Chapter 5

Decomposition and nitrogen use efficiency of high quality tree prunings and low quality crop residues in two agroforestry systems

Abstract

The decomposition and N release patterns of high quality tree prunings (gliricidia and sesbania) and crop residues (pigeonpea leaves and roots, and maize stover) were studied in agroforestry systems, together with *in situ* incubations in litterbags and aluminum cores. All three experiments had a 3 x 6 factorial design, the high quality levels were: no tree prunings (NTP), gliricidia (Gs) and sesbania (Ss), and the crop residue levels were: no crop residues (NCR), pigeonpea leaves (Pea-L), pigeonpea leaves + roots (Pea-LR), pigeonpea roots (Pea-R), and two rates of maize stover (Stover-1 and Stover-2). The study was carried out in 2000-01 (wetter season) and 2001-02 (drier season).

The decomposition rate constants of the individual tree prunings and crop residues followed the order: Gs>Pea-L>Ss>Pea-LR>Stover>Pea-R, and with the mixtures the following general decomposition order was observed: tree prunings>mixtures>crop residues. Maize grain yield and N uptake of Gs/Pea-L, Gs/Pea-LR, Ss/Pea-L and Ss/Pea-LR treatments were statistically not different from Gs/NCR and Ss/NCR during the two seasons. Stover-2 had the highest N fraction immobilized N, 15% and 35% N during the wetter and drier conditions respectively. We conclude that (1) mixing of high quality tree prunings with crop residues enhances the decomposition of low quality crop residues but there is no special interaction, (2) remineralization of N immobilized early in the season by the low quality organic materials is stimulated by well distributed rainfall.

5.1 Introduction

Use of green manure from tree/shrub prunings has been promoted as an alternative source of nitrogen (N) for Sub-Saharan countries. Although it has been shown that addition of such prunings increase soil N and crop yields (Kang *et al*., 1999; Kwesiga *et al*., 1999; Hartemink *et al*., 2000; Stahl *et al*., 2002), the effectiveness of the organic N applied is low compared to that of inorganic fertilizer (Ladha *et al*., 1981; Mulongoy and van der Meersch, 1988; Akinnifessi *et al*., 1997). The low N uptake by crops from the applied organic N is attributed to lack of synchrony between the N released by organic materials and N demand by the crop.

Lack of synchrony can arise from two situations: (i) when mineral N supply comes too late for the demand, in the case of slowly decomposing materials, (ii) when the N supply comes too early for the crop demand and is lost to environment, in the case of fast decomposing organic materials (Myers *et al*., 1994, 1997). Myers *et al*. (1994) suggested that synchrony between N release by organic materials and N demand by the crop may be achieved by combining low and high quality organic materials. Handayanto *et al.* (1995 and 1997) examined the effects of mixing high and low quality organic materials in laboratory and glasshouse experiments, and concluded that N release pattern of high quality organic materials can be manipulated by combining them with low quality material. Becker *et al*. (1994) and Whitbread *et al*. (1999) demonstrated that mixtures of sesbania prunings or pigeonpea leaves with rice straw/stubbles increased the yield of flooded rice more than sesbania prunings alone. In Chapter 3 it was found that mixing of maize stover with sesbania or gliricidia prunings gave additive effects on N uptake by the maize crop in a greenhouse experiment. All these results point at complex relations between N release by crop residues and prunings and N demand by the specific crop.

Pigeonpea is an important food crop, and is the main source of protein for the rural people, in southern Malawi. Because of the acute land shortage it is planted as an intercrop in sesbania-maize relay and gliricidia-maize simultaneous intercropping systems. In such systems, pigeonpea litter and roots are incorporated in the soil besides legume tree prunings and crop residues from the associated crop, usually maize stover. The practice of mixing high quality legume tree prunings and crop residues of different qualities is in line with the second hypothesis of synchrony suggested by TSBF (Table 1.2, Chapter 1), but large proportions of the crop residues in the mixtures may result in asynchrony. As yet, there is no accurate information on the (1) patterns of decomposition and N release that may arise from these mixtures under agroforestry conditions in practice, (2) optimum proportions of maize stover for immobilization of N early in the season and remineralization in the due course of crop demand so as to enhance the synchrony. Information obtained from glasshouse and laboratory experiments may not directly be applied to explain the complex decomposition and N release patterns under field conditions. Most glasshouse experiments do not last long enough as to allow for complete decomposition and also most large soil fauna is usually excluded. In flooded rice (*e.g.* Becker *et al.*, 1994; Whitbread *et al.*, 1999) mineralization occurs under anaerobic conditions and the processes governing mineralization may not be the same as in the upland where aerobic conditions dominate. Evidently there is a knowledge gap in the decomposition patterns of the mixtures and interaction between high and low quality organic materials under practical agroforestry conditions.

Basing in part on the results described in Chapters 3 and 4 we formulated the following hypotheses: (1) decomposition patterns of mixtures of tree prunings and crop residues are not interactive but additive; (2) mixtures of high and low quality organic materials can increase N uptake and yield of the current crop when the immobilized N is released within the course of maize growth. These hypotheses were tested under field conditions in agroforestry systems using mixtures of high quality prunings (gliricidia and sesbania), with low quality crop residues with widely ranging C:N ratios (pigeonpea litter and roots, maize stover). Pigeonpea and maize stover were chosen because they (1) are readily available in the fields and (2) are low in polyphenol, which is a determinant of the rate of N release. In this way carbon added via the crop residue could be the main determinant of N immobilization and mineralization. Objectives of this study were (1) to increase the understanding of the patterns of decomposition and of N mineralization from crop residues combined with tree legume prunings in an agroforestry system (2) to increase the understanding of the interactions between low quality crop residues and high quality tree legume prunings with respect to N uptake and yield of maize, (3) to determine the substitution values of the various organic materials. The performance of the high quality legume tree prunings, crop residues and their mixtures were studied in two ways: (1) *In situ* incubation experiments: mass disappearance of organic material in litterbags, and changes in soil mineral N in aluminum cores were monitored during the course of the experiments; (2) Agroforestry system trial: maize yield and N uptake were assessed and mineral N in the cropped soil was monitored during the course of maize growing in a completely randomised factorial with agroforestry system crop residues as factors.

5.2 Materials and methods

The experiments discussed in this chapter were conducted at MZ 21. Site characteristics, tree and crop management have been described in Sections 2.1 and 2.2. Planting and weeding practices are given in Section 2.2.4. Maize and pigeonpea were planted on the same dates, in 2000-01 season on 16th November 2000, and in 2001-02 season on 20th November 2001. Rainfall distribution for the two season is presented in Appendix 5.1.

5.2.1 In situ incubation experiments

5.2.1.1 Litterbag experiment

The litterbag experiment was conducted in the 2000-2001 season. The experimental design was a 3 x 6 factorial, the same as for the field trial (Section 5.2.2.1). The levels of high quality factor were: no tree prunings (NTP), 15 g gliricidia (Gs) per bag, and 12 g sesbania (Ss) per bag; the levels of the low quality factor, henceforth denoted as crop residues were: no crop residues (NCR), 7.5 g pigeonpea leaves (Pea-L, 3.2 g green leaves and 4.3 g litter), 2.5 g pigeonpea roots (Pea-R), 10 g pigeonpea leaves + roots (Pea-LR), 7.5 g maize stover (Stover-1), and 15 g maize stover (Stover-2). A control treatment without organic materials, NTP/NCR, was of course not applicable in the litterbag experiment.

The organic materials were chopped to about 2 cm long pieces and were placed in 20 x 20 cm nylon bags with 2 mm mesh. The litterbags were lightly buried in the field at MZ21 on 2nd December 2000. The litterbags were sampled after 14, 21, 42, 63, 70 and 84 days, two from each treatment at each sampling time. Soil particles and roots growing in the litterbags were manually removed and the remaining organic material was washed with distilled water and oven dried at 75 °C for 48 hrs. The dry-matter of the remaining biomass was determined. Decomposition rate constants were calculated assuming first-order reactions:

$$Y_t = Y_0 e^{-kt} \qquad \text{Eq. 5.1}$$

Where Y_0 is the original mass and Y_t is the remaining mass at time t, and k is the decomposition constant, assuming that the weight loss is only caused by decomposition. To calculate the decomposition rate constant values the formula was reorganized as:

$$\ln Y_t = \ln Y_0 - kt \qquad \text{Eq. 5.2}$$

$$k = [\ln(Y_0/Y_t)]/t \qquad \text{Eq. 5.3}$$

In a plot of $\ln Y_t$ against time t, the slope of the linear regression line is k.

