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Managing Decomposition and Mineralization of *Senna singueana* (Del.) Lock. Manure to Improve N Use Efficiency and Maize Yield in Morogoro, Tanzania

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Abstract: Carbon: nitrogen (C:N) and lignin: nitrogen (L:N) ratios of organic substances primarily determine the N mineralization and its availability to crop plants. Two field experiments were conducted at Kitete Village, Morogoro, Tanzania in 1998-99 to assess the effects of different C:N and L:N ratios of mixtures of *Senna singueana* foliage and local straw materials on decomposition and N mineralization for optimum N use efficiency of maize. Litterbags and the incubation methods were used for the studies. Residual mass, available mineral N, maize shoot height, N nutrient uptake and yield were measured. *Senna* leaves alone decomposed considerably fast with over 94% mass loss completed within the first 4 weeks of incubation. When these foliages were mixed with different proportions of local straw materials, however, the decomposition rate slowed down, with the mass loss percentage decreasing with increasing proportions of straw in the mixtures. The pattern of N released from *Senna* and straw manures closely resembled to the mass loss. The medium quality *Senna*-straw mixtures (C: N ratio of 30:1 and L: N ratio range of 2.7:1 to 4.5:1), optimally promoted the maize height growth from 160 to 248 cm and grain yield from 1.4 to 4.5 t ha^{-1}. The critical period of high N demand by the maize crop and grand period of vegetative growth were between 4-8 and 4-7 weeks, respectively. It is concluded that the foliage of indigenous shrub *S. singueana* has high potential use for N management in annual crop production. For *Senna*-straw mixtures, the critical C: N ratio should not exceed 30:1 and L: N ratio in the range of 2.7:1 to 4.5:1 for maximizing maize grain yield. In practical terms these ratios imply mixing of 1.6 t ha^{-1} of *Senna* dry leaves with either 3.1, 2.9 or 2.5 t ha^{-1} of maize, sorghum or panicum straws respectively.

Key words: Carbon, lignin, manure, nitrogen, synchronization, *Senna sigueana*

INTRODUCTION

Soil nutrients depletion, especially of nitrogen (N), has been suggested as the main biophysical factor limiting food crop production in many tropical smallholder farms[1].

In the past small-scale subsistence farmers across most of the African continent tried to improve soil fertility by using the traditional shifting cultivation, fallowing and rotational systems[2]. They also incorporated trees in their farming systems in an agroforestry setting or applied green manure, crop residues, compost and animal wastes[3]. Today, however, the traditional farming systems are constrained by the prevailing soil fertility problems caused by population increase which increase overcropping of fertile lands, shortening fallow period, deforestation, overgrazing and erosion. All these contribute to an acceleration of soil degradation, general land impoverishment as well as crop yield decline. Although adequate soil fertility for sustained crop yields can be achieved through widespread application of fertilizers the use of chemical fertilizers by the resource poor farmers is limited by their high prices, pollution problems and their inefficient use caused by erosion, volatilization, leaching and denitrification[1,3]. The use of safe, locally available and low cost organic materials capable of improving soil properties, crop growth and yield, therefore, seems to be a more practical option.

Indeed, addition to the soil of organic materials has been reported to conserve soil moisture[4,5], reduce soil temperature fluctuations[5,6], prevent weed seed germination[5,7], decrease soil erosion[8,9]], improve soil organic matter[10] and structure[11], increase N[5] and phosphorus (P)[12] availability, stimulate soil biological

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activities[13,14], ameliorate heavy metal toxicities (e.g. Al and Mn)[14,15] and improve both crop growth[14] and yield[5].

For an effective nutrient conservation in the cropping systems, however, the nutrients released from these organic N reserves should be synchronized with crop demand/uptake but this synchrony can only be achieved through the proper choice of agroforestry species and time of residue application. The knowledge of organic materials decomposition rates and the factors that affect them, however, is very crucial when choosing the type and time of residue application. Even if it is acknowledged that litter quality, especially its carbon (C) : N, lignin (L) : N, polyphenol:N or (lignin + polyphenol):N ratios control the rates of decomposition and mineralization[14,16,17], evidence exist to show that the C:N, L:N, polyphenol:N or (lignin + polyphenol):N ratio concept alone cannot be used to adequately describe the patterns of plant materials decomposition[6,18].

Although there has been a great deal of research directed at evaluating the effects of litter quality on decomposition and mineralization rates[19-21], most existing research tends to focus on mass loss and mineralization of well known exotic agroforestry tree/shrub species rather than focusing on indigenous species e.g. Senna (*Senna singueana* (Del.) Lock) (Mhumba) (*Caesalpinaceae* sub-family, *Fabaceae* family of the super family *Leguminoseae*)[22,23] which are of low cost, locally available, adapted to the local environmental conditions and well known by the smallholder farmers. Also knowledge about proper ways of controlling the decomposition rate of the applied green manures and thus synchronizing nutrients release with the critical period of high nutrient demand by agricultural crops has not been well studied.

This study, therefore, was designed to determine the agroforestry potential of *Senna singueana* as a source of organic manure and characterize its pattern of application in order to maximize crop production. It was hypothesized that widening the C: N and L: N ratios of *S. singueana* foliages using farm residues promotes plant productivity through the synchronization of nutrients release patterns from mineralizing organic manures with the regimes of crop nutrient demand thus increasing the N use efficiency by agricultural crops.

