass (trash) were weighed. Sub samplings of sugarcane biomass (0.5-1.0 kg) were taken for oven dry at 65°C, thus dry biomass and nutrient contents were determined. Total stalk, shoot and damaged cane numbers were recorded. Ten randomly sampled canes were taken for length and diameter measurement. The sampled canes were divided into 3 parts, bottom, middle and top, grated, mixed and 100 g were sampled for oven dried weight determination. The same 100 g grated sample were put in a cloth bag, boiled, washed in water, dried and then oven dried for fiber (F) determination. Total solid (Brix, B) was determined in the juice extracted from the rest of the sampled canes using refractometer (ATAGO 3T) and temperature was recorded. Polarity (P) was measured with polarimeter. Calculation of commercial cane sugar (CCS) was as follow:

$$CCS = 0.9443P(100-F)/100 - 1/2[(0.966B(100-F)/100 - 0.9433P(100-F)/100]$$

Sugarcane yield was calculated as

Sugar yield = Millable cane fresh weight x CCS (Sunsayavichai et al., 2007).

Sugarcane was harvested in January 14-28, 2002 within the area of 43.2 m². The details of the treatments are presented in Table 3.1

Table 3.1 Treatments of the experiment.

Treatments	Fertilizer application (N-P ₂ O ₅ -K ₂ O kg ha ⁻¹)		
	Preceding legumes (1 month after germination)	Succeeding sugarcane	
		At planting October, 2000	June 2001
1) Peanut	0-0-0	0-47-47	47-47-47
2) Peanut+PK	0-56-38	0-47-47	47-47-47
3) Pigeonpea	0-0-0	0-47-47	47-47-47
4) Jackbean	0-0-0	0-47-47	47-47-47
5) Sunnhemp	0-0-0	0-47-47	47-47-47
6) <i>Crotalaria striata</i>	0-0-0	0-47-47	47-47-47
7) Hairy indigo	0-0-0	0-47-47	47-47-47
8) Weed+N	0-0-0	47-47-47	47-47-47
9) Weed	0-0-0	0-47-47	47-47-47
10) Bare soil+N	0-0-0	47-47-47	47-47-47
11) Bare soil	0-0-0	0-47-47	47-47-47

2.6 Recovery of N from the legume residues

In order to be able to follow the fate of N from legume residues in subsequent crops and to estimate residue N losses by the ¹⁵N balance method. Peanut (nonnod-peanut), pigeonpea, jackbean and sunnhemp were planted and labeled with ¹⁵N fertilizer in concrete tanks. To achieve a relatively uniform ¹⁵N labeling of the plant, ammonium sulfate (10% ¹⁵N excess) was applied in weekly split doses according to plant N requirements. Final isotopic enrichment of peanut, pigeonpea, jackbean and sunnhemp residues was 5.732, 1.708, 1.506 and 1.466 atom % ¹⁵N. Field soil background enrichment was 0.3864 atom % ¹⁵N. The labelled legume residues were cut to approximately 5-10 cm and incorporated into a microplot set at one edge of a sugarcane plot. The residues were mixed into the soil to the depth of 0-10 cm. The microplot size was 1.2 x 0.5 m, bordered by galvanized plates that were driven into the soil to the depth of 80 cm with approximately 10 cm above ground. Two cuttings

of 2 buds of sugarcane varieties Uthong 1 were planted in the middle of the microplot and fertilizer application was similar to the main plot. Sugarcane was harvested at 180 DAP and separated into different plant parts. Soil samples were collected from 0-20, 20-40, 40-60 and 60-80 cm depths from the microplot. Sugarcane sample atom %¹⁵N was derived from weighted means of individual plant parts. ¹⁵N recovery in sugarcane, undecomposed residues and soil (0-80 cm) was calculated as follows:

$$\text{Stover } ^{15}\text{N recovery (\%)} = \frac{(\text{Sample atom\% } ^{15}\text{N} - \text{Background atom\% } ^{15}\text{N}) \times \text{Sample N Yield} \times 100}{(\text{Stover atom\% } ^{15}\text{N} - \text{Background atom\% } ^{15}\text{N}) \times \text{Stover N Applied}}$$

2.7 Nitrogen use efficiency

To evaluate benefits of N contribution from different sources, various indicators of N use efficiency were calculated as follows:

Nitrogen use efficiency (NUE):

$$\text{NUE (Mg DW kg}^{-1}\text{ N)} = \frac{\text{Total dry weight}}{\text{Total N uptake}} \quad (\text{Svecnjak and Rengel, 2006})$$

Apparent fertilizer use efficiency (AFUE):

$$\text{AFUE (\%)} = \frac{(\text{N Plant}_{\text{fert}} - \text{N Plant}_{\text{unfert}})}{\text{N}_{\text{fert}}} \times 100 \quad (\text{Eagle et al., 2001})$$

where $\text{N Plant}_{\text{fert}}$ = total plant N uptake in N fertilized plot, $\text{N Plant}_{\text{unfert}}$ = total plant N uptake in N unfertilized plot and N_{fert} = amount of fertilizer applied.

Internal efficiency of N (IEN):

$$\text{IEN (Mg DW kg}^{-1}\text{ N)} = \frac{\text{Cane yield}}{\text{Total N uptake}} \quad (\text{Segda et al., 2004})$$

Agronomic yield nitrogen use efficiency (ANUE):

$$\text{ANUE (Mg DW kg}^{-1}\text{ N)} = \frac{\text{Cane yield}}{\text{N applied}} \quad (\text{Smith et al., 1988})$$

2.8 Soil sampling and analysis

Soils were sampled before legume planting from 0-15 cm soil depth using an augur (2.5 cm diameter). Five subsamples per plot were collected and bulked. Initial soil quality, such as pH (1:5 soil:H₂O), extractable P (Bray II), exchangeable K, Ca and Mg (ammonium acetate extraction at pH 7, atomic absorption spectrophotometer) were determined. To follow the fate of soil mineral N as affected by legume residue application, 10 subsamples of soils per plot were collected at 4 depths (0-20, 20-40, 40-60 and 60-80 cm) at 4 time intervals, i.e. 8, 147 (beginning of rainy season), 224 (before 2nd chemical fertilizer application), and 287 (1 month after 2nd chemical fertilizer application) after sugarcane planting (DAP). The soils were collected in a furrow between sugarcane plants. Mineral N were analysed by extracting 10 g of fresh soil with 50 ml 1N KCl, then NH₄⁺ and NO₃ contents were determined calorimetrically using a flow injection analyzer (Tecator, 1984).

2.9 Plant analysis

Legume residues, weeds and sugarcane were sub-sampled to determine moisture content by oven drying at 65^oC until the weight become constant. The legume residues were separated into stalks, green leaves, leaf litter and pods while sugarcane residues were separated into canes, brown leaves and top at harvest. They were ground to pass through a 1-mm screen. Legumes were analyzed for initial contents of lignin, fiber, polyphenol, C, N, P, K, Ca and Mg. Lignin was determined by the acid detergent fiber (ADF) method (Anderson and Ingram, 1993). Total soluble polyphenols were determined by the Folin-Denis method using tannic acid as a standard (Anderson and Ingram, 1993). The total C and N were determined by an elemental analyzer (NA 1500, Carlo Erba, Milan, Italy).

2.10 Statistical Analysis

An ANOVA was performed on the data using the MSTATC programme (MSTATC, 1990). Differences between means were compared by least significant

difference (LSD) at $p \leq 0.05$.

3. Results

3.1 Rainfall and temperature of the experiments

Daily rainfall, minimum and maximum temperatures during the experimental period are presented in Figure 3.1. The rainy season is generally from May to September and the dry season is from October to April. The amount of daily rainfall in the year 2000 was 1,661 mm, which was higher than the average between 1990-1999, which was 1,144 mm. Meanwhile, in the year 2001 the rainfall was 1,268 mm. In 2000, the mean maximum and minimum temperatures were 32 and 22°C whereas the mean maximum and minimum temperatures were 34 and 24°C in 2001.

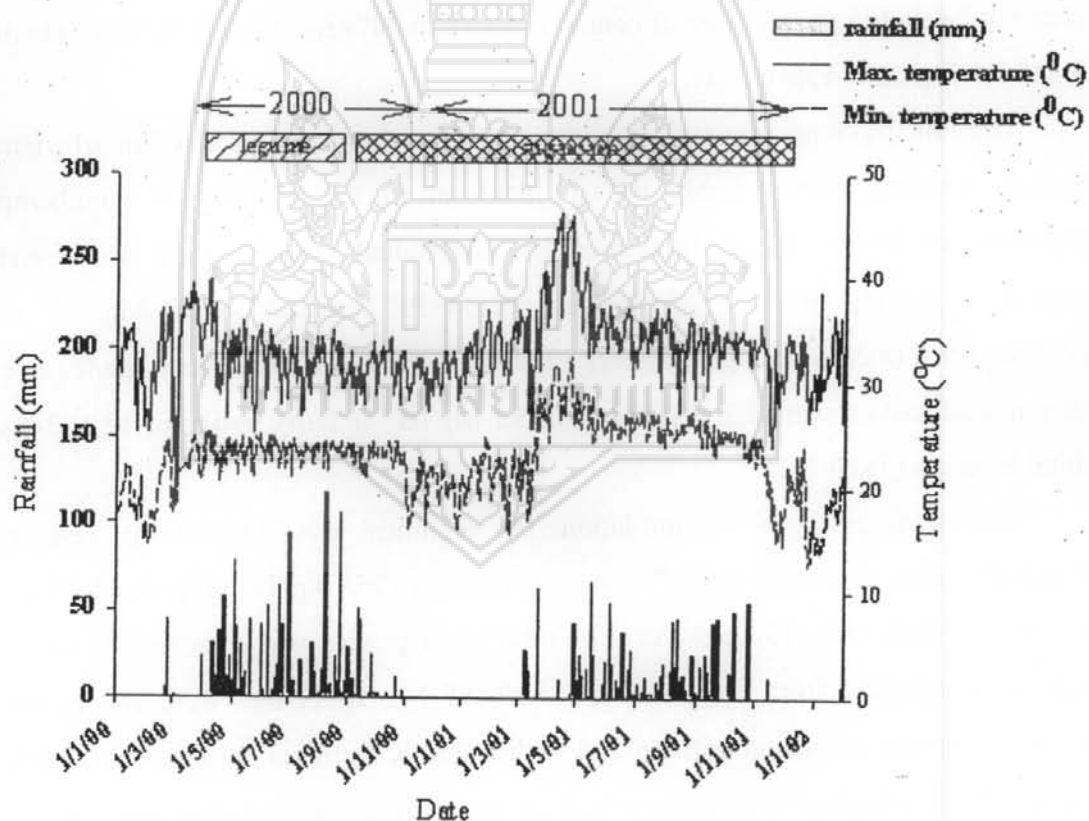


Figure 3.1 Daily rain fall, maximum and minimum temperature during legumes and sugarcane growing period

3.2 Biomass and nitrogen accumulation of legumes

High rainfall in 2000 resulted in poor germination of small seed size legumes, especially hairy indigo and *C. striata*. Gap filling was required to obtain good stand of these legumes. All legumes were harvested at 139 days after planting (DAP). The largest total recyclable biomass (stems, leaves and leaf litters) production of 10.7 Mg ha⁻¹ was obtained from sunnhemp (Table 3.2), followed by hairy indigo and pigeonpea, 9.5 and 9.4 Mg ha⁻¹, respectively. Jackbean and peanut without PK fertilizer yielded significantly less recyclable legume biomass (4.2 and 5.1 Mg ha⁻¹) than the other green manures. The fallow weed treatments obtained weed biomass ranged from 3.4 to 4.6 Mg ha⁻¹. The amount of recyclable residues in peanut without fertilizer application was 5.1 Mg ha⁻¹ and increased to 6.6 Mg ha⁻¹ with P and K application. The pod yields of peanut with and without P and K application were 3.3 and 3.1 Mg ha⁻¹, respectively (Table 3.2). The application of P and K fertilizers increased the shelling percentage of peanut from 72 to 74% resulting in grain yields of 2.2 and 2.5 Mg ha⁻¹, respectively.

