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## Nitrogen Transformations in Soil Amended with Different Plant Residues and Their Impact on Growth of Wheat

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**Abstract:** Laboratory and greenhouse experiments were conducted to study the changes in mineral N, humus N and plant available N during following decomposition of plant residues (wheat straw, maize straw and sesbania straw) for different time periods. Accumulation of mineral N in soil was found to depend on the chemistry of plant residues, more mineral N being released in soil amended with plant residues with narrow C/N ratio i.e., maize and sesbania. These residues also contributed more to humus N and maintained a higher content of potentially mineralizable N. Wheat straw not only caused a net immobilization of N during 8 weeks of aerobic but a substantially higher loss of  $\text{NO}_3^- + \text{NO}_2^-$  -N during anaerobic incubation. The loss of N under these conditions appeared to depend on the length of time the residues were allowed to decompose in the soil, more losses being recorded for residues at early stages of decomposition. Undecomposed or partially decomposed plant residues had a negative effect on plant (wheat) growth; the effect was positively related to N uptake by plants. The negative effect was eliminated by increasing the time of residue decomposition to 8 weeks at which point maize and sesbania had a positive effect on grain yield and total biomass of wheat. Since N availability could be the main yield determining factor, sufficient time for residue decomposition will be required to achieve net N mineralization and thus improved plant growth especially for plant residues with a wide C/N ratio. However, the N released during aerobic incubation (or during land preparation prior to planting) may indeed be lost at first irrigation from the soil-plant system depending upon the content of easily oxidizable organic C.

**Key words:** Anaerobic incubation, humus, organic matter, potentially mineralizable N

### Introduction

Chemistry of plant residues is an important factor governing the release and availability to plants of nutrient elements from the native and applied sources. Easily oxidizable constituents of plants residues like glucose lead to a rapid immobilization-remineralization turnover, while the process slows down with the increase in the complexity of the constituents (Ahmad *et al.*, 1969; Azam *et al.*, 1985; Marumoto *et al.*, 1980; Stenger *et al.*, 2001; Thuries *et al.*, 2001). The chemistry of the plant residues affects nutrient dynamics because of the differences in the build-up and degradation of microbial population or biomass; the process being rapid when easily oxidizable plant constituents are being utilized. Nevertheless, residues high in lignin content contribute directly and substantially to the stable humus fractions (Azam *et al.*, 1985; Haider and Martin, 1975; Kassim *et al.*, 1981; Stott *et al.*, 1983) that have proven beneficial effects on growth and nutrient acquisition of plants.

Freshly applied plant residues are reported to have a negative effect on plant growth mainly because of the release of phenolic compounds during the degradation process and the changes in microbial processes, especially the immobilization of essential nutrient

elements. Nitrogen (N) being the nutrient element required more abundantly by the plants has been of common interest in most of the studies. The release and accumulation of N has been reported during the decomposition of plant residues rich in total N i.e., legumes (Azam *et al.*, 1993; Fox *et al.*, 1990; Ladd *et al.*, 1983; Palm and Sanchez, 1991; Soon and Arshad, 2002). Similarly, incorporation of non-leguminous plant residues obtained at green stage and having a C/N ratio of *ca* 25 may also release substantial proportion of their N during decomposition (Azam *et al.*, 1993; Ibewiro *et al.*, 2000; Seneviratne, 2000). However, the time period elapsed between incorporation of plant residues and introduction of plants may have significant influence on the growth performance of the later. The objectives of the experiment reported here were to study i) the release of N ( $\text{NH}_4^+$  and  $\text{NO}_3^- + \text{NO}_2^-$  -N) during the decomposition of some commonly available plant materials i.e., wheat straw (at maturity), tops of sesbania (a leguminous green manuring crop) and maize tops (generally used as animal fodder but can be used as a soil amendment because of 2-3% N), ii) the changes in  $\text{NH}_4^+$  and  $\text{NO}_3^- + \text{NO}_2^-$  -N content under anaerobic or high moisture conditions, iii) changes in stable humus fractions and iv) growth and N uptake of

wheat grown in soil containing plant residues at different stages of decomposition.

