CHAPTER VI
GENERAL DISCUSSION

Sugarcane in Northeast Thailand is usually planted in late rainy season (October-November) in low fertility sandy soils. The soils are under monocropping of sugarcane for at least 2.5 years (one planted cane followed by 1 ratoon cane). After the last ratoon cane crop harvesting, the soils are left fallow for 5-6 months (May-September) during the rainy season. This provides an opportunity to restore soil fertility by growing green manure legumes during this fallow period.

Continuous monoculture of sugarcane can lead to soil deterioration due to crop removal, burning, leaching of nutrients and denitrification. Green manure is a crop used primarily as a soil amendment and a nutrient source for succeeding crop. It might help adding N to cropping system through biological fixation, and naturally slow release of N from decomposing green manure residues may match with crop growing demand.

The effective managements of green manure crops and their residues in sugarcane-based cropping system were the main goal of this study. Understanding decomposition and nutrient release patterns of plant materials is the important first step towards better management of green manure. Three experiments were conducted. The first experiment aimed to determine 6 potential legumes planted before sugarcane under field conditions on their own biomass production, N_2 fixation, recyclable biomass, N production per area and their effects on sugarcane growth and yields.

To understand patterns of decomposition and N release of legume plants, litter bags containing the quantity of legume residues equivalent to those produced under field conditions were buried between sugarcane rows and retrieved at different time intervals. Effect of legume residues as a substitute for N chemical fertilizer at planting on sugarcane production was determined by incorporating legume residues before planting sugarcane. Then, sugarcane planted with N fertilizer application at recommended rate was used to compare with legume residue application treatments. Nitrogen recoveries from legume residues in sugarcane, soil and undecomposed residues were determined using high ^{15}N enriched residues. The second experiment aimed at understanding patterns of decomposition and N release of individual plant parts (stems, leaves, leaf litter and root) of residues and the combination of aboveground plant parts. The third experiment aimed at investigating the effects of legume residues and rates on early growth of sugarcane under control condition.

6.1 Biomass and nitrogen production from different legumes

Legumes used in this study were grain legume (peanut), recommended green manure legumes (pigeonpea, sunnhemp and jackbean) and weed legumes (hairy indigo and *C striata*). All of these legumes had the potential to grow reasonably well in low fertility sandy soils under unreliable rainfall condition of Northeast Thailand.

Biomass production from this experiment ranged from 4.2 to 10.7 Mg ha^{-1} and N content from 59 to 150 kg N ha^{-1}. All 6 legumes could be used as N provider for succeeding sugarcane crop due to their high biomass and N contents as reported by Cherr et al. (2006a). They reviewed the studies on potential uses of different plant species as green manure and reported that biomass production of the same 4 species as used in the present study ranged from 4.4 to 12.1 Mg ha^{-1} and N content of 58 to 277 kg N ha^{-1}.

In this thesis study, the legumes fixed 61-81% of their N content or 47-193 kg N ha^{-1} in absolute forms. The recyclable biomass of the legumes ranged from 4.2 Mg ha^{-1} in jackbean to 10.7 Mg ha^{-1} in sunnhemp with N content, from 59 kg N ha^{-1} in jackbean to 150 kg N ha^{-1} in hairy indigo. It should be noted that peanut produced total biomass of 8.2-10.7 Mg ha^{-1}, 3.1-3.3 Mg ha^{-1} of which were pod yield, therefore peanut residues were 5.1-6.6 Mg ha^{-1} with N accumulation being 88 and 142 Mg ha^{-1} for peanut without and with PK fertilizer application respectively. Similar N_2 fixed had been reported for peanut (Hemwong et al., 2008; Toomsan et al., 1995), pigeonpea (Kumar Rao et al., 1987; Ramos et al., 2001) and sunnhemp (Perin et al., 2006).

Sunnhemp produced the highest biomass, 10.7 Mg ha^{-1} at 4.5 months after planting. However, late harvesting at 4.5 months was not suitable for sunnhemp to be applied as green manure due to less remaining green leaves. Therefore, stem was the major component of plant residues. Cherr et al. (2006a) reported that sunnhemp, as green manure, at the age of 1.5-3.5 months old contributed 23-227 kg N ha^{-1}.

