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Sustaining Wheat Productivity and Maintaining Soil Fertility in Maize-Wheat System

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Abstract

Field experiments on maize-wheat system were carried out in rainfed upland (*bari*) at Agricultural Research Station, Lumle for three years (1994/95-1996/97) to determine the effect of different quality organic materials on maize and wheat yields and soil properties. Wheat grain yield significantly differed over years and the highest mean grain yield (1.98 t ha^{-1}) was recorded in the treatment of mixture of low and high quality organic materials (maize + leaf litter, farmyard manure). Maize and wheat grain as well as straw yield significantly differed over years. In all the three years, the mixture of low and high quality organic materials produced the highest grain yield of maize plus wheat ranging from 6.72 to 2.20 t ha^{-1} with mean yield of 4.43 t ha^{-1}. Mean N uptake by wheat grain and straw ranged from 32.2 to 40.4 kg ha^{-1} and 13.8 to 16.0 kg ha^{-1}, respectively in different treatments. Similarly, mean P uptake by wheat grain was the highest (25.4 kg ha^{-1}) in the mixture treatment while mean P uptake by wheat straw was the highest (26.5 kg ha^{-1}) in low quality organic materials. Mean soil pH after wheat harvest was the lowest (5.1) in the low quality organic material. Organic carbon and available P ranged from 3.4 to 3.7% and from 329 to 370 ppm, respectively in different treatments while total N and exchangeable K increased to 0.31% and 0.2 me/100g, respectively with the application of low quality organic material. The three years result showed that semi-decomposed organic materials were more efficient in improving and stabilizing production of wheat and maize yields in maize-wheat system as well as in maintaining N fertility than high quality organic materials.

Key words: Maize-wheat system, organic materials, soil fertility, sustainability

Introduction

Nitrogen, essential to plant growth is taken up by plant from the soil in simple inorganic form, ie as nitrate and ammonium. These are released from complex organic compounds by the action of decomposing microorganisms, a process known as mineralization. The amount of nitrogen supplied to a crop after application of manure depends on the interaction of several processes (immobilization, leaching, mineralisation, nitrification, volatilization, denitrification), which are markedly affected by manure type, time and rate of application and management (Shepherd, 1993). However, during decomposition of organic matter, organic acids and carbon-dioxide are formed (Tisdale et al., 1985) and added organic materials appear to have a solubilizing effect on Fe, Al and Ca phosphate due to the increase in biological activities (RAPA, 1986). Nutrient recycling is a dynamic process and it is not easy to assess fertility decline, as it requires long-term monitoring of the soils.

For farmyard manure (FYM) compost to be considered as an effective N source for maize and wheat in the maize-wheat system, it must supply sufficient N and there must be a synchrony between FYM/compost N release and maize and wheat demand. If the mineral N pool in soil is produced too early, it can potentially be lost through leaching and/or denitrification. If released too late, N application will not benefit the crop and possesses a potential threat to groundwater quality via leaching. Wilson and Hargrove (1986), Wagger (1989) used fine-pore (53 µm) litterbag to monitor the rate of residue biomass disappearance and Varco et al. (1989) used 15-N deplete residue to monitor decomposition dynamics. They found that green manures decomposed rapidly (a 50% loss of biomass within a month) in warm soils and could be a significant source of N to the following maize crop.

In the western hills, farmers traditionally apply a lot of semi-decomposed FYM/compost to upland (*bari*) soils for growing different crops. The crop cut survey and associated data suggested that *bari* soils are relatively fertile because they receive most of the available FYM/compost (typically 20 to 50 t ha^{-1} yr^{-1}) (Tuladhar, 1995).

It is essential to know the effect of different levels of decomposed organic materials on wheat grain in maize-wheat system. Therefore, this experiment was designed to determine the potential extent and method by which crop production can be altered by optimizing efficiency of nutrient use through the management of manuring of contrasting chemical composition.