### Materials and Methods

**Soil:** The sandy-loam soil used in the studies was collected from the surface 0-15 cm of the experimental fields of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan. Air-dried and sieved (<2 mm) soil had the following physico-chemical characteristics: organic C, 0.6%; total N, 0.09%;  $\text{NH}_4^+\text{-N}$ , 4.2 mg  $\text{kg}^{-1}$  soil;  $\text{NO}_3^- + \text{NO}_2^- \text{-N}$ , 67.9 mg  $\text{kg}^{-1}$  soil; pH (1:2.5, soil:water suspension), 7.4; EC, 0.8  $\text{dSm}^{-1}$  (1:2.5, soil:water suspension); water holding capacity, 25%; sand, 60%; silt, 21%; clay, 19%.

**Plant residues:** Finely powdered straw of wheat, maize and sesbania were used for incorporation in potted soil. Sub-samples of plant material were analyzed for total carbon (C), total nitrogen (N), 2N  $\text{H}_2\text{SO}_4$  hydrolysable C and hydrolysable N (Table 1). The three types of residues generally differed in most of the characteristics. However, wheat material was entirely different from the other two (especially in N concentration), which among themselves were similar in several respects including C and N content and hydrolysable N.

**Incubation experiment:** Six kg portions of air-dried and sieved soil were placed in 64 plastic pots. Soil in sets of 16 each were amended as follows: i) no amendment (control), ii) wheat straw at 0.5%, iii) maize straw at 0.5% and iv) sesbania straw at 0.5%. Moisture content of the soil was adjusted to 15% (w/w) with tap water and maintained at this level throughout the incubation by making up the weight loss. Incubation was carried out at 22-26°C for 0, 2, 4 or 8 weeks and managed in a way that all the samples were obtained on the same date. Portions of soil were analyzed for  $\text{NH}_4^+\text{-N}$ ,  $\text{NO}_3^- + \text{NO}_2^- \text{-N}$ , total Kjeldahl N, potentially mineralizable N and distribution of N in humus fractions (humic acid, fulvic acid and humins).

**Pot experiment using wheat as indicator crop:** Replicate soil samples obtained after incubation were pooled and thoroughly mixed. 5 and a 1/2 kg portions (on dry weight basis) of the soil were placed in plastic pots using three replicates for each treatment and sown to wheat (*Triticum aestivum* L., var. Inqilab). Five seeds were planted per pot and upon germination the stand was thinned to three seedlings. Moisture content of the soil was adjusted to 15% with a solution of ammonium sulphate and potassium dihydrogen phosphate such that 240 mg N and 150 mg P

were delivered per pot. A second dose of 360 mg ammonium sulphate N was given when maximum tillering was achieved. The plants were grown to maturity and received irrigation as required. Harvested plants were partitioned into root, straw and grain portions and data on dry matter content was recorded. Aliquots of finely ground plant components were analyzed for total N.

**Analytical methods:** For the determination of pH, ECe, texture and water holding capacity, methods described in USDA Handbook 60 (Anonymous, 1954) were used. Total N and mineral N ( $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^- + \text{NO}_2^- \text{-N}$ ) were determined by micro-Kjeldahl method (Bremner and Mulvaney, 1982; Keeney and Nelson, 1982). Plant residues were also subjected to hydrolysis in order to determine the proportion of easily mineralizable C and N. For the determination of hydrolysable C and N, 1-g portions of the plant material were refluxed with 50 ml 2N  $\text{H}_2\text{SO}_4$  for 1h; the contents of the reflux flask filtered through a scintered funnel and the filtrate analyzed for total C and total N. For the determination of potentially mineralizable N, 20 g soil portions of each treatment were incubated under submerged conditions with 25 ml of 1N KCl solution for 2 weeks. Accumulation of  $\text{NH}_4\text{-N}$  was taken as potentially mineralizable N, while changes in  $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^- + \text{NO}_2^- \text{-N}$  were also followed during incubation. Total humic substances from freeze-dried soil samples were extracted with 0.1 M NaOH and with 0.1 M  $\text{Na}_4\text{P}_2\text{O}_7$ . For this, 50g portions of the soil samples were shaken with 150 ml of the extractant for 13 h followed by centrifugation of the suspension at 4000 rpm for 1 h. Aliquots of the supernatant were acidified with to pH with concentrated  $\text{H}_2\text{SO}_4$  and kept at 90°C for 30 min to precipitate humic acid (HA) fraction. The precipitate obtained through centrifugation was dissolved in 100 ml of 0.1 M NaOH solution. Humic acid and fulvic acid fractions were analyzed for Kjeldahl N.