Legume biomass accumulation was dominated by the production of stem materials, ranging from 2.3 Mg ha⁻¹ in jackbean to 8.2 Mg ha⁻¹ in sunnhemp accounting for 54 to 78% of total biomass. Green leaf material gave the lowest contribution ranging from 0.4 Mg ha⁻¹ in peanut+PK fertilizer to 2.0 Mg ha⁻¹ in pigeonpea (or 6 to 23% of total biomass). Leaf litters collected underneath the legume plants at final harvest were 1.2 in peanut and 3.1 Mg ha⁻¹ in hairy indigo or 12 to 34% of total biomass (Table 3.2).

The total nitrogen accumulation by legumes was highest in peanut, particularly when fertilized with P and K fertilizers (258 kg N ha⁻¹) (Table 3.2). However, 45-48% (83-115 kg N ha⁻¹) of total N in peanut was allocated to pods, which were removed from the field, thus only 88-142 kg N ha⁻¹ were left in the recyclable biomass of peanut without and with P and K fertilizers at planting (Table 3.2 and 3.5). The highest recyclable N in legume residues was found in hairy indigo (150 kg N ha⁻¹) followed by peanut + PK fertilizer (142 kg N ha⁻¹) sunnhemp (117 kg N ha⁻¹) and pigeonpea (114 kg N ha⁻¹). The amount of N recycled by weeds in the fallow plots was only 25 to 33 kg N ha⁻¹ (Table 3.2).

Table 3.2 Dry weight and N of recyclable and harvestable plant components, and their proportions relative to the totals of preceding legumes and weeds under the late rainy season sugarcane system.

Treatments	Dry Weight (kg ha ⁻¹)						
	Stems	Leaves	Leaf litter	Total residues	Total		
Peanut	3,370	596	1,175	5,141	8,247		
Peanut+PK	3,981	397	2,261	6,639	9,987		
Pigeonpea	5,409	2,007	1,965	9,381	9,381		
Jackbean	2,259	662	1,310	4,231	4,231		
Sunnhemp	8,187	1,205	1,276	10,668	10,668		
<i>C. striata</i>	3,436	1,541	1,228	6,205	62,05		
Hairy indigo	5,110	1,329	3,055	9,494	9,494		
Weed+N				3,452	3,452		
Weed				4,376	4,376		
Bare soil+N				4,612	4,612		
Bare soil				3,759	3,759		
F-test	**	**	ns	**	**		
CV (%)	40	45	66	46	42		
LSD ₀₅	2,711	737	1,730	4,118	4,119		
Preceding treatments	N quantity (kg N ha ⁻¹)						
	Stems	Leaves	Leaf litter	Total residues	Total		
Peanut	46	20	22	88	171		
Peanut+PK	69	16	58	142	258		
Pigeonpea	35	61	18	114	115		
Jackbean	18	25	16	59	59		
Sunnhemp	62	39	16	117	117		
<i>C. striata</i>	26	42	13	81	82		
Hairy indigo	54	52	44	150	150		
Weed+N				25	25		
Weed				32	32		
Bare soil+N				33	33		
Bare soil				27	27		
F-test	**	*	**	**	**		
CV (%)	39	48	61	47	38		
LSD ₀₅	26	26	24	53	54		
Legumes	Proportion of plant part relative to total dry weight or total N (w/w)						
	Dry weight			N			
	Stems	Leaves	Leaf litters	Stems	Leaves	Leaf litters	
Peanut	0.66	0.12	0.22	0.52	0.23	0.25	
Peanut+PK	0.61	0.06	0.33	0.48	0.11	0.41	
Pigeonpea	0.59	0.23	0.18	0.31	0.53	0.16	
Jackbean	0.54	0.16	0.30	0.31	0.42	0.27	
Sunnhemp	0.78	0.12	0.10	0.53	0.33	0.14	
<i>C. striata</i>	0.57	0.29	0.14	0.32	0.52	0.16	
Hairy indigo	0.54	0.15	0.31	0.36	0.35	0.29	
Treatments	Peanut Yield (kg ha ⁻¹)				N quantity in peanut yield (kg N ha ⁻¹)		
	Pod	Shell	Seed	%shelling	Pod	Shell	Seed
Peanut	3106	859	2247	72	83	7	76
Peanut+PK	3348	842	2506	74	115	7	108

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

For all species, N distribution in various plant components was different from dry weight biomass distribution. Nitrogen distribution ranged from 31 to 53% in stems, 11 to 53% in leaves, and 14 to 41% in leaf litter. When compared among plant components, stem N dominated in peanut (with and without P and K fertilizers) and sunnhemp with 48, 52 and 53% of total residue N, respectively. Leaf N dominated in pigeonpea, jackbean and *C. striata* with 53, 42 and 52% of total residue N, respectively. Leaf litter N of peanut with P and K fertilizers contributed the highest ratio of N than other legumes, due to the fact that leaf fall had just occurred prior to harvest. (Table 3.2)

Table 3.3 Nutrient quantities of preceding legumes and weeds.

Treatment	Nutrient in legume residues (kg ha ⁻¹)			
	P	K	Ca	Mg
Peanut	15	70	61	14
Peanut+PK	11	74	93	16
Pigeonpea	17	71	60	12
Jackbean	10	39	43	8
Sunnhemp	21	89	37	20
<i>C. striata</i>	13	84	22	12
Hairy indigo	22	115	100	15
Weed+N	9	46	19	4
Weeds	12	58	25	5
F-test	*	#	**	**
CV(%)	38	43	52	46
LSD _{0.05}	8	45	39	8

F-test ** = significantly different at $p < 0.01$, * = significantly different at $p < 0.05$, and # = significantly different at $p < 0.10$.

The other nutrient quantities in legume residues are presented in Table 3.3. Legumes had all nutrient quantities higher than fallow weed treatments. Hairy indigo residues showed the highest P, K and Ca quantities and was significantly different from the other legume residues while sunnhemp residues were low in Ca quantities,

but P and K were not significantly different from hairy indigo. Peanut and pigeonpea residues were also high in nutrient quantities which were not significantly different from the highest one (hairy indigo) except K quantities in peanut and P quantities in pigeonpea. Jackbean and *C. striata* residues were always significantly lower in most of nutrient quantities of the other legumes except K quantities in *C. striata* which was not significantly different from the other legumes.

3.3 Nitrogen fixation capability of legumes

At 48 DAP the nodules of the legume were significantly different in number and weight per plant between peanut and the other legumes (Table 3.4). Peanut had the highest number of nodules per plant (160 nodules plant⁻¹) while the other legumes ranged from 3 to 12 nodules plant⁻¹. Nodule weight per plant was highest in peanut (>241 mg plant⁻¹) while nodule weight of the other legumes ranged from 12 to 68 mg plant⁻¹. Nodule size considering from a nodule weight was largest in jackbean (5.52 mg nodule⁻¹) Nodule size of peanut with and without PK fertilizers and sunnhemp were significantly smaller than jackbean nodules with the nodule weights ranging from 1.65 mg nodule⁻¹ in sunnhemp and 1.69 mg nodule⁻¹ in peanut. Nodule of *C. striata* and pigeonpea were medium sized with the weight of 3.43 and 3.74 mg nodule⁻¹, respectively. Nodule occurrence was observed until harvesting time but in lower number than at 48 days except for peanut of which nodule number even increased (data not shown).

The proportion of N obtained from N₂ fixation was high, ranging from 61 to 81% of total N or 47 to 193 kg N ha⁻¹ (Table 3.5). *C. striata* contributed the lowest N from fixation process (61%, 47 kg N ha⁻¹). Among the green manures, the highest amount of N₂ fixed was by peanut with and without P and K fertilizers (193 and 137 kg N ha⁻¹, respectively), followed by hairy indigo, sunnhemp and pigeonpea. Although, adding P and K fertilizers to peanut tended to decrease N₂ fixation, total amount of N₂ fixed was still the highest, 193 kg N ha⁻¹. However, 45-48% of N in peanut was allocated to pods, which were removed from the field at harvest.

Table 3.4 Number and dry weight of nodules per plant and weight per nodule at 48 days after planting (DAP).

Treatments	Nodules 48 DAP		
	Number plant ⁻¹	Weight	
		mg plant ⁻¹	mg nodule ⁻¹
Peanut	160	241	1.69
Peanut+PK	159	244	1.66
Pigeonpea	12	52	3.74
Jackbean	11	68	5.52
Sunnhemp	7	12	1.65
<i>C. striata</i>	3	14	3.43
Hairy indigo	9	27	2.89
F-test	**	**	**
CV(%)	81	50	45
LSD _{0.05}	62	70	1.98

F-test ** = significantly different at $p < 0.01$.

The largest benefits regarding the recyclable N yield in the crop residues were obtained from hairy indigo and peanut with PK, (150 and 142 kg N ha⁻¹, respectively) and lowest from jackbean (59 kg N ha⁻¹). About 11-35 kg N ha⁻¹ of the recycled N was derived from the soil although P and K fertilizers addition to peanut had increased its N uptake from soil to 64 kg N ha⁻¹. The net N balance (e.g. N returned to the soil minus N exported in product) was negative (-3 kg N ha⁻¹) in non-nodulating peanut but positive for the nodulating green manures (47 to 122 kg N ha⁻¹) and the peanut (54 to 78 kg N ha⁻¹) treatments (Table 3.5).

Table 3.5 Total N contents in aboveground biomass, N₂ fixation and recyclable N of the preceding legumes.

Preceding Legumes	Total N (kg ha ⁻¹)	Economic yield (kg ha ⁻¹)	Mean atom % ¹⁵ N excess	N ₂ fixation ¹		N recyclable (kg N ha ⁻¹) ²		
				% of total N	kg N ha ⁻¹	From total (1)	From fixation (2)	From soil (1-2)
NN- peanut ³	24	3	0.185	0	0	21	- (3)	24
Peanut	171	83	0.037	80	137	88	54	34
Peanut+PK	257	115	0.047	74	193	142	78	64
Pigeonpea	115		0.041	78	90	115	90	25
Jackbean	59		0.035	81	48	59	48	11
Sunnhemp	117		0.039	79	91	117	91	26
<i>C. striata</i>	82		0.071	61	47	82	47	35
Hairy indigo	150		0.035	81	122	150	122	28
F-test	**		**	**	**	ns	ns	**
CV (%)	34		29	9	37	42	51	46
LSD _{0.05}	68		0.019	10	58	67	57	22

¹ Using the ¹⁵N dilution method.