5.2.1.2 Aluminum core experiment

The experiment starting on 10th November 2001 was conducted in 2001-2002, which was a drier season than 2000-2001, as shown in Appendix 5.1. The levels of the high quality factor were: NTP, 5 g gliricidia and 4 g sesbania. The levels of the crop residue factor were, NCR, 2.5 g pigeonpea leaves, 1 g pigeonpea roots, 3.5 g pigeonpea roots + leaves, 2.5 g maize stover and 5 g maize stover. A modified method of *in situ* core incubation described by Anderson and Ingram (1993) was used to monitor soil mineral N. The organic materials were placed in aluminum cores, 5 cm diameter and 23 cm long and incubated under field conditions at MZ21. The core was hammered into the soil to about 13 cm deep, and was pulled out. From the bottom end of the core 3 cm of the soil was removed, leaving the inner 10 cm of soil (Fig. 5.1). A plug of pressed soil was inserted to fill the 3 cm gap at the bottom. The soil plug was pressed in order to reduce seeping of soil water from the below ground into the core. The organic materials were mixed with 200 g of soil and placed in the upper 10 cm of the aluminum core. The upper soil layer (mixed with organic materials) and the lower layer (without organic materials) were separated by a 2 mm mesh nylon gauze. An iron cylinder with similar dimensions as the aluminum cores was used to make holes into which the aluminum cores were inserted leaving only about 2 cm protruding above the soil surface. The cores were placed on the ridge in between the maize plants. The cores were sampled after 14, 21, 42, 63, 84 and 104 days. At each sampling time two cores of each treatment were pulled from the soil. The soil in the upper layer was removed and placed in one plastic bag and the soil from the lower part of the core was placed in another plastic bag. The soils were analyzed for mineral

N extracted in 2 M KCl. The soil plug that was placed at the bottom end of the core was also analyzed; it served as a check to verify whether mineral N leached through the core to the bottom. Because the mineral N in the soil plug was the same as in the NCR/NTP soil it was assumed that no mineral N from the below ground had seeped into the core and at the same time that mineral N from the core had not leached through the 20 cm column. Therefore, the N measured in the soil plug has not been included in this report.

5.2.2 Agroforestry systems trial

5.2.2.1 Treatments and design

The field experiment was a 3 x 6 factorial arranged in a randomized complete block design with three replicates. The 18 treatments were combinations of high, medium and low quality materials. The levels of the high quality factor were: no tree pruning (NTP), sesbania pruning (1.5 t ha^{-1}) and gliricidia pruning (3 t ha^{-1}). The levels of crop residues were: no crop residues (NCR), pigeonpea leaves (Pea-L) consisting of green leaves (0.64 t ha^{-1}) + litter (0.86 t ha^{-1}), pigeonpea roots (Pea-R) (0.5 t ha^{-1}), Pea-L (1.5 t ha^{-1}) + roots (Pea-LR) (0.5 t ha^{-1}), 1.5 t ha^{-1} maize stover (Stover-1) and 3.0 t ha^{-1} maize stover (Stover-2). These combinations of high and low quality materials were tested in an existing long-term agroforestry trial at MZ21, using maize as a test crop. The various combinations of high and low quality were tested in a systems comparison: no trees, gliricidia and sesbania trees as described in Chapter 2. The field map showing the treatment set up at MZ21 is presented in Appendix 5.2.

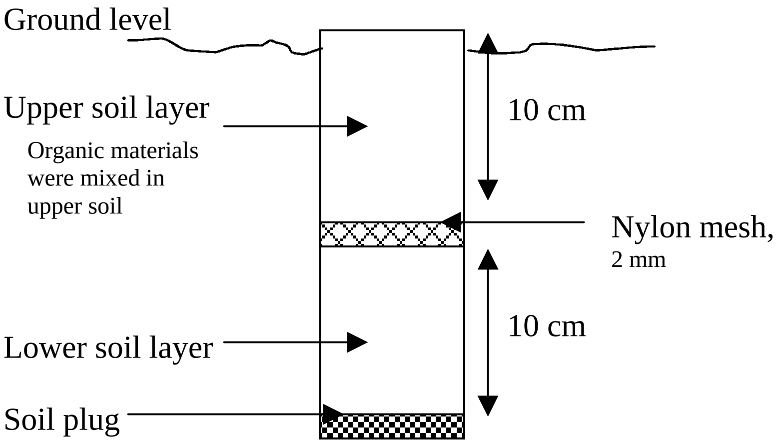


Fig. 5.1. The set up of the *in situ* incubation of organic materials in aluminum core

The gross plot size was 11.7 x 12.0 m and the net plot size was the interior 6.75 x 8.10 m. Each gross plot with trees consisted of 8 rows of leguminous trees with 13 trees per row, and 16 ridges with 13 maize planting hills per ridge. The net plot had 4 tree rows and 9 ridges with 9 maize planting hills. The net plots were pegged in the first season so that the data collection was done within the same area during the two seasons of cropping.

Because of planting of agroforestry trees in furrows and maintaining of ridges in the same position every season (*i.e.* ridges were not shifted during land preparation) we were able to maintain same number of ridges and maize plant population in both tree plots and non tree plots. In this case there were no ridges lost to trees in the agroforestry plots.

5.2.2.2 Management and chemical properties of organic materials

The field trial was conducted in 2000-01 and repeated in 2001-02 at the same site, maintaining the treatments in same plots. In the first season (2000-01), 3-months old gliricidia coppices and 10-months old sesbania trees were cut and incorporated on 11th November 2000. In the second season (2001-02), trees were cut and incorporated in the soil on 6th November 2001. Tree leaves and small twigs were stripped and incorporated on the ridge while fresh. For experimental reasons, prunings and crop residues were collected first from all plots, and chopped and mixed thoroughly, so as to be able to apply uniform and homogeneous portions of prunings and residues to the respective plots. Samples were taken for analyses of the prunings and crop residues. Due to low biomass yield of sesbania the amount of biomass applied was reduced to 1.5 ton DM/ha in both years. Tree and crop management was as described in Sections 2.2.1 and 2.2.2.

Pigeonpea biomass was cut and incorporated at the same time as gliricidia and sesbania. Pigeonpea litter that had accumulated on the ground during the growing period was swept and removed from the pigeonpea plots where we had to apply pigeonpea roots only (Pea-R). The pigeonpea roots growing within the ridge (30 cm soil depth) were removed from the plots where we applied pigeonpea leaves only (Pea-L).

Gliricidia, sesbania and pigeonpea samples were collected a week before cutting for determination of dry-matter; sampling was repeated at the time of incorporation of tree prunings for chemical analysis.

The nutrient mass fractions are tabulated in Table 5.1. Gliricidia, sesbania and pigeonpea green leaves had high N content and low C:N ratio. Maize stover had low N and a wide C:N ratio. The mass fractions of N, P and K in the crop residues decreased in the order of pigeonpea leaves, pigeonpea roots and maize stover. Since pigeonpea green leaves were combined with litter, the combined pigeonpea leaf material was considered as medium quality material. The amounts of organic N applied via the organic materials are presented in Table 5.2.

5.2.2.3 Mineral N in soil profile

Soil samples were collected from the net plot at monthly intervals between October and February from 0 to 20 cm. In December and February the soil samples were collected up to 200 cm deep, to assess the N levels in deeper soil layers. December was chosen because in Malawi rainfall starts intensifying in December and also topsoil mineral N peaks in December (Makumba and Maghembe, 1999). February was chosen as we assumed that at that time some mineral N would have been leached from the topsoil to deep soil layers. NH_4-N and NO_3-N were extracted from fresh soil in 2 M KCl.

Table 5.1. Mass fractions of N, P, K and C (mg/g), and C:N ratio of the organic materials incorporated in the soil.

Organic material	N	P	K	C	C:N
Sesbania	34.4	1.2	11.7	488	15
Gliricidia	28.9	4.0	12.2	467	16
Pigeonpea fresh leaves	32.4	1.4	11.6	463	14
Pigeonpea litter	16.3	1.1	9.8	472	29
Pigeonpea roots	8.6	0.6	13.7	490	57
Maize stover	4.7	0.6	7.9	405	86

5.2.2.4 Maize yield and N uptake

Maize was harvested between first and second week of May. Maize yield was measured from the net plot. All maize stover harvested in the net plot was weighed and the weight was recorded. A sample was taken to determine dry matter content and used to correct the weight of the dry-matter yield of stover. After shelling the maize cobs, grain and rachis were weighed separately and their weights were recorded. Samples of grain and rachis were collected and dried in an oven at 72 ^{o}C for 48 hrs and their dry-matter contents were determined. The dried plant materials were finely ground and analyzed for total N as described in Section 2.4.2. N present in each of the three parts of the maize plant was calculated as the product of its dry-matter yield and N mass fraction. The Total N uptake reported is the sum of the amounts present in the three plant parts.

5.2.2.5 Pigeonpea and tree biomass

Pigeonpea yield and tree (gliricidia and sesbania) biomass and N uptake were recorded at the end of the experiment. The results of these are discussed in detail in Chapters 6 and 7, as the focus in the current Chapter 5 is on the effects of organic amendments on maize yield and N uptake only.

Table 5.2. Organic N and P (kg ha^{-1}) applied in the field trial with the various treatments, and weighted mean C:N. Please, refer to Section 5.2.2.1 for the abbreviations

	Organic N			Organic P			Weighted mean C:N		
	NTP	Ss	Gs	NTP	Ss	Gs	NTP	Ss	Gs
NCR	-	52	87	-	2	12	-	15	16
Pea-L	35	87	122	2	4	14	20	17	17
Pea-LR	39	91	126	2.3	4.3	14.3	24	19	19
Pea-R	4	56	91	0.3	2.3	12.3	57	17	18
Stover-1	7	59	94	0.9	2.9	12.9	86	23	21
Stover-2	14	66	101	1.8	3.8	12.8	86	30	26

5.3 Primary results

5.3.1 *In situ* incubation experiments

5.3.1.1 Litterbag experiment

The weight of tree pruning dry-matter decreased faster than that of the crop residues and their mixtures. After 14 days 56% of gliricidia and 59% of sesbania dry-matter remained in the litterbags whereas for the crop residue the dry-matter ranged from 71 to 97% (Table 5.3). At the end of the experiment, after 84 days, most of the dry-matter of the tree prunings had decomposed and only 8% of gliricidia and 9% of sesbania dry-matter was left in the litterbags; from the crop residues alone 12-36% remained and from the mixtures between 10 and 23%.