### Results and Discussion

Plant residues used in this study differed significantly in their chemical characteristics (Table 1). Carbon content of the residues varied between 35 and 39%, the maximum being in wheat while maize and sesbania showed almost similar values. As expected, wheat straw had low N content of 0.5% resulting in a wider C/N ratio i.e., 80.0. Maximum N concentration of 2.6% was determined in sesbania resulting in a narrow C/N ratio of 13.9. Maize, which is a non-legume, also had characteristics fairly similar to that of sesbania because it was harvested at a relatively tender stage i.e., 6 weeks after germination. It

Table 1: Chemical characteristics of plant residues

Parameters	Plant material		
	Wheat	Maize	Sesbania
Total C, mg g <sup>-1</sup>	390.7a	352.4b	354.7b
% C	39.1a	35.2b	35.5b
Total N, mg g <sup>-1</sup>	4.9c	20.9b	25.6a
% N	0.5c	2.1b	2.6a
C/N ratio	80.0a	16.8	13.9
Hydrolysable C, mg g <sup>-1</sup>	117.8b	148.1a	149.4a
Hydrolysable C, % of total C	30.2b	42.0a	42.1a
Hydrolysable N, mg g <sup>-1</sup>	3.0c	12.8b	19.2a
Hydrolysable N, % of total N	62.1b	61.3a	75.1a
C/N ratio of hydrolysate	38.9a	11.6b	7.8c

\*, figures in a row (set of 3 values each) sharing a similar letter are not significantly different from each other at 5% probability according to Duncan's multiple range test

Table 2: Nitrogen content and C/N ratio of soil after different incubation intervals following amendment with wheat, maize and sesbania

Amendment	Weeks of incubation			
	0	2	4	8
mg N g <sup>-1</sup> soil				
Nil	0.854c*	0.844b	0.833c	0.798b
Wheat	0.905b	0.872b	0.841bc	0.843a
Maize	0.940a	0.942a	0.860b	0.855a
Sesbania 0.950a	0.920a	0.890a	0.869a	
C/N ratio of soil				
Nil	7.28d	7.11d	6.83d	7.00c
Wheat	9.28a	8.73a	8.33a	7.81a
Maize	7.93c	7.50c	7.76c	7.49b
Sesbania 8.56b	8.08b	8.11b	7.91a	

\*, see Table 1

had 2.1% N and a C/N ratio of 16.8, which can be considered optimum for a net mineralization of N. In wheat, 30.2% of the total C was in acid hydrolysable forms, while in maize and sesbania this fraction was 42%. Compared to C, much lower amounts of residue N were hydrolysable being 3.0, 12.8 and 19.2 mg g<sup>-1</sup> material of wheat, maize and sesbania, respectively. In terms of percentage, however, 62.1, 61.3 and 75.1% of the total N was hydrolysable in wheat, maize and sesbania, respectively. Higher proportion of hydrolysable N in sesbania and other legumes may indeed be the reason for a rapid mineralization of their N as reported by other workers (Azam *et al.*, 1985; Azam *et al.*, 1993; Haider and Azam, 1982). The C/N ratio of the hydrolysate was lowest (7.78) in case of sesbania and highest in case of wheat (38.85), with maize showing a value of 11.55. The hydrolysable fraction may also be considered as that more susceptible to microbial transformations. A narrow C/N ratio of the hydrolysate will help in a net mineralization of N, while wider C/N ratio could lead a net immobilization of N and thus its restricted availability to plants. Immobilization and remineralization of N is reported as governed by the labile C component of the plant residues (Azam *et al.*, 1985; Azam *et al.*, 1993; Fox *et al.*, 1990; Haider and Azam, 1982).