Pigeonpea and hairy indigo also produced high biomass. However, pigeonpea grew slowly initially, only became rapid 4 months after planting. Therefore, pigeonpea is not suitable to be planted as green manure in the areas having high early rainfall and need for early cutting before 4 months old. In contrast, in the area with high rainfall during late rainy season, growing pieonpea may reduce the risk of soil erosion as it produces dense canopy and thick leaf litter layer on soil surface. As for hairy indigo it is also a poorly germinated legume because of its small seed size, although, in natural soil conditions it tends to germinate very well from previous year seed buried in the ground. Proper land cultivation and seed treatment may be useful to help establishing hairy indigo stand in the area of high early rainfall, and thus leading to lower soil erosion. Hairy indigo grow vigorously in later growth stage with high concentration of N in leaves, and thus, resulting in the highest N contribution in its residues at harvest. However, high polyphenol in leaves resulted in slower N release, which does not synchronize with sugarcane demand. Nevertheless, the slow N release of hairy indigo might synchronize with sugarcane demand when growing duration was longer.

Low biomass production was obtained from peanut, *C. striata* and jackbean residues. However, N production was high in peanut with P and K fertilizer application. High N concentration, low lignin, polyphenol and C:N caused peanut to decompose fast and subsequently releases high amount of N. Fast N release may not benefit sugarcane at early growth stage as root extension is still slow in sugarcane (Clement, 1980). Fortunately, sugarcane planting in the late rainy season has low risk of nutrient leaching loss, so released mineral N might still be stored in soil until sugarcane develops extensive root system for efficient nutrient uptake. In this experiment, soil mineral N data always showed higher mineral N under peanut residue application. In addition, peanut also provide good ground cover. In contrast, jackbean and *C. striata* showed poor growth. It was observed that jackbean showed poor growth when planted after incorporating sugarcane trash from the previous cropping season. The poor growth might result from competition for N between plants and microorganism decomposers of the sugarcane trash. Similar problem may also occur with *C. striata* as yellowish plants were observed. Growing these two legumes after sugarcane trash incorporation may need N supplement. However, further study is required.

It is therefore concluded that peanut was the best legume as it provided high N contribution to sugarcane, good ground cover to reduce soil erosion and farmers also gained extra income from its pods. However, it cannot be grown in large area because of high seed cost for planting and high labour cost in harvest and depodding.

6.2 Decomposition and N release

Legumes planted in this study had different chemical composition and different proportion of plant parts in the bulk materials. This resulted in different legume decomposition and N release rates, and subsequently soil mineral N. Pigeonpea in all three experiments showed the slowest decomposition and N release rates while peanut was in the group of legumes that had fastest decomposition and N release. The contrasts in concentration of N, lignin and C:N ratio were the main chemical characteristics that were likely to regulate decomposition and N release rates. However, these two legumes (pigeonpea and peanut) showed stable amount of extract mineral N in soil during the first two sampling dates in the undrained pot experiment indicating synchronization of N release and sugarcane demand. Sunnhemp showed slow decomposition in the field but was highest in N release rate. It also showed the highest extractable N under control pot experiment in the earliest date of soil sampling and was rapidly declined in the later sampling dates, indicating smaller N release than uptake.

Hairy indigo, jackbean and *C. striata* under the field experiment were categorized in the rapid decomposition group, especially jackbean that was the fastest in decomposition rate during the first 49 days after incorporation, but in the second phase (77 days onwards), its decomposition rate was second slowest after pigeonpea. Decomposition rate of *C. striata* residues ranked as the second fastest in both stages. Hairy indigo showed intermediate residue decomposition rate in both phases. Under control pot condition with the same weight of legume residue incorporation, sunhemp showed the highest extractable N at 15 days after sugarcane transplanting (DAT). At 68 DAT, only the residues of peanut and pigeonpea showed stable amount of extractable N indicating N release of these legumes synchronizing with N demand by growing sugarcane. Among other legume residues, sunnhemp showed the highest extractable N in the first date but rapidly declined in the second sampling date indicating higher N uptake rate than N release from legume residues. Hairy indigo and jackbean had extractable N similar to sunnhemp except at the first sampling date.