5.3.1.2 Aluminum core experiment

Tree prunings and pigeonpea leaves had a net N released within 14 days of incubation. Between day 14 and day 84, there was not much increase and even a decrease in some cases. Stover-1 and Stover-2 showed an initial immobilization of soil mineral N during the first 42 days. Net N release in Stover was observed after 63 days of incubation (Table 5.4, Appendix 5.3). The mixtures of tree prunings and Pea-L had more N released than the tree prunings alone. Mineral N released was less in the mixtures of the tree prunings with Stover and Pea-R than in Gs/NCR and Ss/NCR throughout the incubation period.

Table 5.3. Fractions of dry-matter remaining in litterbags determined at different times.

Crop residues	Time, days (DAB)[1]	NTP	Sesbania	Gliricidia
NCR	14	NA[2]	0.59	0.56
	21	NA	0.46	0.41
	42	NA	0.30	0.22
	63	NA	0.19	0.13
	70	NA	0.18	0.11
	84	NA	0.13	0.08
Pea-L	14	0.71	0.66	0.61
	21	0.57	0.55	0.48
	42	0.35	0.36	0.27
	63	0.17	0.25	0.16
	70	0.15	0.21	0.13
	84	0.12	0.17	0.10
Pea-LR	14	0.83	0.76	0.68
	21	0.70	0.67	0.56
	42	0.55	0.47	0.34
	63	0.39	0.35	0.22
	70	0.30	0.29	0.19
	84	0.15	0.24	0.16
Pea-R	14	0.80	0.86	0.79
	21	0.77	0.78	0.69
	42	0.60	0.53	0.43
	63	0.44	0.39	0.29
	70	0.36	0.33	0.25
	84	0.32	0.26	0.20
Stover-1	14	0.80	0.67	0.65
	21	0.70	0.53	0.52
	42	0.51	0.34	0.29
	63	0.33	0.23	0.18
	70	0.25	0.19	0.15
	84	0.15	0.15	0.13
Stover-2	14	0.84	0.76	0.68
	21	0.74	0.62	0.55
	42	0.57	0.43	0.36
	63	0.42	0.33	0.27
	70	0.31	0.29	0.24
	84	0.20	0.22	0.21

[1] DAB = days after burying the litterbags

[2] treatment NCR/NTP was not applicable (NA) in the litterbag decomposition experiment

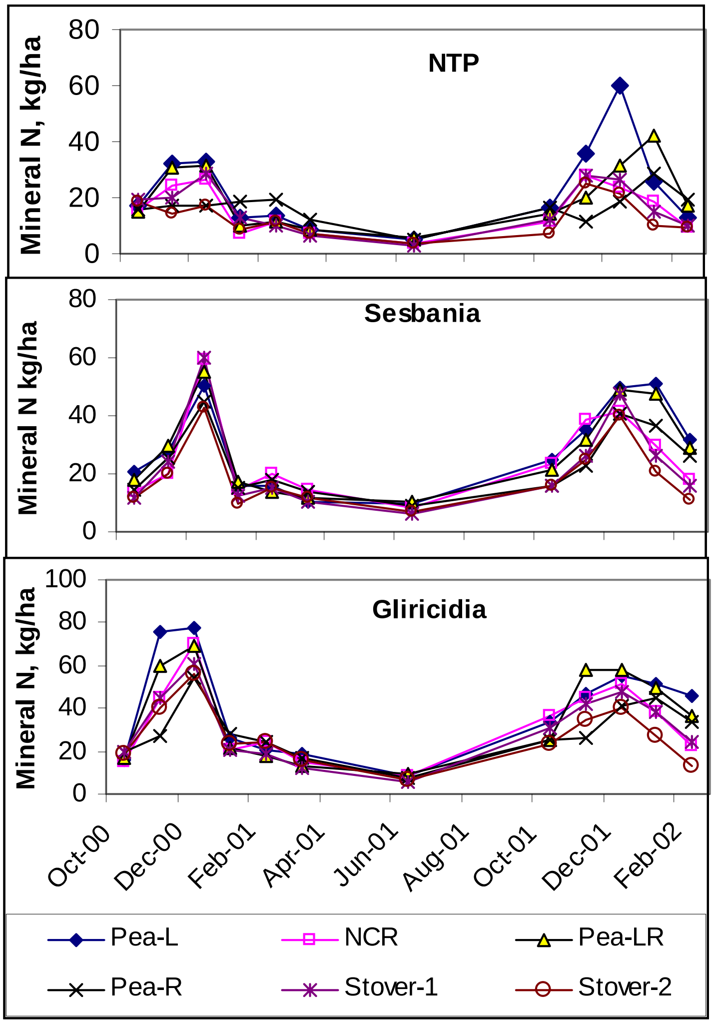


Fig.5.2. Variations of mineral N in the topsoil 0-20 cm between October 2000 and February 2002, as influenced by application of tree prunings, crop residues and their mixtures.

5.3.2 Agroforestry system trial

5.3.2.1 Soil mineral N

During the maize growing period a peak of mineral N in the topsoil (0-20 cm) was observed in December, for both seasons (Fig. 5.2). In December 2000, mineral N averaged to 65 kg ha^{-1} for the treatments that received gliricidia prunings and 52 kg N/ha for sesbania prunings. In the first season (2000-2001) soil mineral N declined by January but in the following season (2001-02), it was rather high until February 2002. Soil mineral N was significantly (P = 0.05) lower in Gs/Pea-R and Gs/Stover-2 than in Gs/NCR in November and December. The trend was repeated in the second season (2001-02) but this time mineral N in tree prunings/Stover and tree prunings/Pea-R was substantially lower than in tree prunings/NCR between December and February.

Soil mineral N in all the treatments decreased with depth (Appendices. 5.4 and 5.5). Subsoil mineral N was higher in December than in February. Subsoil mineral N was high in treatments with pigeonpea.

5.3.2.2 Maize yield and N uptake

Table 5.5 presents the maize grain and total dry-matter yields. In both seasons maize grain yield was highest in gliricidia treatments, but also sesbania significantly ($P<0.001$) increased maize grain yield. In 2000-01, maize yield in treatments with Pea residues/NTP ranged between 1.7 and 2.7 t ha^{-1}, which was significantly ($P = 0.05$) higher than the NCR/NTP (0.85 t ha^{-1}) but the yields with Stover did not differ from NCR/NTP. Maize grain yield was generally higher in Gs/Pea-L, Gs/Pea-LR and Gs/Stover-1 than Gs/NCR in 2000-01 season but this difference was statistically not significant. In 2001-02, maize stover (Stover-1 and Stover-2) reduced maize yield by 30% below NCR/NTP but the difference was not significant. In 2001-02, mixtures of tree prunings with Stover-1 and Stover-2 had significantly lower maize grain and dry-matter yield than tree prunings alone or mixed with Pea-L, while mixtures with Pea-LR and Pea-R took a position in between. Generally, maize yield was lower in 2001-02 than in 2000-01 season. Analysis of variance (Table 5.6) showed significant effects of the addition of high quality and low quality organic materials. Also their interaction on maize was significant, but far less important than the main effects.

Tree prunings significantly ($P <0.001$) increased N uptake, especially gliricidia pruning treatments (Table 5.7). Amongst the crop residue treatments, Pea-L had highest N uptake, and N uptake from the mixtures of the Pea-L with tree prunings was higher than that from tree prunings alone. N uptake by maize in the mixtures of tree prunings with Pea-R, Stover-1 and Stover-2 was statistically not different from the N uptake in the tree pruning/NCR in 2000-01 but N uptake was lower than tree prunings/NCR in 2001-02 season.

The effects of tree prunings on N uptake were much stronger than those of crop residues; both were highly significant. Again their interactions were significant in both seasons (Table 5.8), but less important than the main effects.

Table 5.4. Mineralized N (mg/core) in the *in situ* aluminum core experiment.

Crop residues	Time, days	NTP	Sesbania	Gliricidia
NCR	14	4	28	42
	21	5	41	41
	42	8	44	47
	63	5	42	49
	84	2	35	62
	104	3	32	48
Pea-L	14	16		50
	21	20		55
	42	25		56
	63	26		64
	84	39		72
	104	36		74
Pea-LR	14	11		43
	21	20		45
	42	23		55
	63	32		59
	84	36		61
	104	42		61
Pea-R	14	6		31
	21	6		36
	42	3		41
	63	7		42
	84	2		42
	104	5		46
Stover-1	14	2	15	27
	21	6	22	38
	42	6	28	41
	63	11	38	41
	84	6	38	39
	104	7	41	42
Stover-2	14	2	13	22
	21	4	20	31
	42	3	18	33
	63	8	17	34
	84	6	21	44
	104	6	21	51

Table 5.5. Maize grain yield and total dry-matter yield (t ha^{-1}) as a function of the addition of high quality and low quality organic materials. See text for explanation of the codes.