² Recyclable N calculated as the fixed N₂ returned to the soil in aboveground biomass minus the soil N removed in economic yield.

³ Data were not included in ANOVA

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

3.4 Decomposition of plant residues

The quality of the residues including stems and leaves showed considerable variation among legume species (Table 3.6). The concentration of nitrogen (N) was highest in hairy indigo residue (2.01% N), followed by *C. striata*, peanut and sunnhemp (1.93, 1.86 and 1.72% N, respectively). Weed biomass contained lower N (0.87%) than the legume residues. Carbon (C) concentration was highest in pigeonpea residues (46%) and was lowest in weeds (39%), followed by peanut (41%). The narrowest C:N ratios ranging from 21 to 25 were in the residues of hairy indigo, peanut, *C. striata*, and sunnhemp in an increasing order. In contrast, the residues of pigeonpea and jackbean had C:N ratios of 32 and 37, respectively, and the widest C:N ratio of 46 was found in the weed biomass. ADF concentrations were highest in the

residues of pigeonpea (55%) followed by jackbean (51%) and sunnhemp (50%), and the lowest in the residues of *C. striata* (36%). Lignin concentrations were highest in *C. striata* and pigeonpea residues (14.5 and 13.7%, respectively), while they ranged from 7.8 to 9.7% in the other legume residues. Polyphenol concentration was highest in hairy indigo residues (2.77%), and lowest in sunnhemp (0.80%) and jackbean (0.92%), and they ranged from 1.37 to 1.62% in the rest of the legume residues and 1.20% in the weed. The concentration of phosphorus (P) was highest in hairy indigo residues, 0.41% P, followed by jackbean, 0.38% and peanut, 0.33%, while the other legume residues and weed had the range of 0.23-0.28% P. The concentration of potassium (K) was highest in the peanut, hairy indigo and *C. striata* residues, i.e. 4.3, 4.0 and 3.7% K, respectively and the lowest were in the residues of weeds and pigeonpea (1.36 and 1.53%, respectively).

Table 3.6 Chemical composition and C:N of legume residues in litter bags.

Residues	Concentration (%)							C:N
	N	C	P	K	ADF	lignin	polyphenol	
Peanut	1.86	41	0.33	4.28	41	8.6	1.62	22
Pigeonpea	1.44	46	0.23	1.53	56	13.7	1.37	32
Jackbean	1.19	44	0.38	2.87	51	9.7	0.92	37
Sunnhemp	1.72	43	0.27	2.34	50	8.1	0.80	25
<i>C. striata</i>	1.93	43	0.25	3.74	36	14.5	1.37	22
Hairy indigo	2.01	43	0.41	3.97	45	9.4	2.77	21
Weed	0.87	39	0.28	1.36	46	7.8	1.20	46

Soil moisture at litter bags burying position were lower than 2% at 77 DAB (Table 3.7), causing high variability of data. Therefore, the bags were not retrieved until 134 DAB when there was some rainfall. After the rain soil moisture was still low as presented at 147 DAB. Soil moisture reached close to its field capacity in May 2001 (>10%).

Table 3.7 Soil moisture at 0-20 cm depth at the burying position of the litter bags.

Treatments	Days after buried bags (DAB) and date of sampling				
	49	77	147	179	194
	Dec 4, 00	Jan 24, 01	Apr 2, 01	May 2, 01	May 17, 01
	<-----%----->				
Peanut	5.08	1.49	2.43	11.47	12.74
Peanut+PK	6.22	1.21	2.75	10.30	11.56
Pigeonpea	6.82	1.14	2.65	11.37	12.00
Jackbean	6.01	1.20	2.76	10.86	11.91
Sunnhemp	5.67	1.36	2.33	11.55	11.74
<i>C. striata</i>	5.49	0.97	2.28	10.96	11.05
Hairy indigo	5.38	1.03	2.85	11.26	11.12
Weed+N	6.49	1.24	2.34	10.96	11.45
Weed	5.96	1.05	2.77	10.48	11.72
Bare soil+N			2.30	10.33	12.21
Bare soil			3.28	10.32	11.75

Decomposition of residues was shown as the percentage relative to their initial weight of remaining residue weight in relation to time. Remaining weight of pigeonpea was highest in most of sampling dates throughout 358 DAB while the lowest remaining residue weight was peanut without P and K fertilizers during the first 21 DAB and sunnhemp during 134-194 DAB and *C. striata* during 215 to 301 DAB. These were significantly lower than the remaining weight of pigeonpea (Figure 3.2).

The decomposition was divided into two phases, 0-49 (where the dry period occurred) and 77-358 DAB (Fig 3.2 and Table 3.8). Exponential decay models describing remaining biomass at the first phase (0-49 DAB) were significant at $p < 0.001$, except for peanut with P and K fertilizers and weed residues that were significant at $p < 0.01$, but peanut without P and K fertilizers was significant at $p < 0.05$. All of them showed best fit with the coefficient of determination ranging from 0.82 to 0.99 during 0-49 DAB phase (Table 3.8). The exponential decay model described weight remaining during 77-358 DAP better with all the treatments

showing statistical significance at $p < 0.001$ and coefficients of determination ranging from 0.78 to 0.96 (Table 3.8).

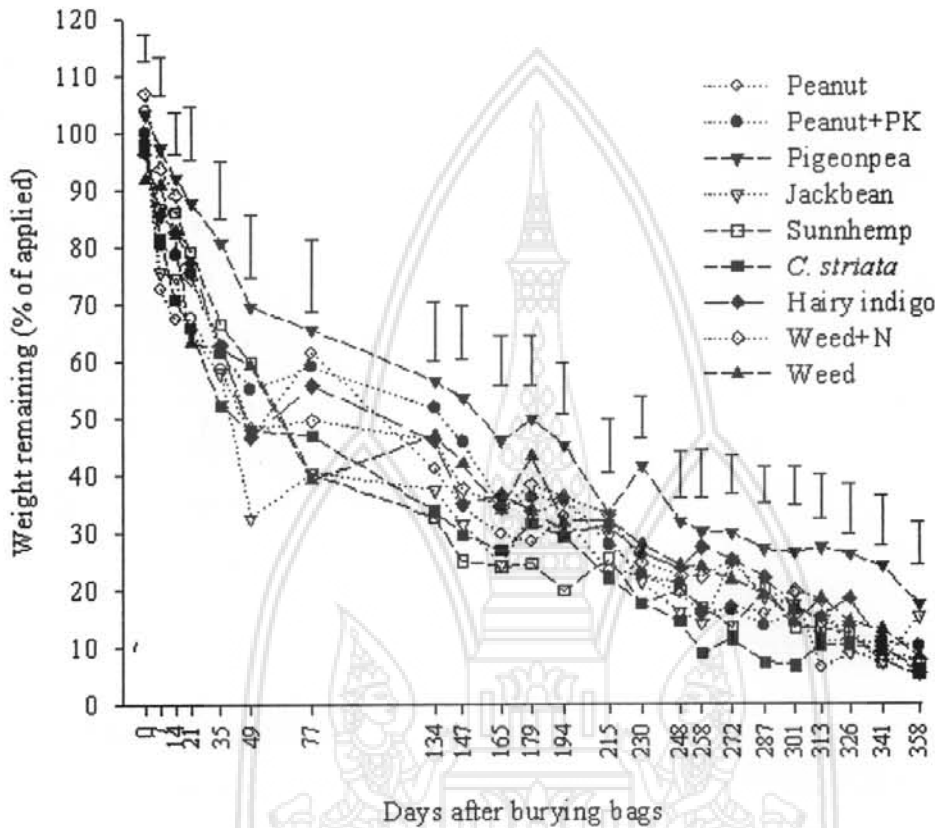


Figure 3.2 Weight remaining (% of applied) of retrieved legume residues and weeds in litter bags under field grown to sugarcane at various time intervals. Error bars indicate LSD at 0.05 level.

At 49 DAB weight remaining of legume residues were 32-69% of initial weights added. The decomposition rate constants (k_w) were highest in jackbean, 0.0180 day^{-1} , so the weight remaining was the lowest, 32%. The lowest k_w obtained in decomposition of pigeonpea residues, 0.0077 day^{-1} , leaving the highest remaining weight, 69% of initial added. Residue decomposition rate was accelerated by mineral N fertilizer application. This was supported by the result of weed residues incorporated in sugarcane plots with mineral N fertilizer application which decomposed faster ($k_w = 0.0158 \text{ day}^{-1}$) than those in the plots without mineral N fertilizer application ($k_w = 0.0108 \text{ day}^{-1}$). The weight remaining of weeds were 48 and

59% of the initial weight added when buried in the plots with and without fertilizer applications, respectively. Rate constants of weed residues were higher than sunnhemp ($kw = 0.0101 \text{ day}^{-1}$) and pigeonpea ($kw = 0.0077 \text{ day}^{-1}$) residues (Table 3.8).

Decomposition of the residues in the second phase (after 77 DAB) showed over 2-fold reduction with kw ranging from 0.0042 to 0.0069 day^{-1} . Pigeonpea residues also had the lowest kw , 0.0042 day^{-1} which was not significantly different from kw of jackbean and weed incorporated in plots without mineral N fertilizer. In this phase, kw was highest in the peanut with and without P and K fertilizers and *C. striata*, 0.0065-0.0069 day^{-1} . The rest of the residues decomposed at intermediate rates with kw ranging from 0.0050-0.0051 day^{-1} (Table 3.8).

Table 3.8 Rate constant ($kw \text{ day}^{-1}$) and coefficient of determination (R^2) from exponential decay model of decomposition of preceding legume and weed residues in buried litter bags during 0-49 and 77-358 days after burying bags (DAB).

	0-49 DAB		77-358 DAB		Damage bags from macro fauna (%)
	$kw \text{ (day}^{-1}\text{)}$	R^2	$kw \text{ (day}^{-1}\text{)}$	R^2	
Peanut	0.0152*	0.82	0.0069***	0.96	2.7
Peanut+PK	0.0118**	0.93	0.0065***	0.95	1.8
Pigeonpea	0.0077***	0.99	0.0042***	0.95	0.9
Jackbean	0.0180***	0.93	0.0043***	0.78	0.0
Sunnhemp	0.0101***	0.98	0.0050***	0.89	14.3
<i>C. striata</i>	0.0157***	0.96	0.0068***	0.92	0.8
Hairy indigo	0.0134***	0.97	0.0051***	0.92	12.5
Weed+N	0.0158***	0.99	0.0051***	0.89	2.7
Weed	0.0108**	0.85	0.0043***	0.80	2.7

*** = significantly different at $p < 0.001$, ** = significantly different at $p < 0.01$, and * = significantly different at $p < 0.05$.