Materials and Methods

The experiment was initiated in summer maize growing season of 1994 in maize-wheat system. The field experiment was conducted continuously for three years (1994/95, 1995/96 and 1996/97) in randomized complete block design (RCBD) with four replications in the rainfed terrace land (1620 masl) at Agricultural Research Station (ARS), Lumle. The plot size was 8- × 4-m, and the net harvested area was 6.0- × 2.5-m. There were four treatments (control, low quality organic materials ie maize stover + forest leaf litters to supply 40 kg N ha^{-1}, high quality organic materials ie FYM/compost to supply 40 kg N ha^{-1} and mixture of low and high quality organic materials to supply 40 kg N ha^{-1}. To supply 40 kg N ha^{-1} through low quality organic materials, 16 kg maize stover and 4 kg forest litters $plot^{-1}$ were applied. Similarly, to supply 40 kg N ha^{-1} through high quality organic materials, 6.5 kg FYM/compost $plot^{-1}$ were applied. The mixture of low and high quality organic materials were supplied through 8 kg maize stover + 2 kg forest litter + 3.2 kg FYM/compost $plot^{-1}$. All the organic materials were incorporated during the land preparation for wheat sowing. In case of maize, similar quantity of 40 kg N ha^{-1} were supplied through wheat straw, leaf litter and FYM/compost in the above treatments. Wheat variety Annapurna 3 was planted in 16 lines $plot^{-1}$ at 25 cm row spacing with continuous seeding. Wheat seeds were sown during the second and the fourth week of Oct. The wheat crop was harvested in the last week of April for all three years.

Composite soil samples were collected before planting the first crop of wheat and analyzed for pH, organic carbon, total N, available P and exchangeable K. Measurements on organic carbon and the total N were made in the sampling plots by collecting soil samples at three weeks interval by mesh litter bag method. Measurements of N mineralisation rate in the sample plots were also made at three weeks interval by field incubation method. There were 5 litter bags in each sample plot. The N and P uptake of the above ground biomass (grain and straw) were determined by collecting the above ground wheat plants at the time of harvest. After the harvest of each wheat crop, soil samples from individual plots were collected and analyzed for different chemical properties. The data were analyzed by MSTATC.

Results and Discussion

Wheat yield

Wheat grain yields over years (1994/95, 1995/96 and 1996/97) decreased significantly for all treatments (Table 1). Differences among treatments were not evident. However, the mean wheat grain yield was the highest in the treatment of mixture of low and high quality organic materials in all three years with the mean of 1.98 t ha^{-1} (Table 1). The declining trend of wheat grain yield in all treatments in later years could be due to insufficient quantity of nutrients particularly N (40 kg ha^{-1}) supplied through different types of organic materials, which could not meet the crop requirements. Moreover, the residual effect of organic fertilizers was not enough in the second and the third year in addition to 40 kg N ha^{-1} applied in each maize and wheat crop.

Wheat straw yields significantly differed over the years but significant treatment effects were obtained only in 1994/95 (Table 2). The mean wheat straw yield of three years showed that the application of 40 kg N ha^{-1} through the low quality organic materials alone or the mixture of low and high quality organic materials gave similar responses, while control treatment produced the lowest straw yield (3.11 t ha^{-1}). The wheat straw yield was drastically reduced in all treatments over the years. The reason of declining straw yield in later years is probably due to low quantity N (40 kg ha^{-1}) applied through organic materials and also negligible residual effect of previous years organic materials.

Combined maize and wheat yield

Analysis revealed that combined mean maize and wheat grain yields significantly differed over years and treatments (Table 1). The mixture of low and high quality organic materials gave the highest grain yield in all years. The total maize and wheat grain yields in all treatments gradually declined in subsequent years indicating that 40 kg N ha^{-1} in each maize and wheat crop supplied through different organic materials were not sufficient to meet the crop requirements in high rainfall area of Lumle.

The combined maize and wheat straw yields also differed significantly among years and treatments (Table 2). The mean straw yield of control treatment was the lowest (7.92 t ha^{-1}) among treatments. Interaction effects were also significant because the trend of declining straw yield was different in different treatments. The straw yields of maize and wheat significantly reduced over years in all treatments showing that 40 kg N ha^{-1} supplied in each maize and wheat crop was not enough to meet crop requirements.