MATERIALS AND METHODS

Study site description: The study was carried out at Kitete Village in Kilosa District, Morogoro, Tanzania (latitude 37°8'E; longitude 6°30'S; altitude 375 m a.s.l). The area receives bimodal rainfall of about 1014.2 mm per year with the long rains coming during February to May and short rains in November to January. The data on some of the initial physical and chemical properties (0-20 cm depth) of the soil in the area indicate to be slightly acidic (pH 6.4) sandy clay loams (26.6% clay, 10.7% silt and 62.7% sand; total soil porosity and bulk density of 50.5% and 1.311 g cm^{-3}, respectively), containing moderate total N (0.121%), OC (1.71%) and SOM (3.43%), available P (59.81 μg g^{-1} soil) and CEC (11.0 Cmol (+) kg^{-1} soil)[24]. The area is covered by miombo type vegetation.

Quality characteristics of plant materials: The foliage of S*enna* (leaves including the petioles and rachis) and straws of Maize (*Zea mays*) (Staha variety), Sorghum (*Sorghum bicolor*) and Panicum *(Panicum maximum Jacq.)* were collected from the Kitete Village local farms after the crops were harvested. They were then air-dried and stored separately in a clean, well-aerated and insect free place. Samples of the collected and dried *Senna* and local straw materials were ground to pass a 0.5 mm sieve and analysed for their separate chemical properties including C:N and L:N ratios. The chemical contents were determined using the standard methods used in determining the soil chemical properties above except the lignin content, which was determined according to the Acid Detergent Fibre (ADF) method[25]. Based on the initial chemical properties of the experimental plant materials, *S. singueana* foliages show high quality attributes (3.65% N, 48.5% OC, 4.32% L, 13:1 C:N ratio, 1.2:1 L:N ratio , 0.21% P, 1.860% potassium (K), 0.778% calcium (Ca) and 0.330% Magnesium (Mg)) as compared with maize straws (0.560% N, 49.8% OC, 4.41% L, 89:1 C:N ratio, 8:1 L:N ratio, 0.200% P, 1.050% K, 0.015% Ca and 0.145% Mg), sorghum straws (0.490% N, 49.3% OC, 5.64% L, 101:1 C:N ratio, 12:1 L:N ratio, 0.040% P, 1.210% K, 0.014% Ca and 0.094% Mg) and panicum straws (0.270% N, 48.2% OC, 9.07% L, 180:1 C:N ratio, 34:1 L:N ratio, 0.220% P, 1.570% K, 0.018% Ca and 0.106% Mg), respectively.

Experimental procedures: The study was carried out through two sets of experiments, namely: (a) determination of the decomposition rate of the *Senna* manures and (b) procedures of controlling N-mineralization and release from decomposing manures, using various proportions of local farm residues, so as to synchronize its availability with the critical periods of nutrient demand by the crop. The experimental work was carried out during the February-June 1998 cropping season and repeated in a similar season in 1999. Both experiments were laid out in a Randomized Completely Block Design with three replications.

***Senna manures* decomposition:** The experiment consisted of 16 treatments and four retrieval dates (2, 4, 6 and 8 weeks after litterbags placement). Based on the classification by Tisdale *et al.*[3] and C:N ratios in the present study, treatments with C:N ratio less or equal to 20:1 are classified high quality, with C:N ratios ranging between 20:1 and 30:1 as medium quality and those with C:N ratios higher than 30:1 as poor quality. Before making the mixtures of *Senna* leaves with various proportions of local farm residues (i.e. maize, sorghum and panicum straws) and subsequent incubations, the straws were chopped (5.0 cm average length pieces). Then, the different treatment mixtures were prepared by keeping constant the quantity of intact *Senna* dry leaves (10 g bag^{-1}) and varying the amounts of control materials (straws) resulting in the subsequent proportions of straw materials in the mixtures varying from 25, 50, 75 to 100% of *Senna* leaves by weight. These *Senna*-straw mixtures also resulted in the C:N and L:N ratios ranging from 13:1 to 180:1 and 1.2:1 to 34:1 respectively. The various *Senna*-straw mixtures were then loosely packed in the 20 cm x 20 cm x 2 mm litterbags, which were buried in the soil and left to incubate at field conditions for 2, 4, 6 and 8 weeks, respectively. In each plot of each block, 4 litterbags each containing one of the mixtures of the N source (*Senna*) and local control materials were placed at 20 cm depth (top soil horizon and maize rooting zone). The locations of the litterbags in each plot (3x3 m) of each block were marked using labelling tags. At each sampling period, one litterbag of each treatment from each replicate was randomly collected and all debris on the litterbags was removed. Then, residual materials were oven dried to constant weight at 60°C and allowed to cool in a desiccator before measuring the residual mass to obtain mass loss percentage. The mass loss percentages of *Senna*-straw materials were determined using the formula below[26]:

$$\text{Mass loss (\%)} = ((W_0 - W_t)/W_0) \times 100$$

Where, W_0 is the initial weight of *Senna* leaves, farm residues and *Senna*-straw mixtures at the time zero of litterbag placement and W_t represents the dry weight of the same plant materials remaining in the litterbag after a specified incubation or litterbag retrieval period or time t.