	2000-01				2001-02			
	NTP	Sesbania	Gliricidia	*Mean*	NTP	Sesbania	Gliricidia	*Mean*
Grain yield								
NCR	0.85 c	2.0 a	3.1 a	*2.0*	1.0 b	1.9 a	3.0 a	*2.0*
Pea-L	2.7 a	2.2 a	3.7 a	*2.9*	1.6 a	2.2 a	3.1 a	*2.3*
Pea -LR	2.4 a	2.2 a	3.5 a	*2.7*	1.5 a	2.0 a	2.5 b	*2.0*
Pea-R	1.7 b	1.5 a	3.1 a	*2.1*	1.3 a	1.4 b	2.4 b	*1.7*
Stover-1	1.5 bc	2.2 a	3.4 a	*2.4*	0.7 b	1.2 bc	2.1 bc	*1.3*
Stover-2	1.4 bc	1.9 a	3.1 a	*2.1*	0.7 b	1.0 c	1.7 c	*1.1*
Mean	*1.7*	*2.0*	*3.3*	***2.4***	*1.1*	*1.6*	*2.4*	***1.7***
Total dry-matter yield								
NCR	1.9 c	3.9 a	6.4 a	*4.1*	2.1 bc	3.9 a	6.1 ab	*4.0*
Pea-L	5.9 a	4.5 a	7.8 a	*6.0*	3.5 a	4.6 a	6.4 a	*4.8*
Pea -LR	5.1 a	4.7 a	7.2 a	*5.7*	3.2 a	4.4 a	5.1 bc	*4.4*
Pea-R	3.5 b	3.2 a	6.5 a	*4.4*	2.6 b	2.9 b	4.8 bc	*3.5*
Stover-1	3.0 bc	4.6 a	7.1a	*5.5*	1.6 cd	2.5 b	4.1 cd	*2.7*
Stover-2	2.9 bc	3.9 a	6.3 a	*4.4*	1.5 d	2.2 b	3.4 d	*2.4*
Mean	*3.7*	*4.2*	*7.2*	***5.0***	*2.4*	*3.4*	*5.0*	***3.4***

Table 5.6. ANOVA Table for the maize grain and dry-matter yield for 2000-01 and 2001-02 seasons (see Table 5.12 for explanation of figures in parenthesis in d.f. column)

		2000-01 season				2001-02 season			
s.v.	d.f.	s.s.	m.s.	f	sign.L	s.s.	m.s.	f	sign. L
Grain									
Rep (R)	2	0.01	0.003	0.03		0.41	0.20	4.85	
Tree Pruning (TP)	2	25.40	12.70	101	<0.001	15.07	7.53	180	<0.001
Crop residue (CR)	5	6.03	1.21	9.58	<0.001	9.00	1.80	42.9	<0.001
TP x CR	10	3.26	0.33	2.59	0.019	1.57	0.16	3.73	0.002
Error	33(1)	4.15	0.13			1.43	0.04		
Total	52(1)	37.64				27.46			
Dry-matter									
Rep (R)	2	0.06	0.03	0.05		1.07	0.54	2.20	
Tree Pruning (TP)	2	110.81	55.41	96.83	<0.001	63.92	31.96	131.	<0.001
Crop residue (CR)	5	29.68	5.93	10.37	<0.001	43.26	8.65	2	<0.001
TP x CR	10	14.82	1.48	2.59	0.019	6.13	0.61	35.5	0.022
Error	33(1)	18.88	0.57			8.28	0.24	3	
								2.52	
Total	52(1)	169.04				122.7			

Table 5.7**.** Total maize N uptake (kg ha^{-1}) in the above-ground crop treated with gliricidia, sesbania prunings and crop residues.

	2000-01				2001-02			
	NTP	Sesbania	Gliricidia	*Mean*	NTP	Sesbania	Gliricidia	*Mean*
NCR	22 c	52 a	78 b	*51*	19 c	41 ab	64 a	*41*
Pea-L	58 a	57 a	96 a	*70*	34 a	45 a	66 a	*49*
Pea -LR	64 a	54 a	81 b	*67*	30 ab	40 ab	54 b	*41*
Pea-R	38 b	43 a	73 b	*51*	25 b	30 bc	53 b	*36*
Stover-1	36 b	54 a	75 b	*55*	16 c	26 c	46 bc	*29*
Stover-2	34 b	49 a	72 b	*52*	15 c	23 c	38 c	*25*
Mean	*42*	*52*	*79*	***58***	*23*	*34*	*53*	***37***

Table 5.8. Analysis of variance for the N uptake by maize.

		2000-01				2001-02			
s.v.	d.f.	s.s.	m.s.	f	sign.L	s.s.	m.s.	f	sign. L
Rep (R)	2	945	472	2.74		174	87	4.40	
Tree Pruning (TP)	2	13253	6627	38.43	<0.001	8419	4209	212.50	<0.001
Crop residue (CR)	5	3410	682	3.96	0.006	3348	670	33.80	<0.001
TP x CR	10	2181	218	1.26	0.029	571	57	2.88	0.01
Error	33(1)	5691	172			674	19		
Total	52(1)	25271				13185			

5.4 Data processing

5.4.1 Decomposition rate constants

Figure 5.3 shows the graphs of natural log of the fraction of remaining weight of dry matter plotted against time t (days). The average decomposition rate constants of the organic materials for the whole period are given by gradient of the linear regression lines and are tabulated in Table 5.9. A decomposition rate constant per day of pure materials was highest for Gs (2.93%) followed by Pea-L (2.64%), sesbania (2.28%), while that for Stover-2 (1.80%) was lowest. Decomposition rate constants of mixtures of tree prunings and crop residues were somewhere in between the decomposition rate constants of the individual components but not necessarily their average. The decomposition rate constant of Stover-2 was less than that of Stover-1 despite that the materials were from the same source.

Expected mean decomposition constants for the mixtures were derived from expected remaining amounts of dry matter in the mixtures (Table 5.9). The measured decomposition rate constants were on average 89% of the expected values.

Also the decomposition rate constants for each period of sampling: 0-14, 14-21, 21-42, 42-63, 63-70 and 70-84, were calculated applying Equation 5.3 (Appendix 5.6). The decomposition rate constants for the crop residues (NTP) were slow for the first 63 days, and gradually tended to increase thereafter. In contrast the decomposition constants for the tree prunings (NCR) were high at the beginning and gradually decreased with time. The decomposition rate constants for the mixtures of tree prunings and crop residues gradually decreased between 0 and 63 days.

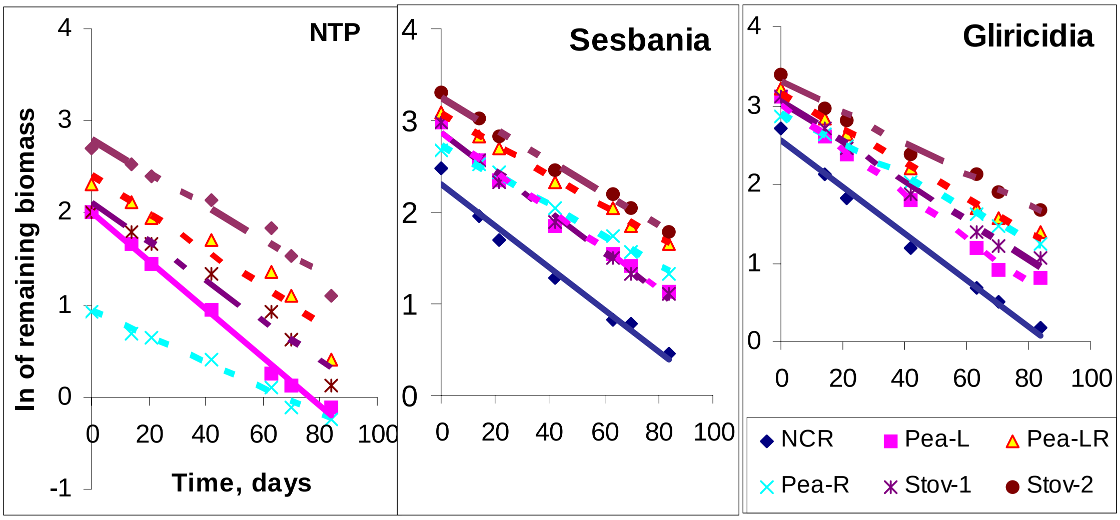


Fig. 5.3. Derivation of decomposition constants of tree prunings, crop residues and their mixtures from the relation of the natural log of remaining mass fraction and time (days). Decomposition rate constants have been tabulated in Table 5.9

Table 5.9. Decomposition rate constants (%day^{-1}) of tree prunings, crop residues and their mixture in litterbag, as derived from Fig. 5.3

	NTP	Sesbania	Gliricidia
NCR		2.28	2.93
Pea-L	2.64	2.11	2.83
Pea-LR	2.01	1.69	2.21
Pea-R	1.38	1.63	1.98
Stover-1	2.14	2.19	2.50
Stover-2	1.80	1.73	1.96
Expected mean decomposition constants[a]			
Pea-L		2.42	2.82
Pea-LR		2.14	2.45
Pea-R		2.05	2.52
Stover-1		2.22	2.58
Stover-2		1.98	2.21

[a] Expected mean decomposition constant for the mixtures are derived from expected remaining amounts of dry-matter in the mixture. The expected value of a remaining amount is equal to the sum of the values of the components of the mixture.

5.4.2 Fractions of N immobilized

From the trends observed in aluminum core *in situ* incubations it is apparent that Stover immobilized soil mineral N early in the season. The three treatments, Stover-1, Stover-2 and Pea-R were further compared with the tree prunings to determine the N fractions immobilized. The procedure described in Section 3.4.2 was deployed to calculate the N fraction immobilized by the Pea-R and Stover (Fig. 5.4). The regression coefficients, R-square and N fraction immobilized are given in Table 5.10. It is clear that more N was immobilized in 2001-02 than in 2000-01 by the time of harvest. Stover-2 had the highest N fraction immobilized in both seasons, 15% in the wetter season (2000-2001) and 35% in the drier season (2001-2002).