Table 2 shows the total N content of soil samples at different incubation intervals as determined by the Kjeldahl method (Bremner and Mulvaney, 1982). Respective C/N ratios are also given in the table. As expected, N content of the soil was lowest in unamended soil followed by that in soil amended with wheat. Maximum N content was determined in soil amended with Sesbania. In all cases, N content decreased with time of incubation, the decrease being 6-9% of the initial. Almost similar trends were observed for C/N ratios. The decrease in soil N content could be attributed to its transformation into mineral forms during incubation and their loss through NH<sub>3</sub> volatilization and/or denitrification. Losses through denitrification are particularly more pronounced in the presence of easily oxidizable C compounds like that added to the soil in the present study (Beauchamp *et al.*, 1989; Simek and Hopkins, 1999). However, the loss of N was in no match to the loss of C (data not shown) and hence C/N ratio did not decrease concurrent to decrease in total N.

Chemical make-up of the plant residues added to the soil had a significant bearing on the mineralization of organic N. In general, the mineral N content of the soil samples increased with the time of incubation except for soil amended with wheat straw where a net immobilization of N was observed (Table 3). At zero incubation, where small amounts of NH<sub>4</sub><sup>+</sup>-N were determined in soil amended with maize and sesbania, mineral N content during incubation was almost entirely determined in the form of NO<sub>3</sub><sup>-</sup>+NO<sub>2</sub><sup>-</sup>-N. Except for unamended soil where a definite increase in mineral N content was observed with time, in other treatments no consistent trends were observed. The accumulation of mineral N in unamended soil was possible because of relatively low microbial activity. An accumulation of mineral N in soils relatively stabilized in terms of microbial activity is of common occurrence. Addition of organic matter not only results in increased microbial

Table 3: Changes in  $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^- + \text{NO}_2^- \text{-N}$  content ( $\text{mg kg}^{-1}$ ) of per- incubated (with powered plant materials of wheat, maize and sesbania) soil during incubation under anaerobic conditions\*

Amendment	Before anaerobic incubation			After 15 d of anaerobic incubation			Changes during anaerobic incubation		
	$\text{NH}_4^+$	$\text{NO}_3^- + \text{NO}_2^-$	Total	$\text{NH}_4^+$	$\text{NO}_3^- + \text{NO}_2^-$	Total	$\text{NH}_4^+$	$\text{NO}_3^- + \text{NO}_2^-$	Total
Samples that were not incubated prior to anaerobic incubation									
Nil	-0.8c	64.6b	63.8b	6.8c	44.0a	50.8a	7.58c	-20.7c	-13.1c
Wheat	0.0c	62.1b	62.1b	12.0b	1.2b	13.2c	12.03b	-60.9b	-48.9b
Maize	6.5b	79.7a	86.2a	28.4a	1.2b	29.6b	21.88a	-78.5a	-56.6a
Sesbania	7.1a	72.6a	79.7a	31.6a	1.2b	32.8b	24.52a	-71.4a	-46.8c
Samples incubated for 2 weeks prior to anaerobic incubation									
Nil	-0.8b	79.7a	78.9a	5.5d	82.0a	87.5a	6.28c	2.3c	8.6c
Wheat	0.0c	41.8c	41.8c	11.0c	1.2c	12.1d	10.95b	-40.6b	-29.7b
Maize	-0.8b	59.8b	59.0b	22.2a	1.4c	23.6c	22.98a	-58.4a	-35.5a
Sesbania	-1.2a	75.1a	73.9a	19.7b	29.3b	49.1b	20.92a	-45.8bb	-24.9b
Samples incubated for 4 weeks prior to anaerobic incubation									
Nil	-1.2a	73.0b	71.8b	2.3c	68.2a	70.5a	3.51c	-4.8c	-1.3d
Wheat	-1.6a	42.4c	40.8c	10.7b	2.0c	12.7c	12.33b	-40.4b	-28.1b
Maize	0.8b	78.1a	78.9a	16.4a	28.0b	44.4b	15.64a	-50.1a	-34.5a
Sesbania	-0.8b	71.5b	70.7b	16.4a	31.8b	48.3b	17.24a	-39.6b	-22.4c
Samples incubated for 8 weeks prior to anaerobic incubation									
Nil	2.0a	81.3b	83.3b	2.4c	77.1a	79.4b	0.3c	-4.3d	-4.0c
Wheat	0.4c	46.7c	47.1c	9.3ab	23.3c	32.6c	8.9b	-23.4a	-14.5a
Maize	-0.8b	82.3b	81.4b	10.1a	68.1b	78.2b	10.9a	-14.2c	-3.2c
Sesbania	-0.4c	97.6a	97.2a	8.4b	77.8a	86.2a	8.8b	-19.8b	-11.0b