Table 1. Wheat grain yield and combined maize + wheat yield at 12% moisture in 1994/95, 1995/96 and 1996/97 at Agricultural Research Station, Lumle

Treatment	Wheat grain yield, t ha^{-1}				Maize + wheat grain yield, t ha^{-1}			
	1994/95	1995/96	1996/97	Mean	1994/95	1995/96	1996/97	Mean
Control	2.30	1.84	0.44	1.53	5.75	2.85	1.17	3.26
Maize stover + leaf litter (2)	2.50	2.04	0.55	1.70	6.06	3.92	2.07	4.02
FYM (3)	2.65	1.75	0.43	1.61	6.33	3.17	1.18	3.56
Mixture (2 + 3)	2.78	2.43	0.75	1.98	6.72	4.38	2.20	4.43
Mean	2.56	2.02	0.54	1.71	6.22	3.58	1.66	3.82
F (year)	-	-	-	**	-	-	-	**
F (treatment)	ns	ns	ns	ns	ns	ns	ns	**
F (year × treatment)	-	-	-	ns	-	-	-	ns

** Highly significant ($P \leq 0.01$); ns, Non significant.

Table 2. Wheat straw yield and combined maize stalk + wheat straw yield at Agricultural Research Station, Lumle

Treatment	Wheat straw, t ha^{-1}				Maize stalk + wheat straw, t ha^{-1}			
	1994/95	1995/96	1996/97	Mean	1994/95	1995/96	1996/97	Mean
Control	4.88	3.48	0.99	3.11	12.75	7.93	3.09	7.92
Maize stover + leaf litter (2)	6.40	4.20	1.35	3.98	16.15	11.71	4.41	10.76
FYM (3)	5.63	3.28	1.29	3.40	14.90	8.68	3.71	9.10
Mixture (2 + 3)	5.30	4.32	1.66	3.76	14.90	12.18	4.25	10.44
Mean	5.55	3.82	1.32	3.56	14.67	10.12	3.87	9.55
F (year)	-	-	-	**	-	-	-	**
F (treatment)	*	ns	ns	**	*	**	ns	**
F (year × treatment)	-	-	-	ns	-	-	-	*

** Highly significant ($P \leq 0.01$); * Significant ($P \leq 0.05$); ns, Non significant.

Nitrogen and phosphorus uptake

Nitrogen uptake by wheat grain and straw differed significantly over years (Table 3) because both wheat grain and straw yields decreased in the second year (1995/96) as compared to the first year (1994/95). A significant effect of treatment on N uptake by wheat straw was evident only in 1994/95. Interaction effects between year and treatment existed only in N uptake by straw, most probably due to high N uptake (19.7 kg ha^{-1}) by wheat straw in the control treatment (10.4 kg ha^{-1}) in 1995/96 as compared to 1994/95. Mean N uptake by wheat grain and straw varied from 32.2 to 40.4 kg ha^{-1} and 13.8 to 16.0 kg ha^{-1}, respectively.

Effects of year and treatment on phosphorus uptake by wheat grain were not observed. However, mean P uptake was the highest (25.4 kg ha^{-1}) in the mixture of low and high quality organic material (Table 3) indicating that semi-decomposed organic materials are better source for P uptake by wheat grain.

Phosphorus uptake by wheat straw did not differ significantly over years but the treatments were different (Table 3). P uptake by straw was higher in 1995/96 in all treatments than in 1994/95 and low quality organic material had the highest P uptake (30.8 kg ha^{-1}) of all other treatments. This is probably due to slow release of nutrients from low quality organic materials, which contributed to P uptake by straw. The mean P uptake by straw over years was the highest (26.5 kg ha^{-1}) again in the low quality organic material treatment.