Although the effects of soil macrofauna were not measured directly in this study, bags damaged by termite were counted. The highest damaged bags were found in bags containing sunnhemp and followed by hairy indigo residues, 14.3 and 12.5% of total number of buried bags, respectively, while the lowest damaged bags were found in those containing *C. striata* and pigeonpea and peanut 0.8 -2.7% of total buried bags and no damaged bags were found in jackbean residues (Table 3.8).

3.5 Nitrogen remaining in retrieved residues

The exponential decay model well described the difference in the remaining N in the retrieved residues (kn) with statistical significance at $p < 0.001$ and the coefficients of determination (R^2) ranging from 0.90 to 0.99 (Table 3.9).

Nitrogen remaining as percent initial N added of the legume and weed residues is presented in Figure 3.3 and the rate constant of N remaining (kn) are presented in Table 3.9. Pigeonpea residues showed higher N remaining than the other legume residues until 230 DAB with the lowest rate constants of N loss (0.0041 day^{-1}). The rate constant of N loss was highest in *C. striata*, 0.0076 day^{-1} , followed by sunnhemp (0.0075 day^{-1}). The rest of the legume residues had intermediate rate constants ranging from 0.0051 to 0.0059 day^{-1} . Similar to the rate constant of decomposition of weed residues buried in sugarcane plots with N fertilizer application, had higher rate constants of N loss (0.0056 day^{-1}) relative to the plot without N (0.0051 day^{-1}) (Table 3.9). After the bags were buried for 301 days, N remaining was highest in pigeonpea residues (26%) and was lowest in *C. striata* residues (7%). The other legume residues had N remaining 16-20% while remaining N of the weeds was 14%, but was 20% when N fertilizer was applied

There were no correlations between initial chemical characteristics and decomposition rate constants of both weight and N remaining except for ADF concentration that correlated with the rate constants of weight decomposition during 77-358 DAB with R^2 of 0.725 and p was 0.015. Besides, ADF concentration also showed correlation with percentage of N remaining at 301 DAB with R^2 of 0.84 and p was 0.0037 (data not shown).

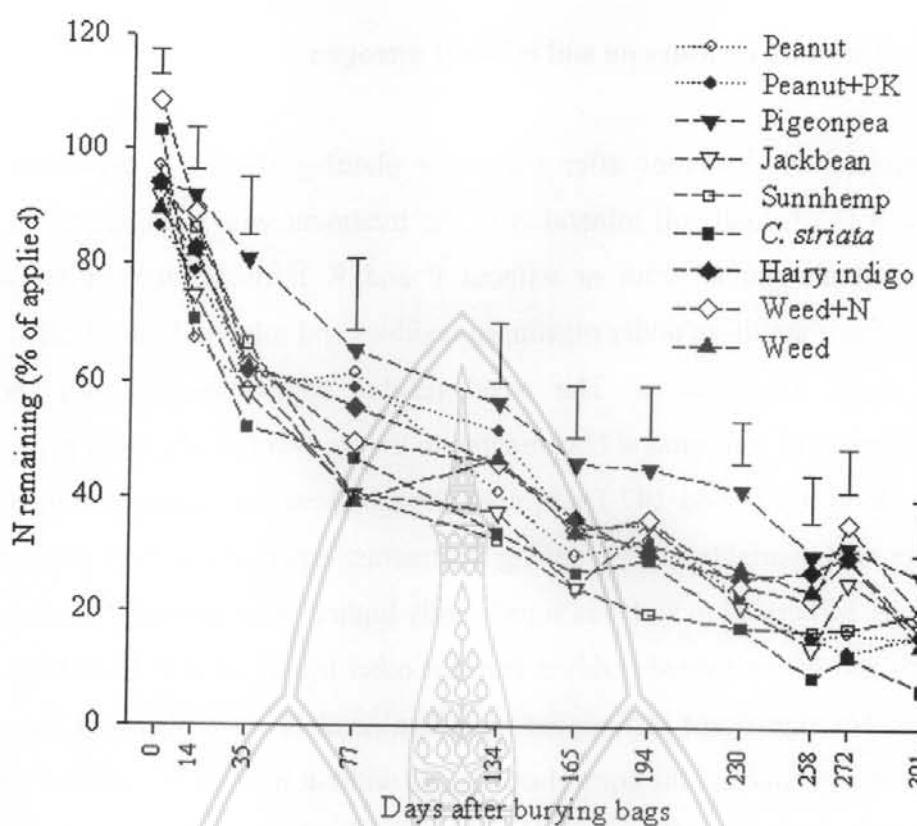


Figure 3.3 N remaining (% of applied) of retrieved legume residues and weeds in litter bags under field grown to sugarcane at various time intervals. Error bars indicate LSD at 0.05 level.

Table 3.9 Rate constant of N loss ($kn \text{ day}^{-1}$) and coefficient of determination (R^2) of retrieved legume and weed residues in litter bags.

Preceding legumes	$kn \text{ (day}^{-1}\text{)}$	R^2
Peanut	0.0058***	0.93
Peanut+PK	0.0054***	0.95
Pigeonpea	0.0041***	0.99
Jackbean	0.0059***	0.91
Sunnhemp	0.0075***	0.96
<i>C. striata</i>	0.0076***	0.92
Hairy indigo	0.0051***	0.96
Weed+N	0.0056***	0.90
Weed	0.0051***	0.91

*** Significantly different at $p < 0.001$.

3.6 Effect of legume residues on soil mineral nitrogen

Soil mineral N dynamics after sugarcane planting (DAP) is presented in Figure 3.4. At 8 DAP, total soil mineral N in the treatment with the application of peanut residues both planted with or without P and K fertilizer application was significantly higher than those under pigeonpea residues and mineral N fertilizer with and without weed incorporation. The weed residue application did not show significant difference in soil mineral N compared to the application of peanut residues.

After a long dry period 147 DAP, even though there was some rainfall, soil moisture content was variable (2-7%) among treatments, especially at 0-15 cm depth (data not shown). Mineral N in soil was significantly higher under mineral N fertilizer treatments with and without weed residues than the other treatment at 0-20 and 20-40 cm soil depths. No significant differences in soil mineral N were observed among legume residue treatments and the control treatments without mineral N fertilizer with and without incorporated weed (bare soil+N and bare soil) (Figure 3.4).

When soil moisture was not a limiting factor, at 224 DAP, mineral N in soil was highest in the mineral N fertilizer treatment without weed (bare soil+N), followed by peanut+PK and the bare soil treatments. All treatments with plant residues either legume residues or weeds resulted in N immobilization except for that under peanut+PK that showed no significant difference relative to the bare soil treatment (Figure 3.4).

At 287 DAP, one month after 47 kg ha^{-1} each of N, P_2O_5 and K_2O were applied, soil mineral N was very low ($<20 \text{ kg N ha}^{-1}$) and no significant differences among treatments on the first 3 soil layers were observed. Higher soil mineral N was obtained from the application of weed alone than the other treatment at 60-80 cm depths, resulting in highest total mineral N under weed application (Figure 3.4).

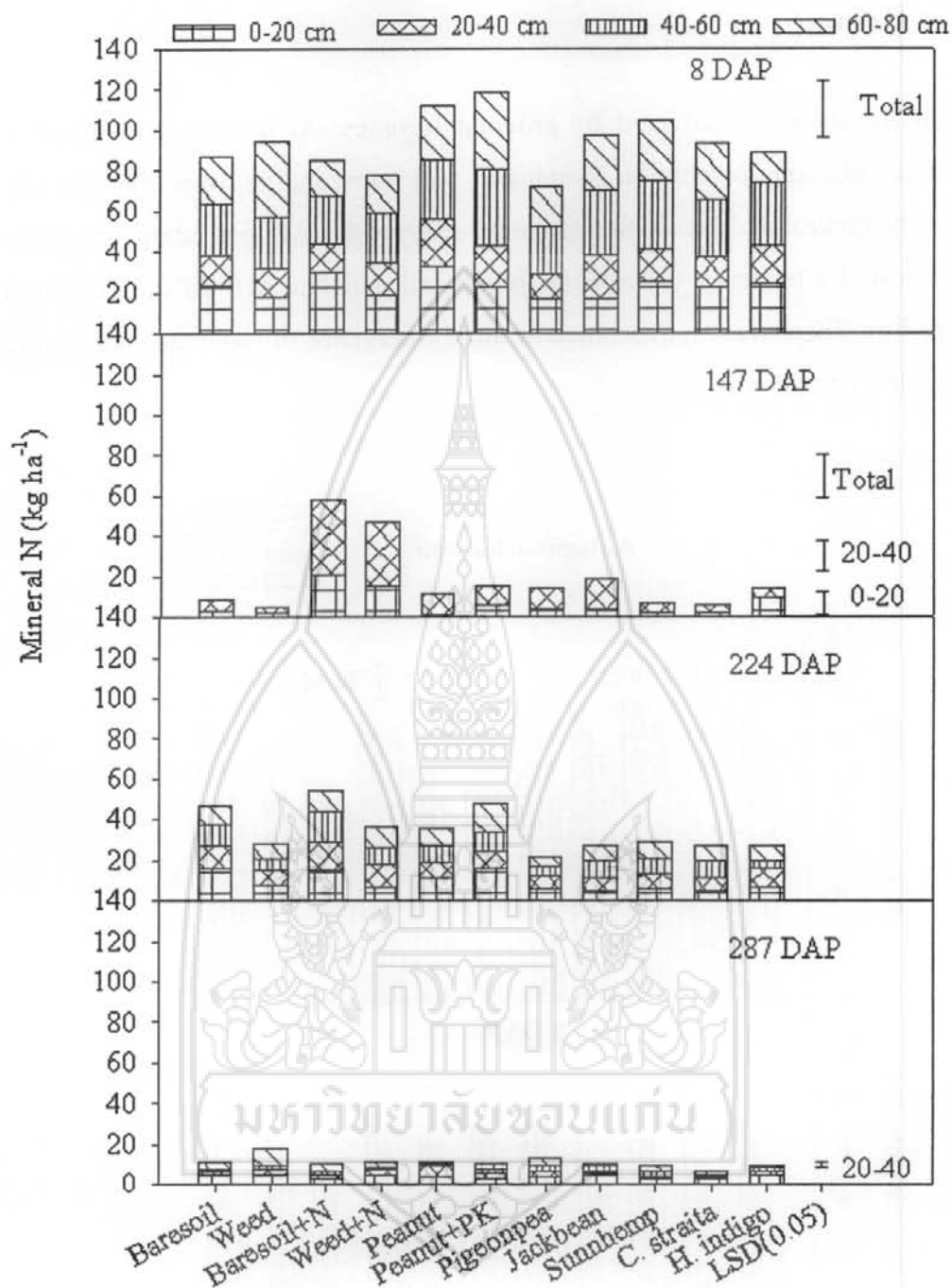


Figure 3.4 Soil mineral N distribution in 4 soil layers at 8, 147, 224 and 287 days after sugarcane planting (DAP) as affected by preceding legumes and the control soil managements. Error bars indicate LSD at 0.05 level of the individual soil layer or total (0-80 cm).