\*, see Table 2

Table 4: Effect of plant residues decomposed in soil for 0-8 weeks on dry matter yield and other parameters of wheat

		Dry matter yield, $\text{g pot}^{-1}$						HI
Weeks	amendment	Spike no.	Grain	Straw	Root	Total Bio	100 g wt	
0	Cont.	15a*	24.3a	24.5a	2.33a	51.0a	3.84a	0.50a
	Wheat	12b	19.9c	19.3c	2.02b	41.3b	3.98a	0.51a
	Maize	15a	24.1a	21.8b	2.04b	47.9ab	3.97a	0.53a
	Sesbania	15a	22.1b	22.9ab	1.95b	46.9ab	3.66b	0.49a
2	Cont.	14a	21.5b	24.5a	1.99b	48.0b	3.66a	0.47a
	Wheat	13b	20.7b	20.4b	1.87c	43.0c	3.81a	0.50a
	Maize	13b	23.0a	22.7b	1.99b	47.7b	3.70a	0.50a
	Sesbania	15a	24.4a	25.5a	2.15a	52.0a	3.60a	0.49a
4	Cont.	14b	22.3a	22.8b	2.05a	47.2a	3.59a	0.49a
	Wheat	14b	18.6b	20.9c	1.84b	41.4b	3.46a	0.47a
	Maize	16a	22.0a	23.2b	1.82b	46.9a	3.45a	0.49a
	Sesbania	15a	23.0a	25.5a	2.05a	50.5a	3.55a	0.47a
8	Cont.	13b	22.5b	21.6b	1.87b	46.0b	3.82a	0.51a
	Wheat	14b	22.5b	21.8b	1.90b	46.2b	3.75a	0.51a
	Maize	15a	25.0a	23.1a	2.06a	50.2a	3.87a	0.52a
	Sesbania	15a	24.5a	23.4a	2.04a	50.0a	3.81a	0.51a

\*, see Table 2

activity leading to higher mineralization of organic N, but it may also cause greater loss of mineralized N through denitrification at the expense of easily oxidizable C (Azam *et al.*, 2002; Beauchamp *et al.*, 1989; Gok and Ottow, 1988; Simek and Hopkins, 1999). In general, higher mineralization of N is recorded in soil amended with plant residues high in N content like Sesbania and maize in the present study (Azam *et al.*, 1993; Eriksen and Jensen 2001; Fox *et al.*, 1990; Ladd *et al.*, 1983; Seneviratne, 2000). Wheat material on the other hand had low N content and thus a net accumulation of mineral N was not observed. In fact, mineral N content in wheat-amended soil was lower as compared to that in unamended soil (average of all incubation intervals being 48 and  $75 \mu\text{g g}^{-1}$  soil, respectively). Such results are frequently reported

and have been attributed to net immobilization rather than net mineralization of N in soil amended with plant residues low in N content and having a wider C/N ratio (Azam *et al.*, 1985; Gok and Ottow, 1988; Kwong *et al.*, 1986; Soon and Arshad, 2002). Indeed, the immobilization and remineralization of N is governed to a considerable extent by the ease with which the plant residues are used by soil microorganisms as a source of C (Ahmad *et al.*, 1969; Azam *et al.*, 1985; Marumoto *et al.*, 1980). Significant changes occurred in  $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^- + \text{NO}_2^- \text{-N}$  content during anaerobic incubation of soil samples obtained after 0, 2, 4 and 8 weeks of relatively aerobic incubation (Table 3). Potentially mineralizable N ( $\text{NH}_4^+\text{-N}$ ) in differently amended soils decreased with the time of incubation and was almost similar in soil amended