Control of N mineralization from decaying Senna foliages to optimise maize N uptake and productivity: This field trial consisted of 14 treatment mixtures prepared based on the fertilization rate of 60 kg N ha^{-1} recommended for the study area (Kilosa District)[27] and the determined N content in *Senna* leaves. The quantity of *Senna* dry leaves (1.6 t ha^{-1}) required to provide 60 kg N ha^{-1} or 0.054 kg N plot^{-1}, was kept constant and that of control materials (straws) varied so as to vary the C:N ratio of the mixtures from 13:1 to 50:1 with corresponding L:N ratios ranging from 1.2:1 to 8.4:1 as follows: (i) T_1: 1.48 kg plot^{-1} *Senna singueana* alone (13:1 C/N; 1.2:1 L:N), (ii) T_2: 1.48 kg plot^{-1} *Senna* + 1.0 kg maize straw (20:1 C/N; 1.8:1 L:N), (iii) T_3: 1.48 kg plot^{-1} *Senna* + 2.75 kg maize straw (30:1 C/N; 2.7:1 L:N), (iv) T_4: 1.48 kg plot^{-1} *Senna* + 5.25 kg maize straw (40:1 C/N; 3.5:1 L:N), (v) T_5: 1.48 kg plot^{-1} *Senna* + 9.25 kg maize straw (50:1 C/N; 4.5:1 L:N), (vi) T_6: 1.48 kg plot^{-1} *Senna* + 0.90 kg sorghum straw (20:1 C/N; 2.0:1 L:N), (vii) T_7: 1.48 kg plot^{-1} *Senna* + 2.60 kg sorghum straw (30:1 C/N; 3.2:1 L:N), (viii) T_8: 1.48 kg plot^{-1} *Senna* + 4.75 kg sorghum straw (40:1 C/N; 4.3:1 L:N), (ix) T_9: 1.48 kg plot^{-1} *Senna* + 8.0 kg sorghum straw 50:1 C/N; 5.5:1 L:N), (x) T_{10}: 1.48 kg plot^{-1} *Senna* + 0.80 kg *Panicum* (20:1 C/N; 2.4:1 L:N), (xi) T_{11}: 1 .48 kg plot^{-1} *Senna* + 2.25 kg *Panicum* (30:1 C/N; 4.5:1 L:N), (xii) T_{12}: 1.48 kg plot^{-1} *Senna* + 3.85 kg *Panicum* (40:1 C/N; 6.4:1 L:N), (xiii) T_{13}: 1.48 kg plot^{-1} *Senna* + 5.75 kg *Panicum* (50:1 C/N; 8.4:1 L:N), (xiv) T_{14}: Control (without plant materials addition). As in the decomposition experiment above, treatments with C:N ratio less or equal to 20:1 (T_1, T_2, T_6 and T_{10}) are classified high quality, with C:N ratio of 30:1 (T_3, T_7 and T_{11}) as medium quality and those with C:N ratios higher than 30:1 (T_4, T_5, T_8, T_9, T_{12} and T_{13}) as poor quality. The green manure was evenly spread over the entire plot (3 x3 m) and, thereafter carefully mixed with the soil using hand hoes. The whole experimental unit was surrounded by two borderlines of test-maize crop (90 x30 cm spacing) sown immediately after the green manuring activity. After maize harvesting in the first cropping season, the treatment plots of each block were continuously maintained, cleaned and re-used in the second cropping season.

Soil was sampled to 20 cm depth 0, 2, 4, 6, 8, 10 and 12 weeks after application of treatments at 5 locations in each plot. These five samples were bulked and a subsample obtained for analysis of soil mineral N. Soil available NO_3^--N was determined colorimetrically and NH_4^+-N by the distillation and titration method[28]. Nitrogen nutrient uptake by maize plants (shoot + root) and shoot heights were measured once every week for 10 weeks of development. The total content of N in maize plant tissues (e.g., shoots + roots) at various growth stages was determined using the semi-micro Kjeldhal procedure[29]. Nutrient uptake by maize shoots and roots was determined as the product of the dry mass multiplied by the nutrient concentration of the respective components. Maize grain, straw, cob and root yields were determined for the two crops harvested in 1998 and 1999. For each parameter measured during the present study, the data for the first and second maize cropping seasons were combined and the resulting average values used for statistical analysis. In order to compare treatment effects, yields were converted to relative increase compared to the control:

$$\text{Yield increase (\%)} = \frac{(\text{Yield}_{\text{treatment}} - \text{Yield}_{\text{control}})}{\text{Yield}_{\text{control}} \times 100} \times 100$$

Overall statistical analysis: Analysis of variance following a RCBD model, was used to determine the treatment effects on *Senna*-straw manures decomposition (mass loss percentage), total extractable available mineral N under field conditions, N-uptake by the maize plant tissues and maize yield. The Duncan's Multiple Range Test (DMRT) by MSTAT-C was used to separate the differing treatment means. Regression analysis was carried out to determine the pattern of correlation between mass loss percentage and straw proportions in the *Senna*-straw mixtures.

RESULTS

Decomposition of *Senna prunings*: The average mass loss percentage under various *Senna*-straw mixtures increased with increasing incubation period. There were significant ($p<0.001$) differences between treatments with *Senna* leaves alone resulting in faster decomposition rate (94.4% mass loss completed within the first 4 weeks of incubation) than *Senna* foliage mixed with various straw materials (58.8-83.1% mass loss). At the end of incubation (8 weeks) 100% *Senna* leaf dry weight was lost. While the maize straw materials alone showed greater dry weight loss (86%) than those of sorghum (71.3%) and panicum (48.0%) respectively, panicum straws failed to attain their half-life at the end of field incubation. The percentage mass loss of *Senna*-straw mixtures was highly and negatively correlated to the proportion of straws in the mixture (Fig. 1).