5.4.3 Apparent N recovery and substitution values

Apparent N recovery from the tree prunings was calculated as described in Section 4.2.3. The apparent N recovery fractions were higher for Gs than for Ss (Table 5.11), and ranged between 0.65 for Gs/NCR and 0.35 for Ss/Pea-LR in 2000-01 season. In 2001-02 the apparent recovery fractions ranged from 0.06 in Ss/Stover-2 to 0.52 in Gs/NCR.

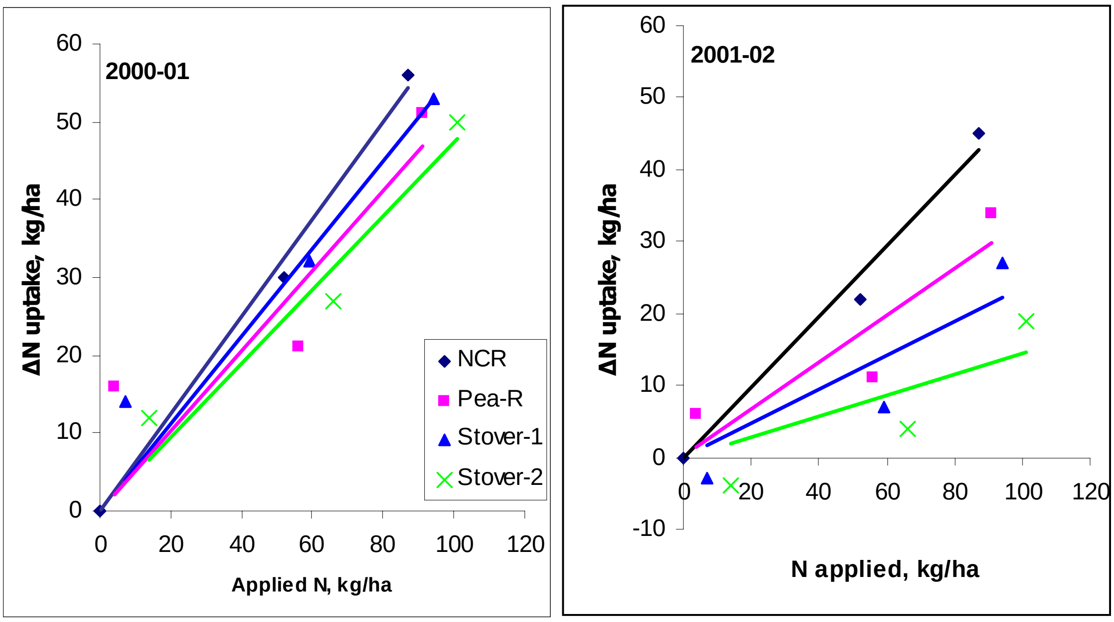


Fig. 5.4 Relationship between Delta N uptake and equivalent N applied for No-CR, Pea-R and Stover determined at the time of harvest. Regression coefficient, **a**, R-square and derived N fraction immobilized are presented in Table 5.10

Table 5.10 Values of regression coefficient a and of R-square of regression coefficient equations (y = ax) relating Delta N uptake at the time of harvest to the applied equivalent fertilizer N.

	Regression coefficient a	R-square	Fraction of N immobilized
2000-01			
NCR	0.63	0.99	
Pea-R	0.51	0.62	0.14
Stover-1	0.56	0.87	0.06
Stover-2	0.47	0.93	0.15
2001-02			
NCR	0.49	0.93	
Pea-R	0.33	0.79	0.17
Stover-1	0.24	0.93	0.26
Stover-2	0.14	0.68	0.35

Generally, recovery fractions were lower for all the treatments in 2001-02 than in 2000-01. Using the mean apparent recovery fraction of CAN (0.75) found in Section 4.3.4 the substitution values of the tree prunings were calculated (Table 5.11). The substitution values were higher for Gs than for Ss and were reduced when the tree prunings were mixed with crop residues in both seasons.

The apparent N recovery from organic materials is generally higher than those reported by others (*e.g.* Haggar *et al.*, 1993; Handayanto *et al.*, 1994; Palm, 1995; Mafongoya and Nair, 1997). However, apparent N recovery fractions of up to 79% have been reported by Xu *et al.* (1992) using ^{15}N in leucaena alley cropping at Katherine Research Station, Australia. Nair *et al.*, 1999 in his synthesis of Nutrient Cycling in Tropical Agroforestry Systems: Myths and Science cited N recovery fractions estimates of 60%. Although such high N recovery fractions have been reported by others we cannot exclude the possibility that in our experiment the high values of N recovery fractions were partly due to N mineralized from the old SOM that accumulated in the soil in the previous seasons and also from the decomposing small tree roots and senescent nodules from gliricidia, sesbania and pigeonpeas (Escalante *et al.*, 1984; Chesney and Nygren, 2002).

The apparent N recovery fractions for the crop residues were incredibly high, especially in 2000-01. The high apparent recovery fractions may in part reflect the long-term effects of the systems themselves in which the crop residues were tested. Alternatively, because of low N applied through the crop residues (*i.e.* 4 kg ha^{-1} for crop residues and 7 kg ha^{-1} for Stover) their effect might have been masked by the N released by weeds incorporated during the two weeding times (since some of the weeds can fix N) and also decomposing maize roots from the previous crop (Singh and Shekhar, 1989) resulting in increased N uptake. Escalante *et al.* (1984) reported that senescent nodules on decomposing release substantial amounts of N. Since apparent N recovery fraction is a function of applied N, small additions of unaccounted for N could result in large deviations. We decided that the values were unreliable for the calculation of SV.

Table 5.11. Apparent N recovery fractions and substitution values of tree prunings and their mixtures with crop residues

	2000-01 season				2001-02 season			
	[a]NTP	Ss	Gs	[b]Mean	NTP	Ss	Gs	Mean
Recovery fractions								
NCR		0.58	0.65	*0.62*		0.39	0.52	*0.46*
Pea-L	1.03	0.41	0.60	*0.51*	0.43	0.33	0.32	0.33
Pea-RL	1.08	0.35	0.46	*0.41*	0.28	0.23	0.28	*0.26*
Pea-R	4.00	0.37	0.56	*0.47*	1.50	0.20	0.38	0.29
Stover-1	2.00	0.55	0.58	*0.57*	-0.43	0.13	0.29	*0.21*
Stover-2	0.86	0.41	0.50	*0.46*	-0.29	0.06	0.19	*0.13*
Mean	*1.79*	*0.45*	*0.56*	***0.50***	*0.30*	*0.22*	*0.33*	***0.28***
Substitution values								
NCR		0.77	0.87	*0.82*		0.52	0.69	*0.61*
Pea-L		0.55	0.80	*0.67*		0.44	0.43	*0.43*
Pea-RL		0.47	0.61	*0.54*		0.31	0.37	*0.34*
Pea-R		0.49	0.75	*0.62*		0.27	0.51	*0.39*
Stover-1		0.73	0.77	*0.75*		0.17	0.39	*0.28*
Stover-2		0.55	0.67	*0.61*		0.08	0.25	*0.17*
Mean		*0.59*	*0.74*	***0.67***		0.30	*0.44*	***0.37***

[a] NTP values are unbelievably high, see text for explanation. Therefore, substitution values were not calculated.

[b] The mean values along the rows are for Ss and Gs only.

5.4.4 Interaction between maize stover and tree prunings

Tables 5.6 and 5.8 showed a significant interaction between tree prunings and crop residues (TP*CR). We assumed this was because pea leaves and roots were quite different materials than maize stover and also different amounts of cumulative effects. Maize stover had low N content and wide C:N ratio, and gave the lowest decomposition rate constants. Therefore, an analysis of variance was done separately for tree prunings and maize stover. Table 5.12 shows that the interaction between tree prunings and maize stover for the yields and uptake parameters was not significant in 2000-01 season, it was significant in 2001-02 season. In the second season, N immobilized early in the season might not have been remineralized yet within the time course of crop's demand because of low rainfall, and hence yields, and N uptake are reduced by stover. The difference between Stover-1 and Stover-2 is depending on the type of tree pruning treatments. Such a relation is not seen in season 2000-01. We believe that the interaction observed in the second season was due to the influence of rainfall. Lack of statistical interaction between stover and tree prunings on maize yield parameters in the first season is due to the fact that N immobilized early in the season had been released within the time of demand by the crop to such an extent that the difference between Stover-1 and –2 has not been affected any more by the tree pruning treatments.

Table 5.12. Two way ANOVA testing the interaction between tree prunings and maize stover on the maize yield parameters.

		2000-01 season				2001-02 season			
s.v.	d.f.[a]	s.s.	m.s.	f	sign. L	s.s.	m.s.	f	sign. L
Grain									
Rep (R)	2	0.13	0.07	0.86		0.004	0.002	0.15	
Tree prun. (TP)	2	17.10	8.55	110	<0.001	9.57	4.78	415	<0.001
Stover (St)	2	0.71	0.36	4.61	0.028	3.34	1.67	145	<0.001
TP x St	4	0.31	0.08	0.99	0.442	0.83	0.21	18.04	<0.001
Error	15(1)	1.16	0.08			0.18	0.01		
Total	25(1)	17.92				13.93			
Dry matter									
Rep (R)	2	0.59	0.29	0.87		0.26	0.13	0.78	
Tree prun. (TP)	2	73.08	36.54	109	<0.001	36.27	18.13	110	<0.001
Stover (St)	2	3.23	1.61	4.81	0.024	14.29	7.14	43.26	<0.001
TP x St	4	1.22	0.31	0.91	0.483	3.57	0.89	5.41	0.006
Error	15(1)	5.03	0.34			2.64	0.17		
Total	25(1)	76.57				57.03			
N uptake									
Rep (R)	2	299	149	1.33		66	33	1.87	
Tree prun. (TP)	2	9303	4652	41.3	<0.001	4923	2461	139	<0.001
Stover (St)	2	132	66	3	0.570	1120	560	31.66	<0.001
TP x St	4	312	78	0.58	0.608	399	100	5.64	0.005
Error	15(1)	1688	113	0.69		283	18		
Total	25(1)	11017				6792			

[a] Stover-1 treatment, replicate 2 for the first season had an out liar hence the data was pulled out and was treated as missing data. In 2001-2002 there was no missing data therefore the d.f. of Error and Total should be equal to 16 and 26 respectively. Tree prun. (TP) = tree prunings.