Study on decomposition of individual parts revealed that green leaves resulted in rapid decomposition and led to net N mineralization immediately, however stem and leaf litter (with the exception of those of peanut and leaf litter of hairy indigo) decomposed slowly and resulted in net N immobilization.

The reason for this finding was the chemical constituents of different plant parts. Stem usually control decomposition rate because of its low N content, high C:N ratio and high ADF. In addition, stem contributed the highest proportion in the bulk residue dry weight.

Ranking of individual plant components for N mineralization when added at the same weight, was as follows in the decreasing order leaves>leaf litter>roots>stems. In bulk residues by species, the decreasing order in decomposition was peanut>hairy indigo>pigeonpea.

Interactions among individual plant parts on decomposition of the mixtures were relatively small for peanut (generally high-quality components) as well as for pigeonpea (low proportion of high quality components, i.e. N rich leaf material). However, a positive interaction occurred during later stages of N mineralization in the hairy indigo as it had a significant proportion of N rich components and absence of highly reactive polyphenols. Thus, for plants with low to intermediate chemical quality attributes, manipulating plant composition (e.g. by varying harvest age, and stem and leaf proportions) can affect significant interactions during decomposition when its components are mixed. Knowledge of interaction in mixture may help us manipulate nutrient available for crop demand. As in field condition, crop residues are applied in the mixture of plant components or different plant species. In this experiment there were low interaction among plant components as stems were the major component. Variation of harvesting age may cause difference in proportion of plant components leading to different residue chemical quality that may cause higher interaction. Knowing the initial amount and quality of each plant component comprising the mixed-components enables us to use data from the individual plant part to calculate predicted decomposition rates, nitrogen release for the mixed components. Differences between predicted and observed values for mixed components could then be used to infer interaction effects due to mixing different components. This is important because any interaction effects on decomposition rates or nutrient release would affect predictions of biomass loss or nutrient release derived from individual plant component. Additionally, such interaction effects would provide a potential different in time or amount of nutrient availability that would assist in manipulation of nutrient release and crop demand.

Study on ^{15}N recovery at 6 months after sugarcane planting revealed that peanut residue resulted in the lowest ^{15}N recovery in cane, soil and total recovery while the highest recovery was found in pigeonpea and jackbean. This indicated that fast decomposition rate resulted in the lowest recovery of ^{15}N and *vice versa* in the slow decomposition rate. The ^{15}N recovery obtained in sugarcane in the present study was between 5.5 to 15.0% which is within the reported range (7-25%) recovered by various crops grown after the application of ^{15}N labeled legume residues (Yaacob and Blair, 1980; Vallis, 1983; Muller and Sundman, 1988; Norman et al., 1990).

6.3 Effects of legume residues on sugarcane growth

Pot trial demonstrated that all legume residue treatments resulted in significantly higher sugarcane biomass production than unamended and N fertilizer treatments. However, the results from the field experiment showed that legume residues applications could increase millable cane yield over the unamended treatments but not significantly different from the recommended N fertilizer treatment.

The different results between pot and field trials may have been due to the fact that pot experiment was conducted under controlled or closed condition where leaching did not occur while in field experiment, some legume residue might not release N to match with the sugarcane demand, and N might have been lost *via* leaching, denitrification and volatilization. In addition, rates of legume residues application in the pot experiment were higher than actual biomass production of legume green manure in the field especially peanut.

6.4 Effects of legume residues on soil fertility

Pot experiment revealed that legume residue applications, with the exception of the peanut residue, led to an increase in soil organic matter over the unamended and the N fertilizer application treatments at 180 days after sugarcane transplanting (DAT). Nitrogen fertilizer application resulted in a decrease of available P and Mg, while legume residue application still maintained P and Mg availability. Pigeonpea, jackbean and sunnhemp were slow in decomposition and showed trends of producing the highest organic matter content. Hemwong et al. (2009) found that slowly decomposed soybean residue resulted in high soil organic matter at final sugarcane harvest, under field conditions. Peanut residues were fast in decomposition and did not increase organic matter in soil, but could still maintain available P and Mg, as reported by Hemwong et al. (2009).