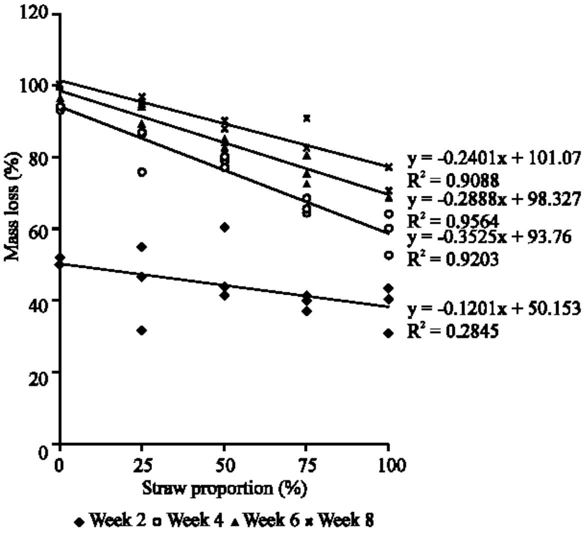

Fig. 1: Relationship between mass loss at different periods of field incubation and proportion of maize, sorghum and panicum straws in the *Senna*-straw mixture treatments at Kitete, Morogoro, Tanzania

Table 1: Total extractable available mineral N level at various sampling periods as influenced by different *Senna*-straw mixture treatments at Kitete, Morogoro, Tanzania

	Average total extractable mineral N ($\mu g\ g^{-1}$ soil) under various treatments at different sampling periods (weeks)					
Treatments	2	4	6	8	10	12
T_1^h	181.3±11.7a	201.3±26.3a	171.8±2.0de	137.1±9.5c	126.4±5.1cd	108.1±5.7c
T_2^h	101.3±13.0de	145.6±8.0b-d	141.8±7.9gh	134.5±1.4c	105.8±5.8de	115.5±0.1bc
T_3^m	134.4±11.3b-d	173.8±20.6a-c	216.1±5.7ab	160.4±5.5ab	161.2±4.2ab	137.1±10.0ab
T_4^p	102.7±7.9c-e	151.7±11.8b-d	157.8±10.0e-g	135.1±2.9c	143.4±4.4bc	117.1±9.4bc
T_5^p	126.7±32.4b-d	165.8±13.2a-c	200.7±6.5bc	142.1±7.8bc	149.6±18.2a-c	120.5±3.9bc
T_6^h	145.6±7.2a-c	156.1±15.8bc	185.3±12.2cd	161.9±3.1ab	131.6±3.9cd	107.4±4.4c
T_7^m	162.0±19.7ab	157.6±5.9bc	227.1±2.1a	173.9±8.5a	168.4±6.8a	152.6±8.7a
T_8^p	113.1±4.7c-e	171.6±3.6a-c	169.0±5.9d-f	137.5±1.6c	136.4±3.1b	117.6±2.8bc
T_9^p	157.1±14.5ab	140.3±18.1b-d	130.6±6.3h	137.7±10.3c	144.3±16.3a-c	146.8±15.0a
T_{10}^h	123.9±5.9b-d	143.7±6.5b-d	168.1±13.8d-f	136.0±8.6c	143.5±8.0 a-c	127.9±4.4a-c
T_{11}^m	138.6±3.2b-d	175.6±7.8ab	200.3±5.5bc	165.4±12.9a	136.2±11.7bc	140.3±10.2ab
T_{12}^p	123.9±6.1b-d	147.0±8.4b-d	145.6±3.2 f-h	121.1±5.3cd	123.2±7.6cd	107.4±7.8c
T_{13}^p	145.5±2.0a-c	129.9±9.9cd	147.0±7.6 f-h	130.1±4.8c	141.7±2.6a-c	114.9±11.6bc
T_{14}^c	078.4±3.8e	109.5±3.5d	99.1±3.9i	100.3±8.1d	85.8±5.8e	82.3±3.4d
Prob.> F-ratio	$p<0.001$	$p=0.008$	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$

^{c}, ^{h}, ^{m} and ^{p} represent control, high, medium and poor quality *Senna*-straw mixture treatments respectively. Means in the same column that are followed by the same letter do not differ significantly ($p = 0.05$) (DMRT)

Field mineral N status after green manuring: The results for total extractable mineral N under plots with or without (control) addition of *Senna* foliages and various *Senna*-straw mixtures indicate that, for all sampling dates, mineral N status was significantly ($p<0.01$) different among treatments (Table 1). The level of mineral N under plots treated with *Senna* leaves alone (T_1) increased rapidly within the first 4 weeks of placement but decreased gradually with time (Table 1). Plots treated with the medium quality *Senna*-straw mixtures (T_3, T_7 and T_{11}), however, maintained high levels of available mineral N within the maize-rooting zone throughout the critical periods of maize crop development (Table 1). Plots treated with poor quality *Senna*-straw mixtures (e.g. T_4, T_9, T_{12} and T_{13}) and those without green manure addition or controls (T_{14}) showed marked decline in mineral N levels, with the controls resulting in lowest values throughout the maize crop development (Table 1).