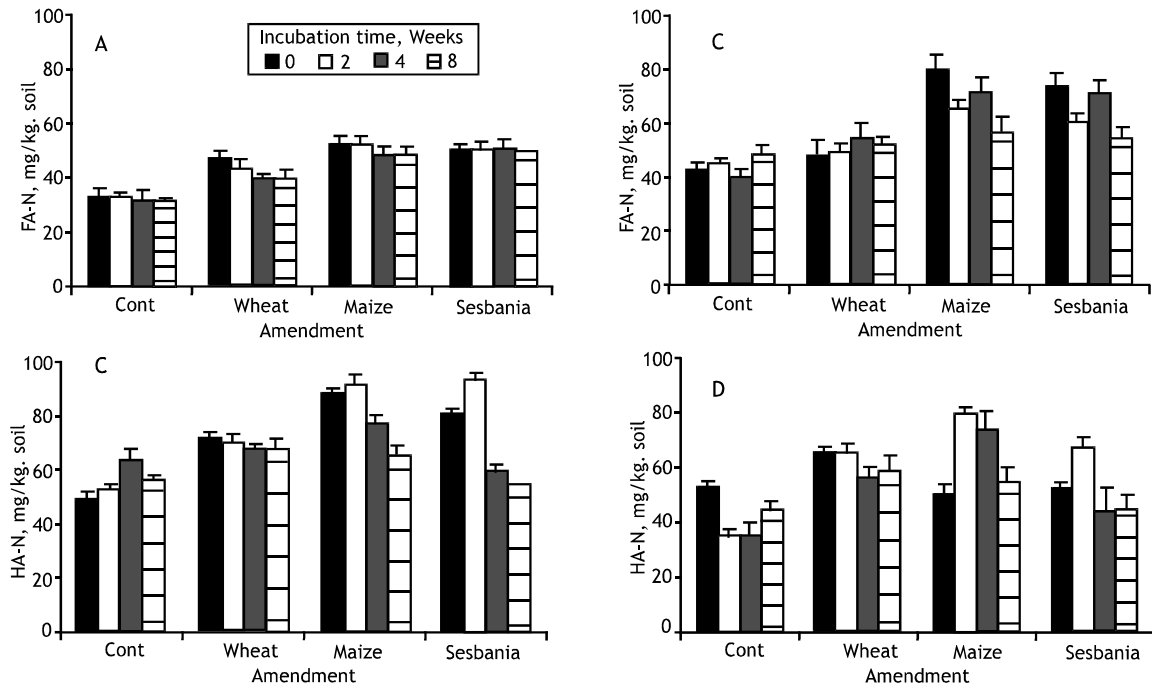


Fig. 1: Distribution of N in fulvic acid (FA) and humic acid (HA) fractions extracted with NaOH (A and B, respectively) and Na<sub>4</sub>P<sub>2</sub>O<sub>7</sub> (C and D, respectively) in soil samples incubated with different plant residues