Table 3. Nitrogen and phosphorus uptake by wheat grain and straw during 1994/95 and 1995/96 at Agricultural Research Station, Lumle

Treatment	N uptake by wheat grain, kg ha^{-1}			N uptake by wheat straw, kg ha^{-1}			P uptake by wheat grain, kg ha^{-1}			P uptake by wheat straw, kg ha^{-1}		
	1994/95	1995/96	Mean	1994/95	1995/96	Mean	1994/95	1995/96	Mean	1994/95	1995/96	Mean
Control	36.1	28.8	32.2	10.4	19.7	15.0	21.0	19.4	20.2	16.2	20.9	18.5
Maize stover + leaf litter (2)	46.2	24.7	35.5	14.8	17.1	16.0	23.6	18.6	21.2	22.3	30.8	26.5
FYM (3)	46.1	25.1	35.6	13.6	14.3	13.9	25.3	17.1	21.2	19.6	22.3	20.9
Mixture (2 + 3)	45.7	35.2	40.4	12.5	15.1	13.9	23.5	27.4	25.4	18.9	27.1	23.0
Mean	43.5	28.3	35.9	12.8	16.6	14.7	23.4	20.6	22.0	19.3	26.3	22.3
F (year)	-	-	**	-	-	*	-	-	ns	-	-	-
F (treatment)	ns	ns	ns	*	ns	ns	ns	ns	ns	*	ns	**
F (year × treatment)	-	-	ns	-	-	*	-	-	ns	-	-	ns

** Highly significant (P ≤ 0.01); * Significant (P ≤ 0.05); ns, Non significant.

Effect on soil chemical properties

The bench mark soil analysis before planting the first wheat crop in Oct 1994 indicated that the soil pH was about neutral (6.3), organic carbon was high (3.4%), total N (0.33%) and exchangeable K (0.43 me/100 g) were medium, and available P was very high (416 ppm). Monitoring of soil pH, organic carbon and total N at 3, 9 and 15 weeks after wheat germination in 1994/95, 1995/96, 1996/97 revealed that soil pH remained low (5.5 to 5.6) upto 6 weeks of wheat germination and increased to 5.6-5.7 and 5.8-5.9 after 9 weeks and 12 weeks of germination, respectively in all treatments. After 15 weeks of germination, soil pH decreased to 5.5 in all treatments (data not shown). The mean (over years) showed that soil organic carbon remained more or less the same (3.2 to 3.3%) upto 9 weeks after germination. After 12 weeks of germination, the organic carbon increased in all the treatments but this increment was greater in the treatment of low quality organic matter and in the mixture of low and high quality organic materials. Again, the organic carbon decreased in all treatments after 15 weeks of germination.

Total N content of the soil increased slowly after 3 weeks of germination up to 8 weeks of germination indicating that the uptake of N by wheat crop was lower most probably due to low soil temperature and low demand of small plants. Sharp decline in total N was obtained after 12 weeks of sampling showing uptake of N between 9-12 weeks after germination. Total N content of the soil remained low in control treatment in all five samples.

In 1995/1996 and 1996/97, mineral-N differed significantly over sampling time (3 to 15 weeks) and treatments differed significantly in the samples collected after 3 weeks of germination only in 1996/97 (Table 4). In 1995/96, mineral N declined slowly after 3 weeks upto 15 weeks, whereas reverse trend was observed in 1996/97. This is probably due to interaction of soil and environment. Further study is required to confirm mineral N variations in different years, as Wilson and Hargrove (1986) reported that N release was highly variable when residues were left on the soil surface. Mean mineral N of two years varied from 7.05 to 9.37 kg ha^{-1} in different treatments.

The soil chemical properties of each individual year and combined analysis of variance over years are presented in Table 5. Organic carbon, available P and exchangeable K significantly differed over years. Organic carbon increased in all treatments in 1997 as compared to that in 1996 and this increase was the highest (5.1%) in the mixture treatment. Though available P was high, it decreased over years in all treatments most probably due to low P supplied through different types of organic materials. Treatments differed for total N and exchangeable K as indicated by the combined analysis of variance. Mean total N was the highest (0.31%) in low quality organic material and the lowest (0.24%) in high quality organic material indicating rapid use of N by wheat crop or loss of N with the use of high quality (well decomposed) organic materials. Exchangeable K was also significantly higher (0.23 me/100 g) in the same low quality organic material treatment showing less use of this nutrient by wheat crop. Interaction effect between year and treatment existed only on exchangeable K. The soil analysis after harvest of the wheat crop showed that, a large amount of total N and exchangeable K was in the soil of low quality organic material treatment indicating residual effect of these two nutrients.