5.5 Discussion

5.5.1 Decomposition rates

The estimated decomposition rate constants of the tree prunings obtained in this study (Table 5.9) are among the highest reported. In literature decomposition rate constants for gliricidia have been found to range between 2.40% and 3.10% day^{-1} (Budelman, 1988; Mwiinga *et al*., 1994; Hartemink and Sullivan, 2001), while for sesbania a rate constant of 2.10% day^{-1} has been reported by Mwiinga *et al*. (1994). The rate constants of gliricidia seem to be related to the pretreatment of the prunings. By Budelman (1988) and in our study fresh materials were used, yielding relatively high rate constants (3.10% and 2.93% day^{-1}, respectively) whereas some researchers (*e.g.* Mwiinga *et al.,* 1994; and Hartemink and Sullivan, 2001) used oven dried prunings.

The rate constants of the tree prunings tended to decline with time. Apparently, the high N content of the tree prunings and the easily decomposable compounds facilitated the initial fast decomposition of the leafy materials and since the remaining twigs were more lignified and recalcitrant to decomposition the decomposition rate decreased. Berg and Meentemeyer (2002) alluded the decrease in decomposition rate constant of organic materials to chemical changes in the substrate itself and the succession in microorganisms able to compete for substrate with a given chemical composition. On the other hand the initial slow decomposition of crop residues could be influenced by the low N content in crop residues that might have affected the colonization by the soil microbes. The decomposition constants of the mixtures of gliricidia and crop residues declined with time and were higher than those of crop residues alone this was because the fast decomposing gliricidia released large amounts of N to offset the N shortage in the crop residues. The decomposition rate constants of mixtures of sesbania and crop residues remained low during the first 63 days, suggesting that sesbania was unable to supply enough N to relieve the N shortage in the residues.

5.5.2 Mineralization, immobilization and remineralization of N

The lower N recoveries in 2001-02 than in 2000-01 suggest that decomposition, mineralization, immobilization and remineralization were dependent on the amount of rainfall. In the first season, 2000-01, when the rainfall was 1200 mm, N uptake by maize in mixtures of tree prunings with Pea-R and Stover were not significantly different from tree prunings/NCR whereas during the drier season, 2001-02 (800 mm, See Appendix 5.1), N uptake in Pea-R and Stover mixtures was significantly ($P = 0.05$) lower than in tree prunings/NCR. Prolonged dry conditions or extreme temperatures delay mineralization because in such conditions the microbial population decline (Myers *et al.*, 1984). We suggest that this effect was the influence of the drier conditions retarding the processes of decomposition, mineralization and remineralization, and it was not a special interaction between crop residues and tree prunings. Also that the measured decomposition rate constants were 89% of the expected values corroborates that there was no special interaction between the crop residues and the tree prunings.

Increasing the rate of stover in the mixtures with tree prunings reduced maize grain and dry-matter yields. The immobilization of N might have been larger in Stover-2 compared to Stover-1, and remineralization of N came too late for the crop demand. Similar effects were also observed in Kenya where maize yield was reduced by 30% after doubling the amount of stover applied (Qureshi, 1987; Nandwa, 1995). The slow remineralization of N by Stover-2 is reflected by the high fraction of N immobilized at harvest (Table 5.10). Also as found earlier in the green house experiment described in Chapter 3 the fraction of N immobilized increased when the proportion of stover in the mixture was increased (Section 3.4.2). Becker *et al*. (1994) showed that increasing rice straw in the sesbania-rice straw mixture decreased the net N mineralization. In a pot experiment Handayanto *et al.* 1997 also found that N recovery by maize decreased when the proportion of low quality peltophorum prunings in the gliricidia-peltophorum pruning mixture was increased.

Our results indicate that mixing of 3 t ha^{-1} gliricidia prunings with 1.5 t ha^{-1} maize stover (or 2:1 prunings: stover ratio) would better synchronize the N release by the organic materials and N demand by maize than the higher rate of 3 t ha^{-1} stover (1:1 ratio of prunings to stover).

5.5.3 Soil mineral N and crop performance

Mineral N in the topsoil (0-20 cm) peaked in December and declined in January (Fig. 5.2). This trend conforms to the trend of mineral N reported in Section 4.3.1.1 for the gliricidia prunings applied in October and also reported by others (*e.g.* Ikerra *et al.*, 1999; Mugendi *et al.*, 1999; Cobo *et al.*, 2002). The early release of N from the tree prunings is in conformity with the initial high decomposition rate constants and high N of the prunings. Mixing pigeonpea leaves with tree prunings increased availability of topsoil mineral N over the tree prunings alone, resulting in high maize N uptake and yield. The higher soil mineral N in the mixtures of tree pruning and Pea-L than tree prunings alone was attributed to extra organic N (35 kg N ha^{-1}) added via the pigeonpea leaves (see Table 5.2) and the fact that the mixtures of Pea-L and the tree prunings had high decomposition rate constants (2.83 and 2.11% day^{-1} for Gs/Pea-L and Ss/Pea-L respectively).

Although soil mineral N was throughout lower in tree pruning/Pea-R and tree prunings/Stover-2 than in Gs/NCR and Ss/NCR in the first season (2000-01), maize grain yield and N uptake in Pea-R and Stover-2 were not significantly ($P = 0.05$) different from those in tree prunings/NCR. This suggests that N immobilized earlier in the season was remineralized later during the course of maize demand. The re-mineralized N in tree prunings/ Stover and tree prunings/ Pea-R could not be detected accumulating in the soil because it was directly being taken up by the maize plants. In the second season again N immobilization occurred as shown by the lower soil mineral N levels in the Pea-L and Stover mixtures with tree prunings than in tree prunings alone. The low maize N uptake and grain yield suggest that the crop did not recover the N immobilized early in the season, as also reflected by the low N recoveries. In the second season (2001-02) the decomposition of crop residues might not have been complete because of the drier conditions. Because of drier conditions moisture was limiting then only little N might have been re-mineralization (Myers, 1984).

Because of enhanced N immobilization by the maize stover, mineral N in the subsoil (140-200 cm) was low in Gs/Stover-2 and Ss/Stover-2 than in Gs/NCR and Ss/NCR respectively. Initial immobilization of N in the topsoil by stover might have reduced the chances of excess N being leached. Although we had high maize N uptake in the Gs/Pea-L and Ss/Pea-L subsoil mineral N was high relative to the tree prunings/NCR this could be partly due to leaching and partly due to mineral N released by decomposing pigeonpea roots of the previous season’s crop.