Grand period of N requirement by maize crop: It is apparent that during the initial maize growth stages (2-3 weeks after sowing), N uptake by the maize plants, as reflected by the N-plant concentrations (Fig. 2), was low, but increased rapidly during 4-8 weeks before declining at maize plant maturity stage (8-10 weeks). For this study, therefore, the 4-8 weeks period represents the critical period of high N demand or uptake by staha maize variety. The maize plants grown under plots treated with the medium quality *Senna*-straw mixtures (T_3, T_7 and T_{11}) showed higher total N nutrient contents (shoots + roots) than those grown under other treatments with the control (T_{14}) giving the lowest amounts.

Maize vegetative growth: The maize plants showed a slow height growth rate during the initial 4 weeks growth stage (Fig. 3). During the 4-7 weeks, however, the height increment rate was very rapid. The 4-7 weeks, therefore, represent the grand period of vegetative growth of staha maize variety. Green manuring, especially with the medium quality *Senna*-straw mixtures (T_3, T_7 and T_{11}), on the average, promoted the maize height growth from 160.0 to 247.8 cm, representing a height increment of 55.0% over controls. The maize plants grown under plots treated with high quality *Senna*-straw manures gave slightly higher maize height values as compared with those grown under plots treated with poor quality manures.

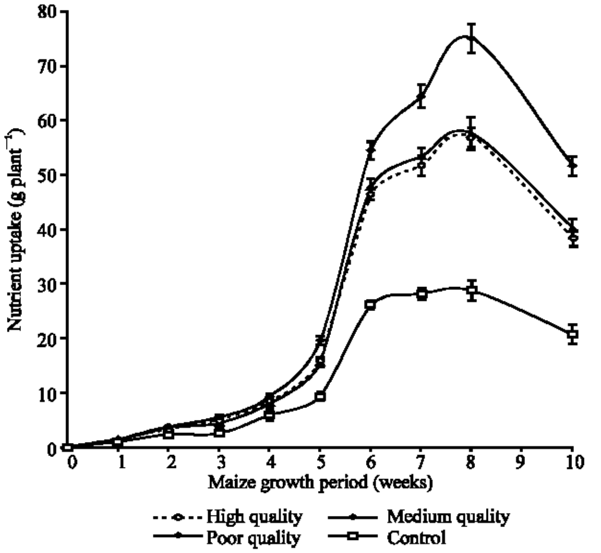

Fig. 2: Average N nutrient content in maize plant tissues (shoots + roots) at different maize growth stages under various *Senna*-straw mixture treatments at Kitete, Morgoro, Tanzania

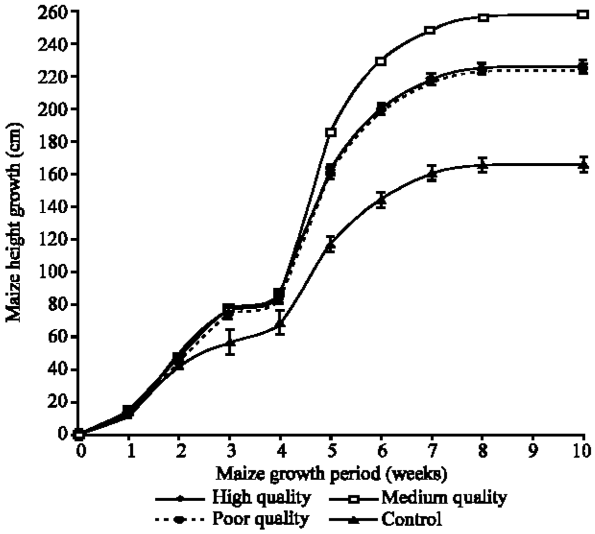

Fig. 3: Mean maize height at different growth stages under different Senna-straw mixture treatments at Kitete, Morgoro, Tanzania

Maize crop production: There were significant ($p<0.001$) differences between treatments with T_3, T_7 and T_{11} (medium quality *Senna*-straw mixtures) resulting in highest maize grain, straw and root biomass yields (Table 2). Plots treated with the poor quality *Senna*-straw mixtures (e.g., T_9 and T_{13}) and the control (T_{14}) gave the poorest grain yields (Table 2). The plots treated with *Senna* foliage alone (T_1), however, showed intermediate yields as compared with other treatments (Table 2). Green manuring with these medium quality materials (T_3, T_7 and T_{11}), therefore, on average increased the yields of maize grain from 1.4 to 4.5 t ha^{-1}, straws from 2.0 to 3.3 t ha^{-1} and cobs from 0.6 to 0.9 t ha^{-1} (Table 2)

Table 2: The mean annual maize biomass production by the various plant components nnder various Senna-straw mixture treatments at Kitete, Morogoro, Tanzania