Table 4. Effect of time on mineral N (kg ha^{-1}) release and accumulation in bag soil during wheat growing season during 1994/95 and 1995/96

Treatment	3 weeks after germination			9 weeks after germination			15 weeks after germination		
	1994/95	1995/96	Mean	1994/95	1995/96	Mean	1994/95	1995/96	Mean
Control	15.7	1.8	8.8	10.8	3.9	7.4	6.0	8.2	7.1
Maize stover + leaf litter (2)	15.1	1.9	8.8	10.4	4.0	7.2	7.4	6.9	7.1
FYM (3)	15.6	3.1	9.4	10.6	3.5	7.1	6.8	9.3	8.1
Mixture (2 + 3)	14.2	2.4	8.3	10.4	4.0	7.2	7.8	9.1	8.5
Mean	15.2	2.3	8.8	10.6	3.8	7.2	7.0	8.4	7.7
F (year)	**	**	-	SED (Y)	-	-	1.2	0.6	-
F (treatment)	ns	ns	-	SED (T)	-	-	0.7	0.4	-
F (year × treatment)	ns	ns	-	SED (Y × T)	-	-	1.2	0.6	-

** Highly significant (P ≤ 0.01); ns, Non significant; SED, Standard error of difference.

Table 5. Soil Chemical properties after wheat harvest in 1995, 1996 and 1997†

Treatment	N, %				P, ppm				K (me/100g)				Organic carbon, %				pH			
	1995	1996	1997	Mean	1995	1996	1997	Mean	1995	1996	1997	Mean	1995	1996	1997	Mean	1995	1996	1997	Mean
Control	0.3	0.3	0.2	0.3	467	389	221	370	0.4	0.3	1.2	0.3	-	2.5	4.0	3.6	5.7	5.5	5.4	5.5
Maize stover + leaf litter (2)	0.4	0.3	0.2	0.3	336	307	173	341	0.5	0.2	0.1	0.3	-	2.6	4.4	3.5	5.6	4.1	5.4	5.1
FYM (3)	0.3	0.2	0.2	0.2	508	442	265	340	0.4	0.3	0.2	0.2	-	2.5	3.6	3.4	5.7	5.4	5.3	5.5
Mixture (2 + 3)	0.3	0.3	0.3	0.3	411	330	295	329	0.4	0.3	0.1	0.3	-	3.6	5.1	3.7	5.7	5.4	5.4	5.5
Mean	0.3	0.3	0.2	0.3	431	367	239	345	0.4	0.3	0.2	0.3	-	2.8	4.3	3.6	5.7	5.1	5.4	5.4
F (year)	-	-	-	ns	-	-	-	*	-	-	-	**	-	-	-	*	-	-	-	ns
F (treatment)	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	**	-	ns	ns	ns	ns	ns	ns	ns
F (year × treatment)	-	-	-	ns	-	-	-	ns	-	-	-	ns	-	-	-	*	-	-	-	ns

** Highly significant (P ≤ 0.01); * Significant (P ≤ 0.05); ns, Non significant; † Part per million; me, mili equivalent.

The wheat grain and straw yields as well as N uptake by grain and straw decreased over years due to low N application (40 kg N ha^{-1}) through organic materials. Combined maize and wheat grain yield also decreased over years in all treatments but this decrease was the lowest in the mixture of low and high quality organic material treatment indicating that semi-decomposed organic material is good for maize and wheat crop in high rainfall area of Lumle. Research should be diverted using higher dose of N through semi-decomposed organic materials and split application of high quality FYM for continuous supply of N for later part of crop growth under high rainfall area.

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