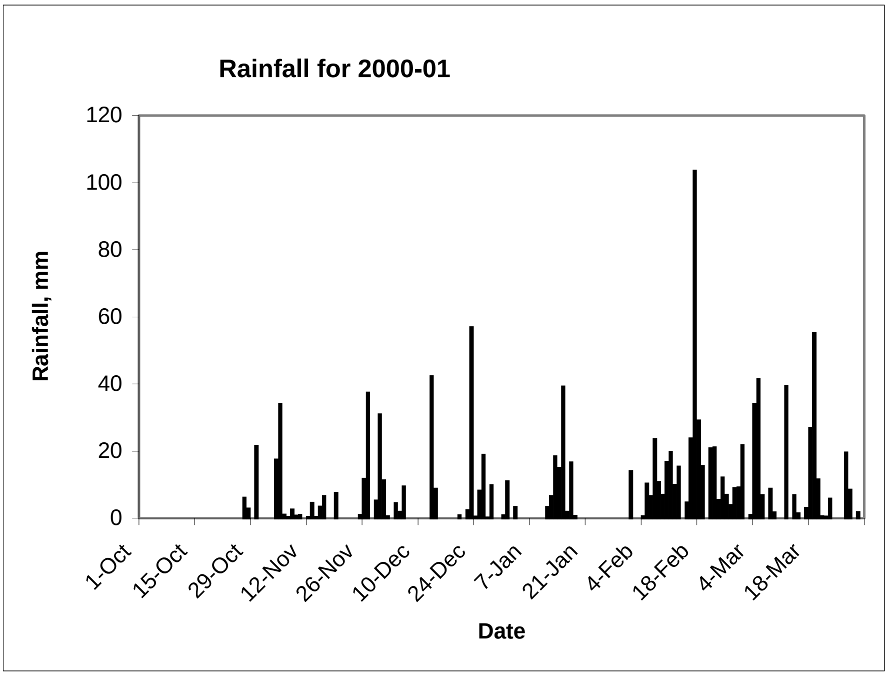
5.5.5 Substitution values

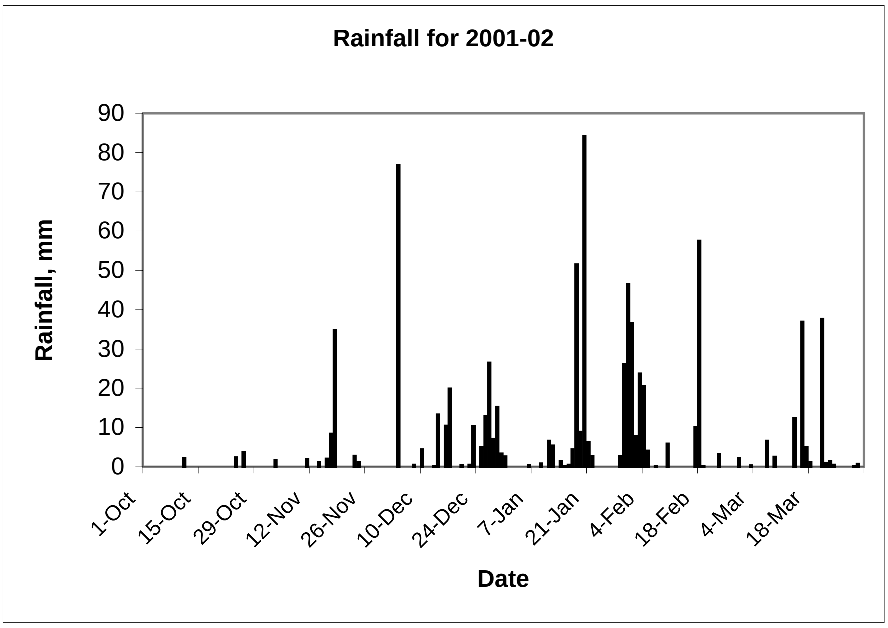
The substitution values for gliricidia obtained from two sites (MZ 18 reported in Section 4.3.4 and MZ 21) for the 2001-02 season were similar, and higher than that for sesbania. Sesbania had smaller leaves and higher twig:leaf ratio than gliricidia. Constinides and Fowness (1990) had shown that twigs reduce the amount of N released when mixed with leaves. Moreover, the twigs of the 9 months old sesbania were more lignified than those of the two months old gliricidia twigs. For these two reasons sesbania prunings had higher lignin:N ratio than gliricidia prunings and that would further reduce rate of decomposition of sesbania.

5.6 Conclusions

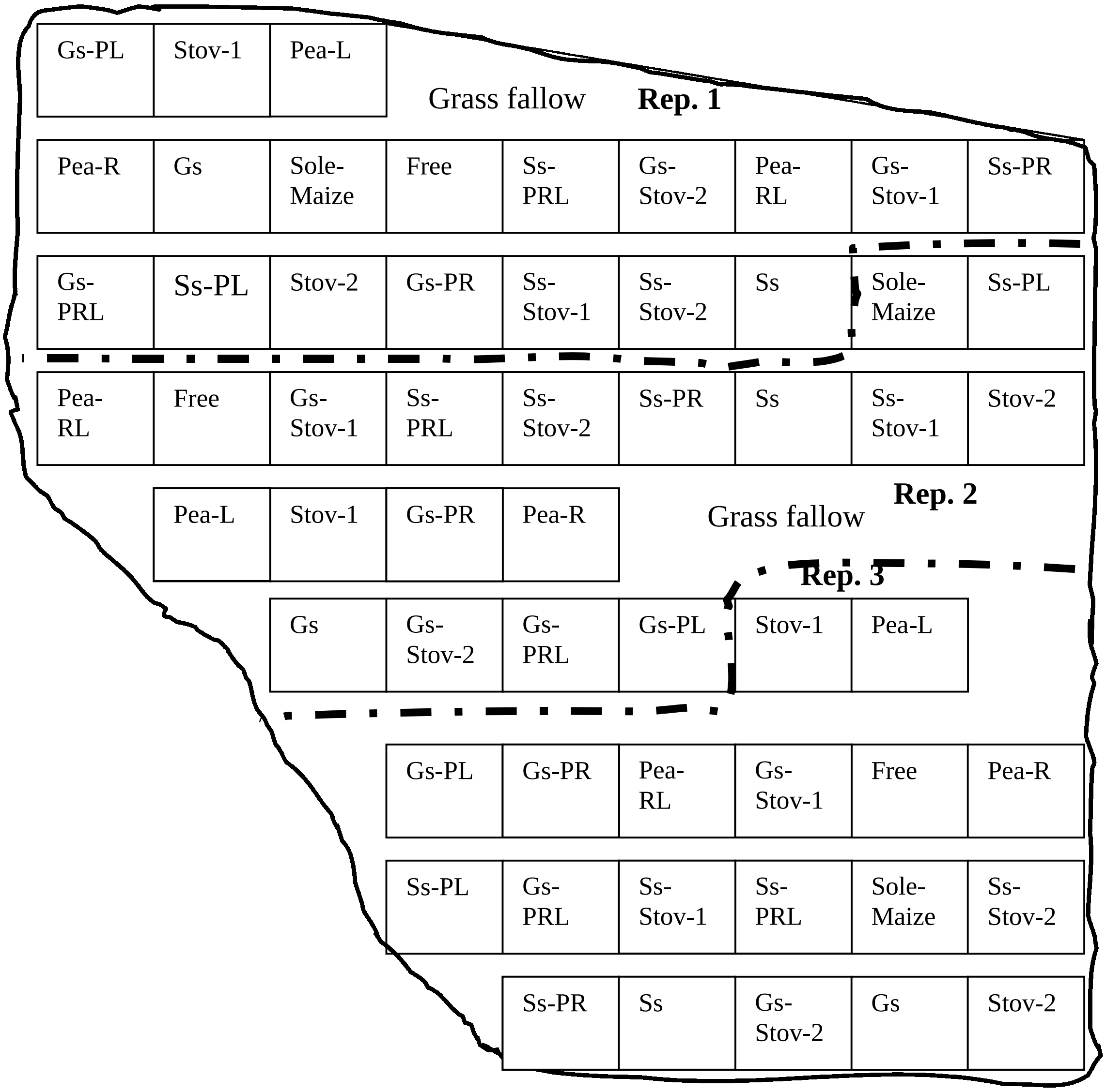
The decomposition pattern of the tree prunings and crop residues followed the order: Gs>Pea-L>Ss > mixtures (tree prunings/crop residues)>Stover-1>Stover-2>Pea-R. The decomposition rate constants of mixtures of high quality tree prunings and crop residues decreased with increasing amount of crop residues. There was no special interaction between high quality tree prunings and maize stover; the apparent statistical interaction can be expected as an effect of rainfall.

Remineralization of N immobilized early in the season was related to the amount of rainfall. During the drier season, 2001-02, Pea-R, Stover-1 and Stover-2 immobilized 17, 26 and 35% N, respectively resulting in reduction of maize N uptake and yield, whereas in the wetter season, 2000-01, N fraction immobilized was 4 to 7 times less and N uptake and maize yield were higher. This result confirms our second hypothesis that N from low quality crop residues may become available for crop uptake when conditions for decomposition and remineralization are good.





Appendix 5.1. Daily rainfall distribution during the period of experiments, in seasons 2000-01 and 2001-02 as recorded at Makoka Agricultural Research Station, meteorological sub-Station