	Average yield of different maize parts (t ha^{-1} $year^{-1}$) under various treatments		
Treatments	Grain	Straw/Stover	Cobs
T_1^h	3.4±0.4c-e	2.5±0.3cd	0.8±0.1a
T_2^h	2.4±0.2e	3.2±0.1ab	0.6±0.1a
T_3^m	3.9±0.4a-d	2.9±0.1bc	0.8±0.3a
T_4^p	3.5±0.3cd	2.8±0.2bc	0.8±0.03a
T_5^p	3.4±0.3cde	2.8±0.1bc	0.7±0.1a
T_6^h	3.7±0.3b-d	2.4±0.4cd	0.8±0.1a
T_7^m	4.6±0.4ab	3.4±0.1ab	0.9±0.03a
T_8^p	3.8±0.2b-d	2.5±0.3cd	0.9±0.03a
T_9^p	3.1±0.2c-e	3.3±0.3ab	0.8±0.2a
T_{10}^h	4.0±0.6a-c	2.8±0.1bc	0.9±0.0a
T_{11}^m	4.9±0.2a	3.7±0.1a	1.0±0.1a
T_{12}^p	3.7±0.5b-d	3.2±0.2ab	0.9±0.2a
T_{13}^p	2.8±0.1de	2.4±0.1cd	0.7±0.8E-08a
T_{14}^c	1.4±0.3f	2.0±0.1d	0.6±0.1a
Prob.>F-ratio	$p<0.001$	$p<0.001$	$p=0.688$

c, ^{h}, ^{m} and ^{p} represent control, high, medium and poor quality *Senna*-straw mixture treatments respectively. Means in the same column that are followed by the same letter do not differ significantly ($p = 0.05$) (DMR)

representing increases of 221.4, 65.0 and 50.0% over control, respectively.

DISCUSSION

***Senna manures* decomposition and field mineral N status:** In these studies, it was found that *Senna* leaves alone decomposed and released N (Table 1) faster than *Senna* foliages mixed with crop residues. An increase in the proportion of straws in the *Senna*-straw mixtures (Fig. 1), however, resulted in increased reductions in mass loss % and levels of available mineral N in the soil. The resemblance between the patterns of N release and mass loss can probably be attributed to the close linkage (covalent bond) between C and N in the protein molecule[30-32], which is in agreement with the observation by Hadayanto *et al.*[18] in studies with *Gliricidia sepium, Leucaena leucocephala, Calliandra calothyrsus* and *Peltophorum pterocarpa*. This, therefore, implies that the rapid breakdown of manures added to the soil, the rapid will be the release of N and the higher will be the level of soil available mineral N and vice versa.

The rapid rate of decomposition and N release from the *Senna* foliages alone can probably be attributed to the increased soil microbial activity as a result of added new sources of energy (C) and nutrients (N) required by microbes involved in the decomposition and mineralization processes for their growth. The enhancement in the soil microbial activity as a result of adding to the soil sufficient amounts of high quality (lower C:N and L:N ratios) green manures has been observed by several workers on other tree/shrub species and crop residues[33-36].

Since, for practical reasons, the addition to the soil of such fast-decomposing organic N reserves is carried out just before the crop seeds are sown out, it may result in inefficient use of the released N by the slow growing agricultural crops because the rapidly mineralizing N would be released before the crop sufficiently establishes itself. This results in N being made available to the crop roots before the critical periods of high nutrient demand with most N being wasted through leaching and volatilization. These results support the findings of other studies, which have shown that when the rate of release of soluble N (e.g. No_3^-) by microbial activity exceeds the rate of use by growing plants, the N in excess is lost through leaching, volatilization (ammonia) and/or denitrification[37], often resulting in severe N-deficiencies at the critical stages of plant flowering, fruiting, seed setting and, subsequently, low crop yields inspite of the rich application of high quality manures.

The slowed down decomposition rate of *Senna*-straw mixtures and delayed availability of soil mineral N as evidenced in Fig. 1 and Table 1 is possibly a result of the increased amounts of both carbon and lignin and reduced N concentrations in the mixtures which thus reduced the activity of soil microorganisms involved in organic materials decomposition and mineralization processes. The effectiveness of widening both the C: N and L: N ratio of *Senna* manures using the poor quality (high C:N and L:N ratios) straw materials in regulating the rates of decomposition and N release from these sources, possibly resulted from the increased reductions in supply of both energy (i.e. gaseous loss of carbon dioxide or C) and N nutrient (i.e. NH_4^+-N) essential for soil microbial growth and activity.

The regulatory effect of lignin or L:N ratio of organic N reserves on their decomposition and N mineralization rates can be attributed to the high capacity of lignin in reducing the availability of both carbohydrates and proteins by complexing them[38-40]. In addition to this, the lignin may probably have played an important role in controlling the rates of decomposition and N mineralization from *Senna*-straw manures by being degraded to simpler polyphenolic compounds[18] resulting in increased presence of insoluble protein complexes. These results are also in agreement with the findings by Seneviratne *et al.*[41] and[42] suggesting that the proper mixing of the fast-and-slow-decomposing materials results in the synchronization of N release from these sources with crop demand. The reduced decay rate and N availability to either soil microbes or plants following application to the soil of N-poor organic materials (i.e. high C: N ratio) and those rich in lignin or polyphenols had been reported earlier for other species[38,43,44].

The observed high levels of the total extractable available mineral N within the maize rooting zone (Table 1) throughout the crop growing period and critical maize growth stages under plots treated with medium quality *Senna*-straw mixtures (T_3, T_7 and T_{11}), therefore, is a good indication that widening the C: N and L: N ratios of *Senna* manures using crop residues up to 30:1 and range of 2.7:1 to 4.5:1 respectively may be a convenient way of improving the prunings N use efficiency by maize. The lowest level of soil mineral N observed under plots without green manure addition (T_{14}) initially having high total extractable available mineral N (Table 1) can probably be caused by its uptake by maize crop and immobilization by soil microorganisms or leaching losses of nitrate N from the top soil horizon and its accumulation in the sub-soils scarcely penetrated by the maize roots.