3.7 Soil moisture

Soil moisture was affected by growing legumes. At harvest, soil moisture contents after planting pigeonpea, sunnhemp and hairy indigo were significantly lower than the control and jackbean treatments. Even at 8 DAP, preceding sunnhemp treatment showed a tendency to have the lowest soil moisture at 0-20 and 20-40 cm depth (Fig. 3.5). There was no difference in shoot emergence of sugarcane among the treatments (data not shown).

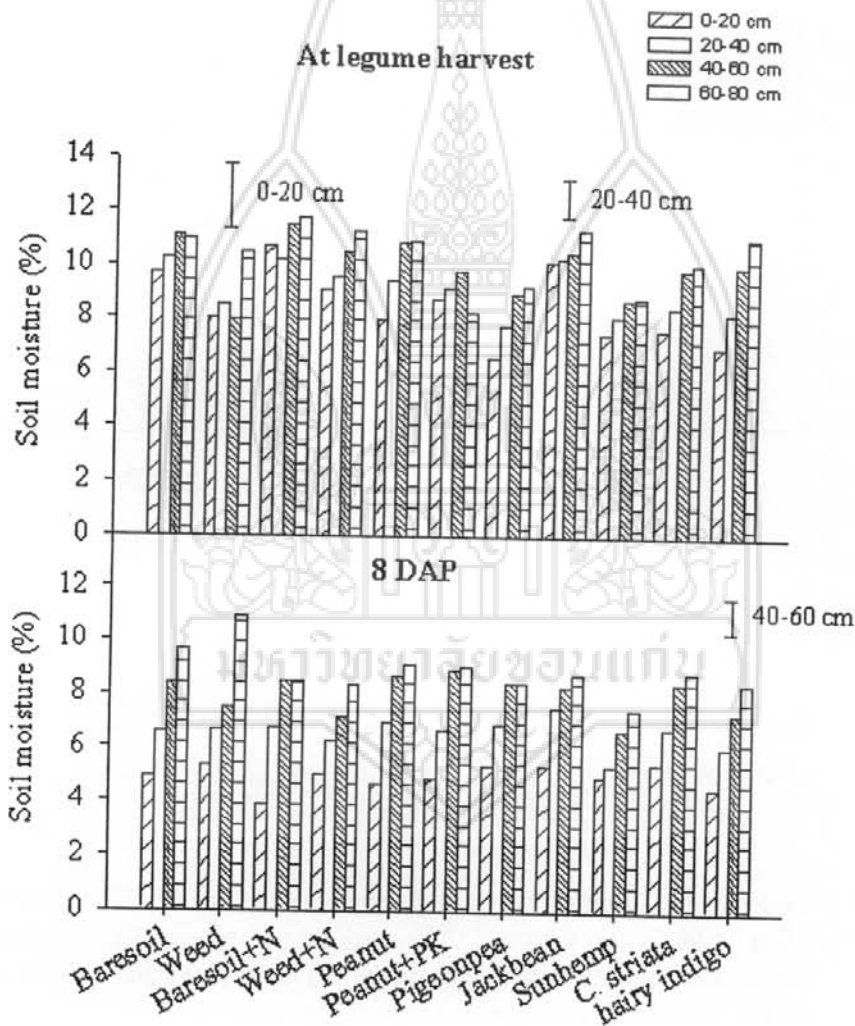


Figure 3.5 Soil moisture at 4 soil layers at legume harvesting date and 8 days after sugarcane planting (DAP) as affected by preceding legumes and soil managements. Error bars indicate LSD at 0.05 level of legume harvest date at 0-20 cm and 20-40 cm soil depths and of 8 DAP at 40-60 cm soil depths.

3.8 Sugarcane growth and yield

3.8.1 Biomass accumulation and nutrient uptake

At 151 DAP, dry weight of cane, trash and total biomass had a tendency to increased over the bare soil and weed treatment under the legume residues incorporation, except the pigeonpea residues. The biomass was not affected by weed application but was markedly increased with mineral N fertilizer applications (N and weed+N) (Table 3.10).

At 285 DAP, dry weight of cane and total biomass of sugarcane significantly increased over the bare soil under the mineral N fertilizer application (bare soil+N). Meanwhile application of weeds reduced sugarcane biomass (Table 3.10).

Table 3.10 Biomass of cane and trash of sugarcane at 151, 285 and 443 days after sugarcane planting (DAP) as affected by preceding legumes and the control soil managements.

Legumes	151 DAP			285 DAP			443 DAP(Harvest)		
	Cane	Trash	Total	Cane	Trash	Total	Cane	Trash	Total
	-----Dry biomass (Mg ha ⁻¹)----->								
Peanut	2.76	6.16	8.92	8.74	8.88	17.62	33.15	10.37	43.52
Peanut+PK	2.81	6.60	9.41	6.33	8.22	14.55	30.00	11.14	41.14
Pigeonpea	1.66	4.60	6.26	6.07	7.84	13.91	27.75	9.60	37.35
Jackbean	2.37	5.45	7.82	7.05	8.56	15.61	26.69	10.34	37.03
Sunnhemp	2.23	5.92	8.15	6.87	8.21	15.08	31.16	10.01	41.17
<i>C. striata</i>	2.70	6.24	8.94	6.80	8.32	15.12	29.49	10.37	39.86
Hairy indigo	2.10	6.16	8.26	7.44	8.66	16.10	37.50	11.64	49.14
Weed+N	2.39	5.65	8.04	9.37	9.13	18.50	30.94	11.18	42.12
Weed	1.79	4.86	6.65	4.72	6.75	11.47	23.40	9.27	32.67
Bare soil+N	3.46	7.47	10.93	9.84	10.29	20.13	33.25	11.52	44.77
Bare soil	1.74	4.90	6.64	7.15	8.83	15.98	26.73	10.13	36.86
F-test	ns	ns	ns	*	ns	#	ns	ns	ns
CV (%)	44	23	28	27	18	21	21	25	19
LSD _{0.05}	1.51	1.90	3.35	2.81	2.20	4.70	9.21	3.83	10.94

F-test * = significantly different at $p < 0.05$, # = significantly different at $p < 0.10$ and ns = not significantly different at $p > 0.05$.

At 443 DAT, the final harvest, sugarcane biomass increased under legume residues and mineral N fertilizer treatments, while decreased under weed incorporation relative to the bare soil. Application of hairy indigo gave higher sugarcane biomass than the mineral N fertilizer treatments. However, no significant differences were observed (Table 3.10).

Nutrient uptakes of sugarcane harvested at 151 DAP are shown in Table 3.11. Weed application resulted in reduction of N, K, Ca and Mg uptake in cane, and all N, P, K, Ca and Mg in trash and total biomass relative to the bare soil treatment. In contrary, most of legume residue applications resulted in increased uptakes of all nutrients in cane, trash and total of sugarcane biomass except for uptake of P and K in the pigeonpea and that of Ca in the jackbean. Among 11 treatments, the highest uptakes of all nutrients were obtained in the mineral N fertilizer treatment without plant residues (bare soil+N). However, weed application reduced all nutrient uptakes by sugarcane relative to the mineral N fertilizer treatment.

Nutrient uptakes of sugarcane at final harvest, 443 DAP, are presented in Table 3.12. For cane, the lowest uptakes of N, P, K and Mg were obtained in the control treatments without N application irrespective of weed incorporation while Ca uptake was lowest under peanut without P and K fertilizers. The highest uptakes of N, P and Mg were found under the application of hairy indigo residues, while K uptake was highest under peanut without P and K fertilizers and Ca uptake was highest under the mineral N fertilizer with weed incorporation (weed+N). The lowest nutrient uptakes were mostly under no mineral N fertilizer with weed incorporation (weed), except for Ca uptake, which was lowest under the application of peanut without P and K application.

In aboveground components (trash), the highest N, P, K and Mg uptakes were obtained in mineral N fertilizer application without weed incorporation (bare soil+N) except for Ca uptake which was highest under pigeonpea residue application (Table 3.12). Application of legume residues only had a tendency to increase all nutrient uptakes (except Ca) in trash biomass over that of weed without mineral N fertilizer application (weed).

As for nutrient uptake in total biomass, the highest N and P uptakes were obtained under hairy indigo application while K uptake was highest in peanut without

P and K fertilizer treatment. Meanwhile, the highest Ca and Mg uptakes were found under the application of mineral N fertilizer with weed (weed+N) and without weed (bare soil+N) incorporation. The lowest nutrient uptakes were found under the application of weed without mineral N fertilizer. Adding legume residues increased N, K and Mg uptakes over the control bare soil (Table 3.12).

3.8.2 Sugarcane yield at final harvest

Application of legume residues increased millable cane yield ($94-105 \text{ Mg ha}^{-1}$) compared to the unamended soil treatment (bare soil) (87 Mg ha^{-1}) (Table 3.13). However, significant increases in yields were only observed in the application of peanut with and without P and K fertilizers, jackbean and hairy indigo residue treatments. In contrast, addition of weed caused a reduction of millable cane yield (81 Mg ha^{-1}) compared to unamended soil and all applications of legume residues. Mineral N fertilizer application increased yield of sugarcane significantly without weed (112 Mg ha^{-1}) and with weed (106 Mg ha^{-1}).

Application of legume residues, weed and mineral N fertilizer at planting had a tendency to reduce sugar (CCS) (Table 3.13). Weed application treatment (weed) were noted to reduce CCS and it was reduced more with mineral N fertilizer (weed+N) application. Hairy indigo and peanut with P and K fertilizer treatments led to higher CCS than the other treatments. However, there were no significant differences observed. Sugar yields were higher under legume residue and mineral N fertilizer applications but lower under weed application relative to the control (bare soil). The highest sugar yield was found under mineral N fertilizer application without weed application (bare soil+N).

Trash dry weight increased under some legume residue application (hairy indigo and peanut with P and K fertilizer application), and drastically increased with mineral N fertilizer (bare soil +N). In contrast, weed residue application (weed) resulted in a reduction of trash dry weight, which was increased with mineral N fertilizer application (weed+N) relative to bare soil treatment.

Cane number was not significantly different among the treatments. However, it was reduced under weed and jackbean residue application and also without any sources of N application (bare soil).

Table 3.11 Nutrient uptake in cane, above ground biomass (trash) and total biomass of sugarcane at 151 days after sugarcane planting (DAP) as affected by preceding legume residues and the control soil treatments.