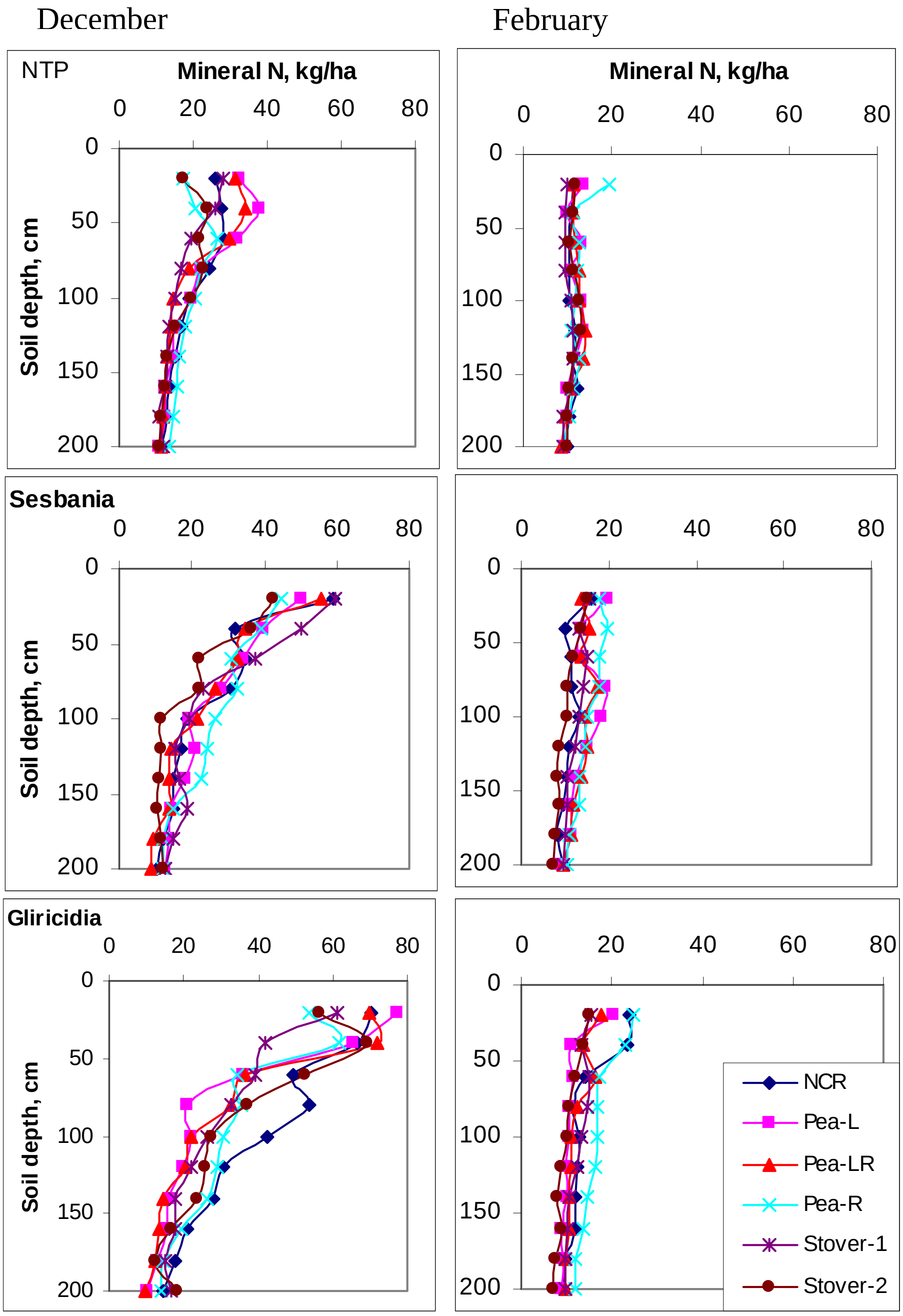


Appendix 5.2. Experiment layout of gliricidia-maize simultaneous intercropping, sesbania-maize relay cropping, sole-maize and pigeonpea and their combinations at MZ21 field.

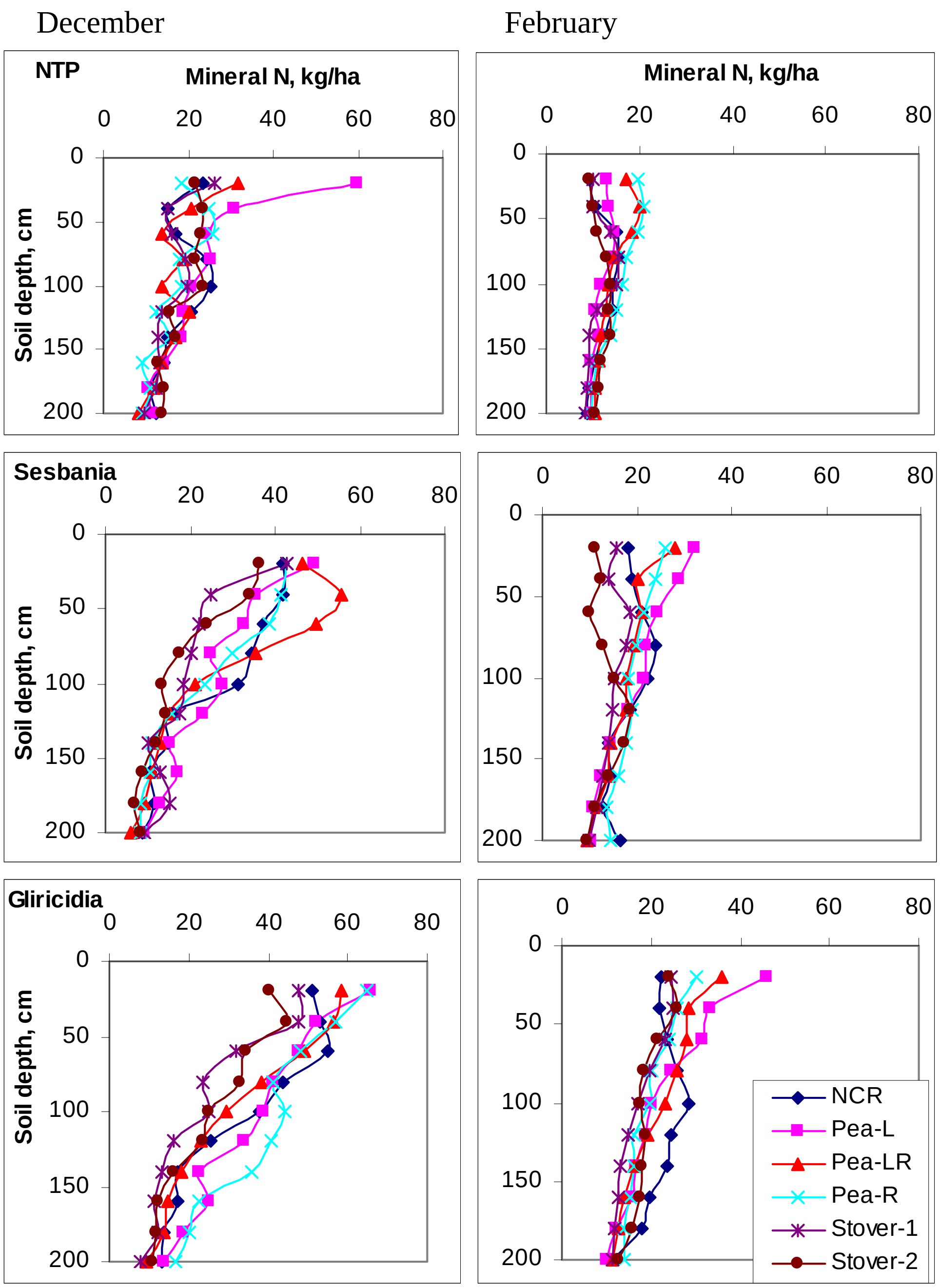
Sole-Maize = Control, Stov-1 = 1.5 t/ha maize stover added, Stov-2 = 3.0 t/ha maize stover, Pea-L (also PL)= Pigeonpea (only leaves incorporated), Pea-LR (PLR) = Pigeonpea leaves + roots, Pea-R (PR) = Pigeonpea roots, Gs = gliricidia, Ss = Sesbania, Free = the plot was cropped but data was discarded.

Appendix 5.3. Mineral N (mg) in the upper and lower soil (10 cm layer) in Aluminum core *in situ* incubation

	Time	Upper soil			Lower soil		
		NTP	Ss	Gs	NTP	Ss	Gs
NCR	14	3	14	24	2	14	17
	21	3	23	23	2	18	18
	42	3	26	27	5	18	20
	63	3	21	26	2	21	23
	84	1	18	26	1	17	37
	104	2	16	20	2	16	28
Pea-L	14	9		27	8		23
	21	12		29	8		25
	42	16		30	8		26
	63	15		34	11		29
	84	20		32	9		40
	104	18		30	18		44
Pea-LR	14	4		20	6		23
	21	14		21	7		23
	42	14		30	9		25
	63	20		25	12		34
	84	17		20	19		41
	104	20		20	22		42
Pea-R	14	1		16	5		15
	21	1		19	4		17
	42	1		19	2		22
	63	4		21	3		21
	84	1		19	1		24
	104	1		18	3		27
Stover-1	14	2	7	19	1	8	8
	21	2	13	21	4	9	18
	42	2	18	27	4	10	14
	63	2	24	22	8	14	19
	84	4	25	24	2	12	15
	104	3	27	24	3	13	18
Stover-2	14	1	8	14	1	5	8
	21	1	10	21	3	10	10
	42	2	11	25	1	7	8
	63	1	10	24	7	7	10
	84	1	14	27	5	7	17
	104	5	15	29	1	6	22



Appendix 5.4 Mineral N (kg per ha per 20 cm layer) along the soil profile, 0-200 cm depth, assessed in December 2000 and February 2001



Appendix 5.5 Mineral N (kg per ha per 20 cm layer) along the soil profile, 0-200 cm depth, as assessed in December 2001 and February 2002

Appendix 5.6 Stepwise decomposition k constants (% day^{-1}) for various time intervals, as derived from the litterbag experiment, using Eq. 5.3.

Time (Days)	Crop residues	NTP	Sesbania	Gliricidia
14	NCR		3.77	4.14
	Pea-L	2.45	2.97	3.53
	Pea-LR	1.33	1.96	2.75
	Pea-R	1.59	1.08	1.70
	Stover-1	1.59	2.86	3.09
	Stover-2	1.25	1.97	2.75
21	NCR		3.61	4.34
	Pea-L	3.14	2.60	3.42
	Pea-LR	2.43	1.74	2.77
	Pea-R	0.55	1.39	1.91
	Stover-1	1.91	3.35	3.29
	Stover-2	1.81	2.89	3.03
42	NCR		2.02	3.00
	Pea-L	2.37	2.05	2.80
	Pea-LR	1.15	1.71	2.32
	Pea-R	1.19	1.84	2.20
	Stover-1	1.54	2.14	2.76
	Stover-2	1.27	1.74	1.97
63	NCR		2.13	2.38
	Pea-L	3.30	1.81	2.72
	Pea-LR	1.64	1.49	2.26
	Pea-R	1.48	1.55	2.11
	Stover-1	1.99	1.95	2.45
	Stover-2	1.43	1.29	1.50
70	NCR		0.64	2.75
	Pea-L	2.07	2.02	2.29
	Pea-LR	3.75	2.26	1.79
	Pea-R	2.87	2.00	1.63
	Stover-1	4.11	2.02	1.98
	Stover-2	4.49	1.90	1.27
84	NCR		2.36	2.27
	Pea-L	1.59	1.59	1.81
	Pea-LR	4.95	1.48	1.23
	Pea-R	0.93	1.67	1.59
	Stover-1	3.65	1.69	1.07
	Stover-2	3.05	1.78	1.05