Grand period of high N demand and height growth of maize plants: The slow rate of N uptake by very young maize plants (Fig. 2) and maize height growth (Fig. 3) during the initial 3 weeks of maize development was possibly a result of insufficiently developed root system. At this stage, the roots of the young maize plants had not yet made sufficient contact with the soil moisture and essential nutrients, especially N, required by maize plants for growth and photosynthesis. Slow initial maize plant growth rate due to inadequate levels of food reserves (carbohydrates) and N uptake, have also, been reported in other studies[45].

The efficiency of the maize plants in N nutrient uptake (Fig. 2) increased rapidly to a maximum at approximately 8 weeks as both the vegetative and root parts got fully developed before it finally declined as the maize plants matured. Similar N uptake trends by various field crops during the grand period of vegetative growth were also reported from other studies[21]. The findings by Barraclough[46] and those reported by Shiyu *et al.*[47] also confirmed that established younger plants have high N uptake activity as compared with mature ones. The period of 4-8 weeks (Fig. 2) corresponding to the period of optimum maize plant root system activity and at the same time coinciding with the grand period of vegetative growth (Fig. 3), therefore, represent the peak period of high N demand by the staha maize variety. This, also, is in line with the findings by Shiyu *et al.*[47] showing positive correlations between N uptake activities and both plant age and total root length up to 48 days or 7 weeks after planting and a gradual decline in N uptake activity at physiological maturity stage of wheat plants. The slight differences between the results from the present study and those reported by Shiyu *et al.*[47], however, can probably be explained by differences in the crops studied and frequencies of observations.

The enhanced vegetative plant growth as a result of the optimized root system activity has, also, been reported by other reachers[3,21]. The grand period of maize vegetative/height growth (4-7 weeks) obtained in the current study (Fig. 3), however, slightly deviates from that of 4-6 weeks reported from other studies with *Gliricidia sepium*, *Calliandra calothyrsus* and *Senna siamea*[48]. These varied results can be attributed to differences in experimental procedures, N availability for maize uptake associated with organic materials placement methods and frequency of their application, soil management, ecological/weather conditions, maize sowing periods and varieties.

Maize yield: The results for maize yield (Table 2) show that the maize grain component gave highest biomass and the maize root part the lowest values. The increased maize grain yield under plots green manured with the medium quality *Senna*-straw mixtures (T_3, T_7 and T_{11}) can probably be attributed to the increased efficiency of widening both the C: N and L: N ratios of the high quality *Senna* foliages using poor quality crop residues in regulating the supply of both energy and food required by the soil microorganisms involved in the decomposition and mineralization processes. This resulted in synchronization of N release from these organic inputs with the maize crop demand. The results from the present study, therefore, are in full agreement with studies on interaction among crop stovers and prunings of *Erythrina poeppigiana* and *Gliricidia sepium*[49] and interaction among sawdust and *Gliricidia sepium* leaves[17] suggesting that application to the soil of an appropriate mixture of poor and high quality organic materials results in improved tree prunings N use efficiency by agricultural crops. This is also in conformity with the studies by Hadayanto *et al.*[42] indicating that mixing the fast-decomposing litters of *Gliricidia sepium* with the slow-decomposing prunings of *Peltophorum dasyrachis* delayed the N release from the mixture. The synchronized N supply with the uptake by the maize plants grown under the medium quality manures (T_3, T_7 and T_{11}) optimized the maize grain yield (Table 2). The enhanced maize crop production as a result of an adequate supply of N through green manuring, had, similarly been reported for *Leucaena leucocephala*[50], *Cassia* (*Senna*) *siamea* and *Terminalia brownii*[51], *Acacia julifera* and *Sesbania sesban*[52] and *Dalbergia latifolia*, *Acacia crassicarpa* and *Gliricidia sepium*[53]. The positive influence of proper addition to the soil of leguminous green manures and crop residues on N uptake by field crops observed in this study compares well with the findings from other studies on various organic N reserves[37,54] thus confirming the existence of close relationships between (i) field mineral N status and maize grain yield[55], (ii) quantity of prunings added to the maize farm and maize production[5,56] and (iii) N uptake and crop productivity[57].

The intermediate maize yields (Table 2) obtained under treatments with the high quality and fast-decomposing foliages of *Senna* alone (T_1) relative to the medium quality *Senna*-straw mixtures (T_3, T_7 and T_{11}) probably confirms the earlier observed losses of N in advance of the critical maize growth stages as most N had been released from the *Senna* foliages when the roots of maize plants were too young to absorb it. The negative impact of inappropriate N application on crop performance has, also, been reported with fertilization research elsewhere[58]. Yamoah *et al.*[59] reported that high levels of N released from *Gliricidia sepium*, *Flemingia congesta*, and *Senna siamea* prunings were associated with lower maize yields mainly due to the lack of synchronization of N released from these organic reserves with the maize plant demand.

The considerably low maize grain yield (Table 2) recorded under control plots (T_{14}) probably resulted from the insufficient and declined availability of N for maize plant roots uptake, attributable to soil structure deterioration and lowered levels of Soil Organic Matter (SOM). The loss of SOM, probably played an important role in reducing the maize crop performance under controls by modifying the maize root system development and distribution, thus restricting the utilization by the maize plants of water and nutrients, especially N, from the deeper soil horizons which is in conformity with the reports by a number of researchers[3,21,60,61].