Treatment	Nutrient uptake (kg ha ⁻¹)				
	N	P	K	Ca	Mg
	←-----Cane----->				
Peanut	18.24	4.58	52.03	6.57	5.96
Peanut+PK	15.27	3.86	39.74	6.18	5.33
Pigeonpea	10.51	2.82	29.57	4.90	3.96
Jackbean	12.01	3.40	38.02	4.27	4.33
Sunnhemp	13.14	3.79	41.26	5.40	5.21
<i>C. striata</i>	15.01	4.23	43.65	5.18	5.47
Hairy indigo	12.46	3.56	36.88	4.67	4.14
Weed+N	14.73	4.02	46.08	5.21	4.88
Weed	8.89	2.98	25.57	3.47	3.43
Bare soil+N	19.97	5.52	61.97	7.30	7.52
Bare soil	9.10	2.98	27.53	3.79	3.41
F-test	ns	ns	ns	ns	ns
CV(%)	42	36	45	38	47
LSD _{0.05}	44.8	1.98	26	2.82	3.3
	←-----Trash----->				
Peanut	51.77	10.99	96.44	33.44	10.66
Peanut+PK	53.06	10.28	91.90	31.78	11.18
Pigeonpea	42.24	8.44	74.09	26.49	8.05
Jackbean	46.31	8.65	90.84	23.30	9.21
Sunnhemp	55.32	10.55	101.32	31.52	10.77
<i>C. striata</i>	52.46	9.71	101.26	29.82	11.18
Hairy indigo	54.69	10.71	101.93	31.94	9.76
Weed+N	48.83	9.41	90.93	27.40	9.25
Weed	37.80	7.91	73.67	22.62	7.67
Bare soil+N	64.80	12.00	117.81	35.11	13.23
Bare soil	40.57	8.80	82.50	24.95	8.14
F-test	*	*	#	*	ns
CV(%)	20	16	20	18	28
LSD _{0.05}	14.6	2.2	27	7	4
	←-----Total----->				
Peanut	70.01	15.57	148.46	40.01	16.63
Peanut+PK	68.33	14.14	131.64	37.96	16.50
Pigeonpea	52.75	11.27	103.65	31.38	12.01
Jackbean	58.32	12.05	128.86	27.58	13.54
Sunnhemp	68.45	14.34	142.58	36.93	15.98
<i>C. striata</i>	67.47	13.94	144.91	35.00	16.64
Hairy indigo	67.14	14.27	138.81	36.61	13.90
Weed+N	63.56	13.43	137.01	32.61	14.13
Weed	46.69	10.89	99.24	26.09	11.10
Bare soil+N	84.78	17.52	179.77	42.40	20.76
Bare soil	49.67	11.78	110.03	28.75	11.54
F-test	#	*	ns	*	ns
CV(%)	24	20	26	19	38
LSD _{0.05}	22	3.9	50	9.2	2.82

F-test * = significantly different at $p < 0.05$, # = significantly different at $p < 0.10$, and ns = not significantly different at $p > 0.05$.

Table 3.12 Nutrient uptake in cane, above ground biomass (trash) and total biomass of sugarcane at 443 days after sugarcane planting (DAP) as affected by preceding legume residues and the control soil treatments.

Treatment	Nutrient uptake (kg ha ⁻¹)				
	N	P	K	Ca	Mg
	←-----Cane----->				
Peanut	61.10	26.37	79.76	3.28	22.63
Peanut+PK	55.03	16.25	41.55	7.24	24.01
Pigeonpea	46.31	20.03	42.32	5.68	22.45
Jackbean	54.24	19.85	32.43	6.06	25.15
Sunnhemp	47.24	18.79	33.92	7.31	26.88
<i>C. striata</i>	43.79	20.22	47.40	5.98	24.55
Hairy indigo	65.98	27.09	65.23	6.84	28.69
Weed+N	48.10	24.94	65.77	9.79	25.19
Weed	33.62	14.64	26.38	5.38	17.98
Bare soil+N	60.04	23.14	46.52	7.03	27.56
Bare soil	37.94	19.89	31.06	7.16	20.89
F-test	#	*	ns	ns	ns
CV(%)	29	26	66	48	32
LSD _{0.05}	21	8	44	5	11
	←-----Trash----->				
Peanut	34.00	6.19	83.14	5.61	12.22
Peanut+PK	40.23	6.61	52.54	6.62	13.19
Pigeonpea	36.48	6.16	57.11	6.94	15.13
Jackbean	41.54	6.56	74.51	5.22	13.04
Sunnhemp	37.97	6.46	88.50	4.94	11.96
<i>C. striata</i>	35.77	6.01	66.17	5.63	12.85
Hairy indigo	40.90	7.20	75.29	6.39	12.88
Weed+N	40.88	6.53	81.58	5.50	10.11
Weed	27.24	5.18	51.14	5.91	12.15
Bare soil+N	42.87	7.65	95.45	4.51	15.76
Bare soil	38.74	6.47	60.00	6.24	10.11
F-test	ns	ns	ns	ns	ns
CV(%)	24	23	53	45	36
LSD _{0.05}	13	2.1	54	3.7	6.6
	←-----Total----->				
Peanut	95.09	32.56	162.90	8.89	34.85
Peanut+PK	95.26	22.86	94.09	13.86	37.20
Pigeonpea	82.79	26.19	99.43	12.62	37.57
Jackbean	95.77	26.41	106.94	11.66	38.19
Sunnhemp	85.21	25.26	122.42	12.25	38.84
<i>C. striata</i>	79.56	26.23	113.57	11.61	37.40
Hairy indigo	106.88	34.29	140.53	13.23	41.57
Weed+N	88.99	31.47	147.35	15.29	35.31
Weed	60.87	19.83	77.52	11.28	30.13
Bare soil+N	102.91	30.78	141.97	11.54	43.32
Bare soil	76.69	26.36	91.06	13.40	31.00
F-test	ns	#	ns	ns	ns
CV(%)	22	22	50	33	28
LSD _{0.05}	28	8.7	86	6	15

F-test * = significantly different at $p < 0.05$, # = significantly different at $p < 0.10$ and ns = not significantly different at $p > 0.05$.

Table 3.13 Cane and sugar yield, CCS, trash biomass and cane number at final harvest as affected by preceding legume residues and the control soil treatments.

Legumes	Millable cane (Mg ha ⁻¹)	CCS	Sugar yield (Mg ha ⁻¹)	Trash DW (Mg ha ⁻¹)	Cane number (cane ha ⁻¹)
Peanut	105	11.98	12.58	8.05	59,816
Peanut+PK	100	13.07	13.20	11.14	61,329
Pigeonpea	96	12.90	12.46	9.59	60,852
Jackbean	102	12.26	11.73	10.34 *	53,744
Sunnhemp	94	12.38	11.90	10.01	55,859
<i>C. striata</i>	94	12.71	12.04	10.37	57,586
Hairy indigo	102	13.08	13.34	11.64	57,884
Weed+N	106	11.31	11.96	11.18	59,068
Weed	81	12.00	9.80	9.27	53,064
Bare soil+N	112	12.75	14.27	11.51	58,891
Bare soil	87	12.85	11.18	10.13	54,535
F-test	*	ns	#	ns	ns
CV (%)	11.09	8.9	14	8.9	8.65
LSD _{0.05}	11	1.55	2.47	1.6	9,791

F-test * = significantly different at $p < 0.05$, # = significantly different at $p < 0.10$ and ns = not significantly different at $p > 0.05$.

In conclusion, millable cane yield ranged from 81-112 Mg ha⁻¹ with total aboveground biomass dry matter was in the range of 33-49 Mg ha⁻¹. Total nutrient uptakes were N 61-107, P 20-34, K 77-163, Ca 9-15 and Mg 30-43 kg ha⁻¹. Nutrients removed along with millable cane were N 34-66, P 16-27, K 26-80, Ca 3-10 and Mg 18-29 kg ha⁻¹.

3.9 ^{15}N recoveries

The legume ^{15}N distribution in soil at 180 DAP was mostly detected in the soil profile, 39-62%, while in sugarcane plant, it was 5.5-15.0%, and 2.7-9.3% still remained in the undecomposable residues (Table 3.14).

Recovery of ^{15}N in sugarcane plant was highest in jackbean residues (15.0%), followed by the application of sunnhemp (13.7%). The lowest N contribution to sugarcane from legume residues came from peanut residues (5.5%) and followed by pigeonpea residues (9.0%). They were equivalent to 7.9, 10.5, 10.4 and 16.5 kg N ha⁻¹ under the application of peanut, pigeonpea, jackbean and sunnhemp residues, respectively (Table 3.14). The main recovery of N was found in soil layers, the highest of which was in 0-20 cm depth and they ranged from 31 to 43%. In sub-soil layer (20-40 cm), ^{15}N recovery was approximately 6%, except, peanut treatment (2% ^{15}N recovery). At 40-60 cm depth, 4% of ^{15}N recovery was found under the application of pigeonpea and jackbean residues and only 2% under the application of peanut and sunnhemp residues. At 60-80 cm soil depth, the highest ^{15}N recovery was found under the application of jackbean residues (9%) and were low under the application of the rest of the legume residues (0.7-2.2%).

^{15}N still remained in non-decomposable residues that were highest in jackbean and pigeonpea residues (9%) and followed by sunnhemp residues (5%) and was lowest in peanut residue application (3%).

Total ^{15}N recovery was highest with the incorporation of jackbean residues (87%) followed by pigeonpea, sunnhemp and peanut residues (62, 60 and 47%, respectively) (Table 3.14).

Table 3.14 Recovery (% of ^{15}N initially added) in sugarcane plants, legume residues remaining and soil at different layers at 180 days after sugarcane planting (DAP).

Preceding legumes	Sugarcane plant	Legume remaining residues	Soil depth (cm)				Total in soil	Total N recovery
			0-20	20-40	40-60	60-80		
<-----% of initial N added----->								
Peanut	5.5 (7.9) ¹	2.7	34.4	2.0	2.0	0.7	39.1	47.3
Pigeonpea	9.0 (10.5)	9.1	30.8	6.8	4.4	2.2	44.2	62.3
Jackbean	15.0 (10.4)	9.3	43.0	6.1	4.5	8.9	62.4	86.7
Sunnhemp	13.7 (16.5)	5.1	32.0	6.3	1.9	1.3	41.4	60.2
F-test	*	*	ns	**	**	**	**	**
CV(%)	32	48	17	13	16	17	13	19
LSD _{0.05}	5.5	5.0	9.7	1.1	0.8	0.9	9.8	12.9

¹ N recovery in sugarcane (kg N ha^{-1}).

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

3.10 N use efficiency

Nitrogen use efficiency (NUE) was significantly different at 151 days and at harvest. At 151 DAP, it was highest under incorporated weed ($0.26 \text{ Mg DW kg}^{-1} \text{ N}$), followed by unamended treatment (bare soil, $0.25 \text{ Mg DW kg}^{-1} \text{ N}$), and was lowest under application of peanut, pigeonpea, sunnhemp and hairy indigo residues ($0.22 \text{ Mg DW kg}^{-1} \text{ N}$) (Table 3.15). At 285 DAP, NUE was not significantly different that ranged from 0.18 to $0.20 \text{ Mg DW kg}^{-1} \text{ N}$. At harvest, it was highest in the application of sunnhemp residues ($0.51 \text{ Mg DW kg}^{-1} \text{ N}$) but was lowest in the application of jackbean ($0.40 \text{ Mg DW kg}^{-1} \text{ N}$) (Table 3.15).

The apparent fertilizer use efficiency (AFUE) showed different effect of the treatments at 151 DAP. It was highest under the application of mineral N fertilizer without weed (bare soil+N, 44.9%) while there were not significant differences in the rest of the treatments. AFUE was also highest with bare soil+N treatment at 285 DAP (40.5%) and at harvest (37.5%), though, no significant differences of the treatments were observed. Legume residue treatments obtained low AFUE in

comparison with bare soil +N treatment in all sampling dates. Among the legumes, peanut without P and K fertilizers obtained the highest AFUE at 151 DAP (17.9%) and 285 DAP (23.2%) while jackbean and hairy indigo obtained the highest AFUE at harvest (24.3%) (Table 3.15).