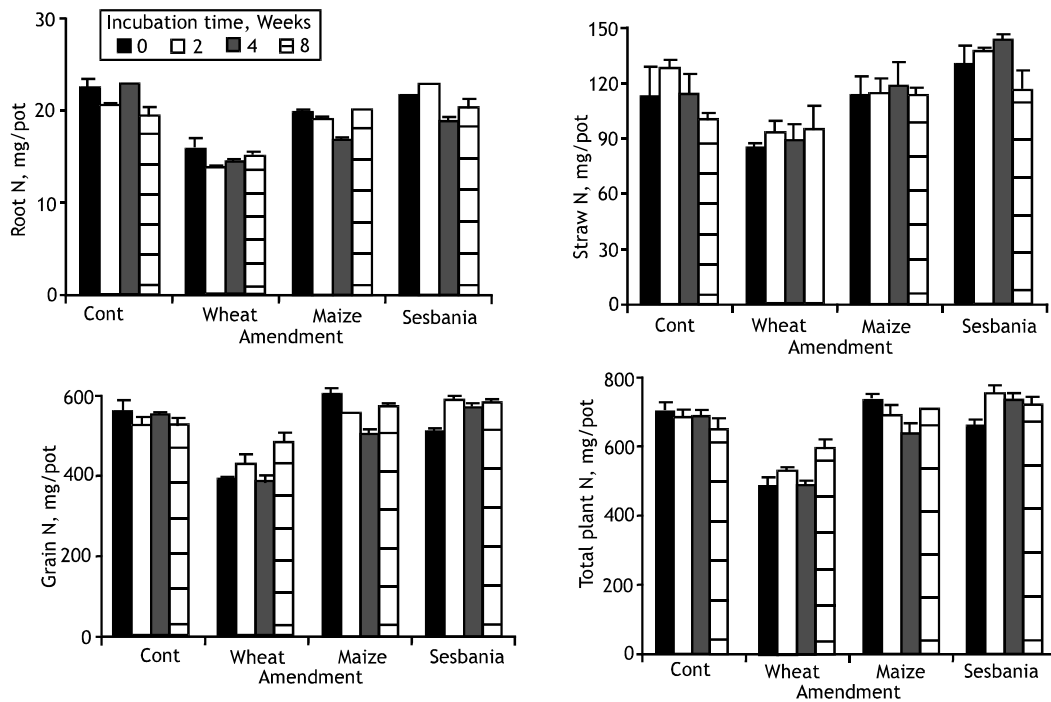


Fig. 2: Effect of plant residues decomposed for different time intervals (0, 2, 4 and 8 weeks) on N content of root, straw and grain portions of wheat

with maize and sesbania. In soil amended with wheat straw, mineralizable N decreased by 25% during incubation compared to about 60% in other two amendments. A decrease in mineralizable N also suggested that a good part of the organic N was already mineralized during aerobic incubation for different time intervals. There was a good degree of similarity between organic N mineralized under anaerobic conditions and  $\text{NO}_3^-$ -N lost. A close correlation was observed between the two processes ( $r = 0.9$ ). The loss of  $\text{NO}_3^-$ -N was more when soil samples containing freshly added plant residues i.e., at 0-day of incubation. Higher losses of  $\text{NO}_3^-$  from soil samples containing less decomposed plant residues (i.e., incubated for a shorter time period) suggests the availability of easily decomposable plant residues. The available C decreased with time and thus loss of  $\text{NO}_3^-$ -N was also reduced. The three types of plant residues had almost a similar effect on the loss of  $\text{NO}_3^-$ -N suggesting that C availability was not very different. A close relationship between easily oxidizable C and loss of  $\text{NO}_3^-$  through denitrification has frequently been observed (Azam *et al.*, 2002, Beauchamp *et al.*, 1989; Gok and Ottow, 1988; Simek and Hopkins, 1999). Since under anaerobic conditions, organic matter is decomposed/fermented mainly by anaerobic microorganisms, more C is available for denitrifying population that is also encouraged by low oxygen supply. Because of the substantial loss of  $\text{NO}_3^- + \text{NO}_2^-$ -N, a net decrease in mineral N content of the soil samples was observed during anaerobic incubation. However, while determining potentially mineralizable N, generally no attention is given to the loss of  $\text{NO}_3^- + \text{NO}_2^-$ -N. The three amendments differed considerably in affecting the decrease in mineral N, maximum loss being observed for wheat straw. The loss of mineralized N under high moisture conditions generally encountered following irrigation and land preparation for cropping may have a significant bearing on the N economy of agroecosystems. The difference in the nature of crop residues being incorporated will also affect the subsequent crop vis-à-vis the loss and availability of N from native and applied sources.

Soil samples obtained at different incubation intervals were extracted with 0.1M NaOH as well as with 0.1M  $\text{Na}_4\text{P}_2\text{O}_7$  (Na-pyrophosphate) to determine the distribution of N in humic acid and fulvic acid fractions. Fig. 1 presents the data on FA-N and HA-N extracted with NaOH and Na-pyrophosphate, respectively. On per g soil basis, HA extracted with NaOH contained higher amounts of N ranging from 50-90  $\text{mg kg}^{-1}$  soil, while FA contained about 33-50  $\text{mg N kg}^{-1}$  soil in different treatments. Organic amendment had a positive effect on the build up of humus

fractions. However, incubation time had no consistent effect on the amount of N in the two humus fractions, although average values of different treatments showed a decrease in humus N. Soil amendment had a positive effect on FA-N, the three amendments being not very different. A greater proportion (53-66%, data not presented) of the N extracted with NaOH was found in HA, while a similar proportion was recovered as FA in Na-pyrophosphate extract. Soil treatments did not appear to significantly affect the percentage distribution of extractable N. However, relatively higher percentage of N extractable with NaOH was found in HA of unamended soil. Almost similar was true for Na-pyrophosphate. The proportion of soil N extractable was similar (average of all the observations; data not presented) with either of the extractants, but a decrease in extractability with time of incubation was observed. Soil amended with sesbania had the highest proportion in extractable forms, while unamended soil had the lowest thereby suggesting the differences in stability of humus fractions. The differences in the soil humus content in differently treated soil may be a factor responsible for differences subsequently observed in plant growth.