Legume residue application could supply adequate N for sugarcane requirement as indicated by higher biomass production than unamended and N fertlizer treatments in the pot trial. This implied that legume residues could supply basal N fertilizer at the planting time. Field experiment revealed that all legume residue applications had a tendency to increase sugarcane biomass over the unamended and N fertilizer treatments at 151 DAP which was in agreement with the pot trial. However, top dressing with N fertilizer at 6 months after planting is still required, in order to get high millable cane yield. Similarly, Hemwong et al. (2009) reported that peanut residue application could supplement basal N fertilizer during the first 6 months. However, N top dressing is necessary in order to get maximum yield.

6.5 Application of legume residues for sugarcane production

The results from this study indicated that all 6 legumes could be used to supplement basal N fertilizer at the time of sugarcane planting in Northeast Thailand with 4.2 to 10.7 Mg ha^{-1} of biomass and 59 to 150 kg of N ha^{-1}. However, to substitute mineral N fertilizer at planting, the legume should release N to match with uptake demand of sugarcane. Decomposition and N release patterns showed differences among legumes. Legumes with fast N release pattern might benefit growing sugarcane more than slow N release legumes as the result of no or negligible leaching in less rainfall area.

Legume residues in this study could be classified into 3 groups according to their chemical quality, which affect decomposition and N release rates. The first group included fast decomposing legume residues, termed high quality residues, which have rapid N mineralization. The second legume residues termed intermediate quality have N immobilization in early stages followed by N mineralization at later stages, and the last group termed low quality legumes with slow decomposition resulting in N immobilization during most of incubation period.

Slow decomposition and N release of pigeonpea residues might not benefit sugarcane growth in short term. There are a number of possible management interventions for altering the N release patterns by manipulation of the quality of legume residues in order to achieve a better synchrony of N supply and crop N demand for growth.

1. The quality of legume residues can be altered physically by cutting into different sizes (Vanlauwe et al. 1994). Cutting into smaller sizes might increase accessibility by microorganisms. Different legumes might release different amounts of N with different sizes of residues that need further study. In practice, machine ploughing by cutting blade is needed before incorporation.

2. Alterations in chemical quality of residues

Quality of legume residues can easily be manipulated by cutting at different age. The stage of growth affects the degree of lignification as well as other constituents, such as the polyphenol. Sunnhemp, in this study, was harvested late when fallen leaves were larger than 50% of total plant components and at incorporation period stems were major proportion of plant parts. Different proportion of plant parts affect chemical quality of bulked plant parts leading to change in decomposition and N release rates (Collins et al., 1990).

Mixing residues of different quality is another approach to manipulate plant quality. Vityakon et al. (2000) manipulated N release by mixing peanut residues with rice straw and, as the result, N mineralization could be delayed and prolonged. In this study, pigeonpea residues were slow in decomposition and N release, in contrast to peanut residues. Mixing pigeonpea and peanut residues may change rate of decomposition and timing of N release.

Mixing residues of different legume species can be managed by cut and carry system. Such management can control both proportion of individual legume in the mixed residues (quality) and the rate of application (quantity). However, such operation needs high investment for residues transportation. Planting different species together as mixed cropping is another approach. Gathumbi et al. (2002) suggested that mixing complementary species in fallows gave more advantages than monoculture fallows, as well as reducing insect and pest incidence. They reported that sowing siratro in between rows of sesbania resulted in improved total foliage biomass and N production per unit area, at the same time mixed legume sward was observed to conserve topsoil water resources due to dense ground cover. Mixing different legumes in this study could change pattern of residue decomposition and N release. Further studies on mixing two legume residues are needed as such knowledge may help to improve management of green manure, which may benefit not only sugarcane and other crop productions.

Grain legume, peanut, may be appropriate for extension to small farmers because its pods can provide edible products as well as cash income. Legume green manure i.e. sunnhemp, pigeonpea, hairy indigo may be suitable for larger farmers. However, seed production of sunnhemp and pigeonpea may limit their wide uses.