Internal efficiency of N (IEN) showed significant differences among treatments at harvest. At harvest, application of sunnhemp residues was highest in IEN (0.38 Mg DW kg⁻¹ N) which was significantly higher than those application of jackbean, peanut+PK and hairy indigo residues (0.29-0.32 Mg DW kg⁻¹ N) (Table 3.15).

Agronomic yield N use efficiency (ANUE) showed significant differences among treatments all sampling dates. It was highest under mineral N fertilizer application (bare soil+N) at 151 DAP (0.23 Mg DW kg⁻¹ N) while was highest under the bare soil treatment at 285 DAP (0.34 Mg DW kg⁻¹ N) and at harvest (0.79 Mg DW kg⁻¹ N). At 151 DAP, incorporated legume residues or weed with mineral N fertilizer (weed+N) caused a significant reduction in ANUE. Similarly, at 285 DAP and harvest addition of mineral N fertilizer, weed and legume residues also caused significantly reduction in ANUE from the bare soil treatment (Table 3.15).

Table 3.15 Nitrogen use efficiency (NUE), apparent fertilizer use efficiency (AFUE), internal efficiency of N (IEN) and agronomic yield nitrogen use efficiency (ANUE) of sugarcane at different growth stages as affected by preceding legumes and the control soil treatments.

Treatments	NUE (Mg DW kg ⁻¹ N)			AFUE (%)			IEN (Mg DW kg ⁻¹ N)			ANUE (Mg DW kg ⁻¹ N)		
	DAP			DAP			DAP			DAP		
	151	285	harvest	151	285	harvest	151	285	harvest	151	285	harvest
Peanut	0.22	0.20	0.46	17.9	23.2	21.2	0.06	0.10	0.36	0.10	0.13	0.32
Peanut+PK	0.24	0.18	0.43	13.5	12.7	16.2	0.07	0.08	0.31	0.07	0.08	0.22
Pigeonpea	0.22	0.16	0.43	6.1	17.1	13.3	0.06	0.07	0.32	0.05	0.09	0.23
Jackbean	0.24	0.20	0.40	8.8	20.5	24.3	0.07	0.09	0.29	0.13	0.15	0.35
Sunnhemp	0.22	0.18	0.51	13.5	15.9	8.7	0.06	0.08	0.38	0.07	0.09	0.25
<i>C. striata</i>	0.24	0.20	0.47	11.3	14.4	13.9	0.07	0.09	0.35	0.11	0.12	0.31
Hairy indigo	0.22	0.19	0.43	12.3	14.4	24.3	0.05	0.09	0.32	0.05	0.08	0.25
Weed+N	0.23	0.20	0.45	8.9	30.0	22.5	0.06	0.10	0.33	0.10	0.15	0.34
Weed	0.26	0.20	0.49	44.9	40.50	37.5	0.07	0.08	0.35	0.22	0.15	0.42
Bare soil+N	0.24	0.21	0.44				0.07	0.10	0.33	0.23	0.21	0.48
Bare soil	0.25	0.19	0.47				0.07	0.09	0.34		0.34	0.79
F-test	*	ns	**	*	ns	ns	ns	ns	*	**	**	**
C.V. (%)	8.4	13.1	3.96	89.4	61.5	60.4	22.1	19.0	10.3	35.3	21.2	17.6
LSD _{0.05}	0.03	0.04	0.01	19.9	18.8	17.8	0.02	0.02	0.05	0.06	0.04	0.09

F-test ** = significantly different at $p < 0.01$, * = significantly different at $p < 0.05$, and ns = not significantly different at ($p > 0.05$).

4. Discussion

4.1 Legumes as green manures

4.1.1 Biomass production

Legumes used for green manures should produce high biomass and N content. Cherr et al. (2006a) reviewed the potential use of many plant species and reported that biomass production of most species used in this study ranged from 4.4 to 12.1 Mg ha⁻¹ with N quantities of 58 to 277 kg N ha⁻¹. In this study, biomass production ranged from 4.2 to 10.7 Mg ha⁻¹ and N quantities ranged from 59 to 150 kg N ha⁻¹. Therefore, these legumes have a potential to be used as green manures and N resource for succeeding crops. However, decomposition and N release of legume residues must match with N demand of succeeding crops. Among the green manure legumes jackbean and *C. striata* showed poor growth with low biomass production (4.2 and 6.2 Mg ha⁻¹). It is noted that the plot used in this study was previously grown to sugarcane and sugarcane trash was incorporated into the soil before planting green manure. Decomposition of sugarcane residues might have some detrimental effect on jackbean and *C. striata* growth and yield. However, these two legumes have been observed to grow well in low fertility northeast soils without preceding sugarcane crop.

Early heavy rain resulted in poor germination of small seed legumes e.g. hairy indigo and *C. striata* and required gap filling. The slow initial growth of pigeonpea and sunnhemp resulted in a high level of soil erosion especially when there was early heavy rainfall. As a consequence, pigeonpea, sunnhemp, *C. striata* and hairy indigo may not be suitable for controlling soil erosion in early heavy rainfall areas. Jackbean and peanut are more suitable for such a purpose.

Ramos et al. (2001), Seneratne and Ratnasinghe (1995) and Steinmaier and Ngoliya (2001) reported that sunnhemp at 8-14 weeks had biomass of 6.1-12.1 Mg ha⁻¹ and N 161-227 kg N ha⁻¹. In this study, even though higher biomass production was obtained (11.7 Mg ha⁻¹), its N contribution was only 117 kg N ha⁻¹. This is because its main component was stalk which was low in N concentration. Biomass of the stalk was 8.2 Mg ha⁻¹ but it contributed only 62 kg N ha⁻¹. Peanut gave lower

recycled biomass production (5.1-6.6 Mg ha⁻¹) than the other legumes except for jackbean, however, N contributions were higher, 88-142 kg N ha⁻¹. Peanut with P and K application showed high N content in leaf litters, because the leaves had just senesced prior to harvest. Promsakha Na Sakonnakhon et al. (2005) reported biomass production of the same peanut cultivar to be 6.8 Mg ha⁻¹ and 167 kg N ha⁻¹, which were similar to those found in this study. It can be concluded that, these legumes had potential to be used as green manure.

4.1.2. Nitrogen (N₂) fixation capacity of legumes

The successful development of legume green manures as N supplement will depend on the ability of the legumes to produce N (via N₂ fixation) and then effectively supply this N to subsequent crops. N₂ fixing by the legumes in this study ranged from 61 to 81% of total plant N (47 to 193 kg N ha⁻¹) and recyclable residues had N quantities ranged from 59 to 150 kg N ha⁻¹ which were in acceptable ranges. Similar results were reported by several researchers (McDonagh et al., 1995a; Hemwong et al., 2008) i.e. 101-170 kg N ha⁻¹ was fixed by peanut. Pigeonpea fixed 27-91% of its nitrogen requirement (Kumar Rao et al., 1987; Ramos et al., 2001) and sunnhemp at 68 days fixed 57% (174 kg N ha⁻¹) with recyclable residues at 150 kg N ha⁻¹ (Perin et al., 2006).

4.1.3 Effect of legumes on soil moisture

Soil moisture content is important for sugarcane emergence. Green manure grown before sugarcane planting should not have negative effect on soil moisture. In this experiment, most high biomass legumes showed a tendency to reduce soil moisture due to late harvesting. However, after sugarcane was planted, no differences in soil moisture among the treatments were observed. Therefore, we concluded that under northeastern Thailand conditions the selected legumes should not have negative effect on soil moisture for planting sugarcane. Biederbeck and Bouman (1994) studied soil water depletion by green manure legumes (Black lentil, Tangier flatpea, chickling vetch and feed pea) and reported that legume water use exceeded that of fallow at 4 to 6 weeks after seeding. When legumes were incorporated into the soil at full bloom stage, differences in water content between cropped treatment and fallow were largest

and most consistent in the top 0.6 m soil depth, suggesting that the legumes extracted water primarily from this depth. In an extreme drought year, substantial water depletion might occur below 0.6 m. This result may remind us in drought year of northeastern Thailand that growing preceding legumes might result in soil moisture depletion and subsequently affect shoot emergence of sugarcane. Manipulation of green manures needs to consider their effect on soil moisture depletion of sugarcane planting.

4.2 Decomposition and nutrient release

The C:N ratios of the legume residues ranged from 22 to 37. The theoretical C:N ratio is 25:1 where net mineralization would occur (Heal et al., 1997). Pigeonpea decomposed significantly more slowly than the other legume residues. Exponential model suggested that the early decomposition with the higher decomposition rate constant (k_w) were obtained from jackbean, weeds in mineral N fertilized plot, *C. striata* and peanut without P and K fertilizer. At later stages, where recalcitrant substrates were dominant, higher k_w value were obtained under the applications of peanut with and without P and K fertilizers and *C. striata* residues.

Litter bag study showed rapid decomposition at 49 DAB due to availability of easily decomposable compound at this stage. Some legumes had remaining weights less than 50% while the most slowly decomposed residues had 69% of their initial weight remain. Nitrogen remaining in the retrieved residues was 40 to 70%. However, due to the lack of rainfall in the dry season, the released N was not subject to losses (leaching, denitrification and volatilization) and may have been available for uptake by sugarcane seedlings.

The rapid decomposition of peanut and slow decomposition of pigeonpea as shown in the litter bag study resulted in contrasting ^{15}N uptakes by sugarcane, i. e. sugarcane took up 5.5% of initial N added from peanut residues which was lower than the pigeonpea, 9.0%. In addition, pigeonpea residues resulted in higher N recovery in the soil than peanut. Hemwong et al. (2009) reported N recovery at 6 months of sugarcane planting to be 4% of initial N added from peanut residues which was close to this study of 5.5%. However, total recovery of N added (50%) was higher than the

present study (39%). Nitrogen recovery was highest in Jackbean residues in both sugarcane uptake and soil layers.

Soil fauna might have had some effects on residue decomposition as measured by the litter bag technique. The highest number of damaged bags from termite was observed under sunnhemp and hairy indigo residues. Njunie et al. (2004) observed that termite was an important factor of mass loss from the more lignified woody branches while bark and leaves were less affected. In this study sunnhemp residues were composed mainly of stems (53%), that might be cause of the heavy attack by termite. Meanwhile, hairy indigo residues were not dominated by any particular plant parts. Even though the damaged bags were discarded in the present study, termite may have been a factor affecting interpretation of decomposition and nutrient release as affected by residue chemical composition.

Nitrogen applied to the soil whether in the form of plant residues or mineral fertilizers, can be lost through several processes, i.e. uptake by plants, leaching, volatilization, denitrification and microbial immobilization. Total N loss by these processes accounted for 25% of N remaining in the soil in more or less stable forms (Azam et al., 1985). Potential nutrient contributions of green manures in this study ranged from 59-150 kg N ha⁻¹ (Table 3.2). These are full amounts but N recovery in plants receiving these legumes was only 5-15% in this study (Table 3.14) and 5-10% in Hagggar et al. (1993).