Table 4 shows the data on different agronomic parameters of wheat grown to maturity in soil containing plant residues at different stages of decomposition. Number of spikes increased due to maize and sesbania amendment but decrease in the presence of wheat. Period of decomposition had apparently no significant effect. Similarly, higher grain yield was obtained with maize and Sesbania while wheat straw had a negative effect. Undecomposed plant residues (0 weeks of incubation), especially wheat straw, lead to a significant decrease (15%) in grain yield as well as total biomass. Even sesbania material had an effect similar to wheat straw when undecomposed. The negative effect was mitigated by prolonged period of decomposition and after 8 weeks no difference was observed. Similar trends were observed for straw and root biomass. Total biomass was the maximum in Sesbania amended soil followed by maize amendment (average of different incubation intervals). Soil amendment had a negligible effect on 100 grain weight and harvest index when expressed as an average of incubation intervals.

The incubation time and soil amendment appeared to affect the biomass yield through a control on N availability to plants. Results presented in Fig. 2 reveal that wheat straw amendment had a negative effect on the N content of all plant parts, while maize and Sesbania had a positive effect. Wheat straw maintained its negative effect on N uptake even after 8 weeks of incubation, however, the effect was much less compared to that

observed for 0 week of incubation. Maize residues enhanced the uptake of N when undecomposed but showed a negative effect at 4 weeks of incubation. After 8 weeks of decomposition, however, maize and sesbania had a similar effect on N content of grain and total biomass. Interestingly, however, N uptake decreased with prolonged incubation of unamended soil while reverse was generally true for amended soils. This could be attributed to gradual mineralization and loss of N from unamended soil during incubation leading to exhaustion of nutrient resources before wheat was planted. In comparison, amended soil maintained a sustained availability of nutrients. A higher proportion of plant N (ca 80%) was determined in the grain portion compared to about 50% of dry matter (data not shown), different treatments and period of incubation having a negligible effect. Different soil amendments had variable effect on percent N and no definite trends were observed with respect to time of incubation (data not presented). However, wheat straw amendment generally led to a significantly low N content of all the three plant components and at all incubation intervals. The differences in other treatments including control were generally non-significant.

Significance of N content of plant residues incorporated in the soil in determining biomass yield is well established and often reported (Azam 1990; Ibewiro *et al.*, 2000; Ladd *et al.*, 1983; Laos *et al.*, 2000; Lehmann *et al.*, 1999). In addition, N uptake by plants was closely related with the chemistry of plant residues applied, while a close correlation was obtained between N content of plant components and their dry matter yield (correlation coefficient between the two parameters was 0.83, 0.95 and 0.95 for root, straw and grain portions, respectively, using data for all observations). Sesbania, which had a higher N content and a narrow C/N ratio of hydrolysable fraction, caused a significant increase in N uptake and consequently the biomass yield. Sesbania was closely followed by maize, while wheat material with low N content as well as low hydrolysable N had a negative effect on N uptake and biomass production. Other workers (Antil *et al.*, 2001; Azam *et al.*, 1990, 1991) have reported similar results.

In view of the effect of organic matter on microbial activities and nutrient dynamics, the chemistry and stage of decomposition of organic matter is expected to affect plant growth and uptake of nutrients especially N. Plant residues with a narrow C/N ratio or at an advanced stage of decomposition will have a positive effect on plant growth not only because of increased availability of N (which is generally the limiting factor in crop production), but because of the added physiological effects on root

growth and favourable changes in physico-chemical characteristics of the soil. Humus substances produced during decomposition of plant residues are known to have a positive effect on root development and soil characteristics (Wallace, 1994). Soil humic matter interacts in a dynamic and complex way with plants by enhancing their metabolism (Nardi *et al.*, 1994, 1996; Vaughan and Linehan, 1976) and causing a rapid and larger growth in roots and shoots (Vaughan and Malcolm, 1985; Nardi *et al.*, 1996).

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