Critical C: N and L: N ratio for maximizing maize productivity and their implications to the smallholder farmer: The increased N availability (Table 1) throughout the critical maize growth stages and maximized maize grain yield (Table 2) under plots treated with the medium quality *Senna*-straw mixtures (T_3, T_7 and T_{11}) are a good indication that the 30:1 C: N ratio and the corresponding L: N ratio range of 2.7:1 to 4.5:1 are the critical levels in the *Senna*-straw mixtures. This implies that adequate N supplies through proper addition to the soil of *Senna* manures not only will optimize N uptake by maize crop but also will maximize its productivity. This means that addition to the soil of organic N reserves whose C: N and L: N ratios which are below 30:1 and 2.7-4.5:1 respectively (e.g. T_1 and T_2) will result in loss of the fast mineralized and released prunings N while application of materials having C: N and L: N ratios greater than these critical levels with slower rates of N mineralization and release, will force microbes to use the insufficient soil N reserves for their survival and hence reduce its availability for maize crop uptake. These results, therefore, are in full agreement with some arguments suggesting that immobilization of soil N is favoured by addition to the soil of poor quality organic N reserves e.g. > 30:1 C: N and 4.5 L:N ratios[3,11,62].

While sufficient energy (C) and food (N) supplies are basic, the C: N or L: N ratio concepts alone, however, cannot be used to adequately predict the rates of *Senna*-straw manures decomposition (Fig. 1), N mineralization (Table 1) and maize grain yield (Table 2). This is because some *Senna*-straw mixtures may have similar C: N ratio but differ in L: N ratio (e.g. T_2, T_7 and T_{12}) or they may have similar L: N ratio but differ in C: N ratio (e.g. T_5 and T_9 or T_8 and T_{12} or T_5 and T_9), resulting thus in differences in terms of decomposition rate. These differences are attributable to the differential responses of soil microorganisms to the added materials, which vary greatly in terms of their chemical properties e.g. contents of both protein and lignin and variations in lignin composition or reactive groups in the structures of lignin[63]. This therefore, suggests that, balancing the ratio of energy source (C) to nutrient (N) and the ratio of lignin to N may not only satisfy the NH_4^+ ion need by soil microorganisms but also may increase N availability for uptake by crops. Some workers with *Leucaena leucocephala* and *Gliricidia sepium*[18,64], *Flemingia microphylla*[64], *Calliandra calothyrsus* and *Peltophorum pterocarpa*[18] have also reported differences in N mineralization from prunings having similar C: N ratios.

In practical terms for the smallholder farmers, the medium quality *Senna*-straw mixtures (30:1 C:N ratio and L:N ratio range of 2.7:1 to 4.5:1) imply 1.6 t ha^{-1} *Senna* dry leaves mixed with either 3.1, 2.9 or 2.5 t ha^{-1} maize, sorghum or panicum straws, respectively. Based on the conversion of *Senna* biomass harvested from local farms (1.6 t ha^{-1} *Senna* dry leaves equivalent to 60 kg N ha^{-1}) into an average farm manure containing 0.5% N (24 t ha^{-1})[60] or a commercial N containing fertilizer equivalent like urea (46% N) (130.4 kg ha^{-1}), it can be noted that, in cash terms, application of *Senna* foliages is a saving for the small scale and resource poor farmers who have very little or no purchasing power for such vital inputs like inorganic fertilizer.

CONCLUSIONS AND RECOMMENDATIONS

From these results it is concluded that the foliages of *Senna* alone decompose considerably fast, attaining their half-life (50% mass loss) within 2 weeks and over 94% decomposition in four weeks but when mixed with low quality farm residues or straws the decomposition rate gets slowed down in inverse proportion with the added straws, C: N and L: N ratios of the mixtures. The decomposing and mineralizing *Senna*-straw mixtures optimize N availability, for the maize crop uptake when in the proportions that result in the C: N ratio of 30:1 and L: N ratios in the range of 2.7:1 to 4.5:1. Pure *Senna* foliages and *Senna*-straw mixtures that result in the proportions with less C: N and L: N ratios, waste a large part of the released N through leaching and volatilization before the crop establishes sufficiently to effectively utilize the nutrient. Application of appropriate amounts of ideal *Senna* manure mixtures, enables the grand period of vigorous vegetative maize growth (4-7 weeks) to coincide with the critical period of high N nutrient demand for plant growth, flowering and grain setting (4-8 weeks) and enhances the maize yield. Carbohydrates, protein and lignin contents of organic N reserves added to the soil through organic manures jointly play an important role in influencing N availability for crop uptake. Neither the C: N nor L: N ratio concepts separately can be used to adequately predict the rates of *Senna* manures decomposition and N mineralization. The two plant factors are interrelated and reciprocated in their pattern of influence and processes. Only organic materials with appropriately balanced proportions, therefore, should be applied to the soil in order to optimize crop production. It is, therefore, recommended that when growing the staha maize variety (i.e. slow-growing crop), the adoption of N conserving practices using various *Senna*-straw mixtures and other farm residues which are of low cost and locally available should be encouraged among the smallholder farmers in order to synchronize N release from these organic reserves with the crops demand and maximize farm productivity. To optimize N uptake by the maize crop and thus increase its production on a sustainable basis, the L: N and C: N ratios of *Senna*-straw mixtures added to the soil should not exceed the critical C: N ratio of 30:1 and the corresponding L: N ratio range of 2.7:1 to 4.5:1.

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