Application of peanut residues (with or without P and K fertilizers) resulted in higher N uptake at 151 DAP than the other legume treatments and the mineral N fertilizer application with weed incorporation (weed+N), but was lower than the mineral N fertilizer application without weed incorporation (bare soil+N). This resulted in higher sugarcane biomass production under peanut than the other treatments except the mineral N fertilizer application without weed incorporation (bare soil+N). Such finding indicated that peanut residues had a beneficial effect on early growth of sugarcane. Hemwong et al. (2009) also reported the benefit of peanut residues for early growth (6 months) of sugarcane.

4.3 Benefits of green manure to sugarcane

At 8 DAP incorporation of peanut residues with and without P and K fertilizer brought about higher N availability to sugarcane than the other treatments. The high mineral N available from peanut residues was not expected to be beneficial to sugarcane as it had not yet emerged. Sugarcane, Uthong 1 cultivar, was slow to germinate as its young shoots started to appear approximately 20 DAP. Clements (1980) studied the development of the bud on a single bud cutting and reported that a single root from the bud of the cutting had just started to emerge at 6 DAP. The shoot of the cutting appeared at 15 DAP. As the soil moisture gradually declined, it may have restricted N availability from mineral N fertilizer and thus may have been a reason for lower mineral N in soil than that under peanut residue application. Plant residues were incorporated to the soil at least 15 days before sugarcane planting so they received adequate soil moisture for decomposition and subsequently released mineral N. Vityakon et al. (2000) found that peanut residue under upland conditions showed immediate net N mineralization which peaked at 4 weeks after residue incorporation. Thippayarugs et al. (2008) using the same material as in this study showed that decomposition and N loss of bulked peanut components (stems, leaves and leaf litter) at 14 days were larger than 50% of initial quantity added at soil moisture 60% field capacity. Mineral N in the soil of peanut residue treatment in their study also indicated immediate mineralization while pigeonpea showed net immobilization through 133 days. Hairy indigo in the same study showed net N mineralization at 63 days. In the present study, the same trend occurred with pigeonpea residues, which resulted in lower mineral N in soil than the control bare soil that indicated immobilization.

At the beginning of the rainy season (147 DAP) when soil moisture was still limited, soil mineral N contents from the mineral N fertilizer treatments were higher than the legume residue treatments (average 12%). Even though, no significant differences were observed among jackbean, hairy indigo, pigeonpea and peanut with and without P and K fertilizers, they showed higher soil mineral N than the two control soil treatments (bare soil and weed), and thus indicating the rates of N mineralization from these legume residue treatments were still higher than those of

sugarcane uptake. Sunnhemp and *C. striata* treatments showed similar amounts of mineral N as the two control soil treatments (bare soil and weed) indicating immobilization or equal rate of N mineralization and the rate of sugarcane uptake.

At 224 DAP, sugarcane growth was active (tillering stage) and soil moisture was not limited leading to large amount of nutrient uptake. Mineral N in soil were highest under mineral N fertilizer, peanut+PK and bare soil treatments. Weed and legume residues resulted in lower soil mineral N than bare soil treatment. This indicated higher N uptake by sugarcane than N released from the plant residues. Only N fertilizer and peanut with P and K showed synchrony of N release with sugarcane demand.

At 287 DAP (1 month after top dressing with 47 kg ha⁻¹ each of N, P₂O₅ and K₂O), soil mineral N was lower than those in the other sampling dates, which indicated a high demand of sugarcane at this stage. Mineral N was the highest under weed and pigeonpea application, even though, it was the lowest during all previous sampling dates. Russell and Fillery (1996) suggested that decomposition of a material with a low nitrogen content can be increased considerably if a suitable source of nitrogen is added.

4.3.1 Benefit of N, P, K, Ca and Mg from green manure

Sugarcane yield (81-112 Mg ha⁻¹) removed N 61-107, P 20-34, K 77-163, Ca 9-15 and Mg 30-43 kg ha⁻¹. Recyclable legume residues in this study were able to provide N in the range of 59-150, P 13-22, K 70-115, Ca 22-100 and Mg 8-20 kg ha⁻¹. Legume residues as green manure can play a major role in nutrient capture and cycling. Long duration fallow period can rebuild soil fertility. The figures above may lead to the conclusion that legume residues can provide adequate for sugarcane production. Nevertheless, not all these nutrients would be available to the crop due to potential nutrient losses (denitrification, leaching, etc), nutrient immobilization by the microbial biomass or simply by incorporation into recalcitrant soil organic matter pools (Vanlauwe et al., 1997a). In the present ¹⁵N recovery study using enriched residues, only 5-15% of N initially added were taken up by sugarcane plants and fortunately, the remainder N was still presented in the soil layers. Results of this study can be used as indicators of the potential amount and rate of N supply. Nitrogen

releases patterns of residues were different among different plant residues. Thus, benefit to sugarcane may depend on releasing time which match the time of sugarcane demand for those nutrients. Nitrogen release from peanut, jackbean and hairy indigo seemed to match sugarcane requirement due to higher yield of sugarcane under the application of these legume residues.

4.3.2 Benefit of green manures to sugarcane yield at final harvest

Green manure increased millable cane fresh weight over the bare soil and weed treatments, especially peanut, jackbean and hairy indigo. Peanut in this experiment was categorized as the low biomass production green manure but it was high in N, even though some were removed in pod yield. It also was in the group of fast N release. Sugarcane in the Northeast was planted in late rainy season, thus N leaching was limited. Thus, N still had benefit to sugarcane, even though N release may be earlier than root initiation as shown in Figure 3.4. Jackbean showed poor growth with lowest N. However, it showed highest contribution of N (15%) to sugarcane in ^{15}N recovery study. In addition, it showed highest decomposition rates during the first 49 days after bag burying. Meanwhile, hairy indigo produced high biomass and highest N content. Its decomposition rate was in the intermediate range compared to the other legumes studied. However, due to its highest polyphenol content in leaves this resulted in prolonged N release as shown in Chapter V.

Legume residue applications could lead to increase sugarcane yields. According to Chikowo et al. (2003), a legume crop contributes about 30% of the fixed nitrogen to the succeeding crops. Only peanut with P and K fertilizers and hairy indigo had N close to mineral N fertilizer application at the rate 47 kg N ha^{-1} . It may have been the reason for high sugarcane yield under these legumes. Hemwong et al. (2009) found that preceding peanut residues led to an early increase in sugarcane tillering. This study obtained a similar result of higher total N uptake under the application of peanut residues as compared to the 3 control treatments, i.e. bare soil, weed incorporation (weed), and weed+N.

4.3.3 ^{15}N recoveries from green manure

^{15}N recovery from green manure in sugarcane plant (5.5 to 15.0%), in soil from 0-80 cm (39-62%) and from the whole system (47-87%) of ^{15}N application were low in comparison to Seo et al. (2006) who summarized N recovery from various studies (Ladd and Amato, 1986; Janzen et al., 1990 and Harris et al., 1994) that ^{15}N recovery in plant was 10-20%, in soil 49-66% and total 63-84%. Results of this experiment were close to Seo et al. (2006) who reported their own work of recovery in plant of 15%, soil 38% and total 54%. In this experiment, total ^{15}N recovery was lowest under peanut residue application (47%), meaning that 53% of ^{15}N applied were lost. Seo et al. (2006) suggested N losses depended on growing season, precipitation and soil texture.

The lowest ^{15}N recovery in all compartments (sugarcane plants, soil layers, and legume remaining residues) was likely due to N losses *via* different processes, especially leaching. Peanut as a green manure for the late rainy season sugarcane decomposed too rapidly for the sugarcane to absorb the released N. In addition, the study soil could not retain the mineral N released.

On the other hand, jackbean had highest N recovery in all compartments. Jackbean, as opposed to the peanut, had intermediate rate of decomposition although the early phase (0-49 DAB) was rapid but the later phase (77-358 DAB) of decomposition was among the slowest. The decomposition pattern led to higher N recovery in jackbean as compared to the peanut.

4.3.4 N use efficiency from green manure

Nitrogen use efficiency (NUE) was calculated from total biomass and N uptake changed with sugarcane age. At final harvest, sunnhemp and weed showed the highest NUE which was in the same ranges with Hemwong et al. (2009). Apparent fertilizer use efficiency (AFUE) was much lower with legume residue application than with mineral N fertilizer, which agreed with the recovery study that only 5-15% of N from legume residues were found in sugarcane. However, contribution of N from peanut had similar AFUE as reported by Hemwong et al. (2009). Internal efficiency of N (IEN) was higher with the application of sunnhemp and peanut without P and K fertilizers. However, agronomic N use efficiency (ANUE) was highest in unamended

soil. It was higher than that reported by Hemwong et al. (2009) and it also showed evidence of synchrony of N applied which was higher with jackbean, peanut and hairy indigo.

5. Conclusions

The use of legume green manures did not lead to better sugarcane yield, but comparable to those of farmers' conventional practices, i.e. the use of chemical fertilizers. However, legumes could substitute for chemical fertilizer and may lead to more sustainable in a long-term sugarcane production. The legumes studied did not bring about significantly different sugarcane final yields, however they had different attributes leading to their different decomposition and N release patterns. For examples, peanut had highest N content, which was advantageous to sugarcane growth as shown by sugarcane N uptake. However, peanut had low biomass, which is considered disadvantageous as a green manure. In addition, peanut decomposed very rapidly (less than 10% was remained close to sugarcane harvesting) indicating that it might not be an effective a long-term soil amendment. Meanwhile, pigeonpea had high biomass but its chemical composition (e.g. low N content) was such that its decomposition and N release were slow. Consequently, sugarcane yield was low. However, unlike the peanut and other legumes studied, the high remaining biomass indicated that it has potential for a long-term soil improvement. Unlike both peanut and pigeonpea, jackbean produced low biomass and had low N content, but it led to high sugarcane yield comparable to the peanut. In addition, it had different decomposition pattern than the former 2 legumes in that it had rapid initial phase (0-49 DAB) decomposition, but slow in later phase. These attributes of jackbean led to N releasing pattern which may have synchronized with sugarcane N uptake. The highest ^{15}N recovery in sugarcane under jackbean was a prove of its synchrony with sugarcane N uptake pattern, while the highest ^{15}N recovered in the soil showed that jackbean led to the lowest N loss. This is desirable for sugarcane production in sandy soils.

Nitrogen (N_2) fixation in all the legumes studied, with the exception of *C. striata*, was considered high, 74-81 % of total plant N. This is an advantage of the use

of legume green manure over the conventional chemical fertilizer. A consequence of N_2 fixation is reduction in soil N use. Among the legumes studied, jackbean used the least soil N.

Legume green manures are not only N providers but they also provide ground cover for soil conservation. Jackbean and peanut can provide full soil cover within one month after their planting. Meanwhile, pigeonpea, and hairy indigo have slow initial growth so it cannot provide good ground cover at an initial stage. This should be a criterion for selecting green manure crops in addition to their capacity to fix N_2 , synchronize their decomposition and N release with the sugarcane demand.

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