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REGULAR ARTICLE

Effect of nitrogen fertilizer with mushroom compost of varied C:N ratio on nitrogen use efficiency, carbon sequestration and rice yield

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ABSTRACT

Integrating fertilizer nitrogen (N) with organic manures can foster a sustainable agricultural system in subtropical soils low in organic matter. A two year field experiment was conducted on a sandy loam soil at Allahabad, India to evaluate the effect of incorporating spent white button mushroom compost (WB-SMC) with a narrow C:N ratio (15.18) and spent oyster mushroom compost (OY-SMC) of a wider C:N ratio (37.58) with and without fertilizer N on rice crop production, N use efficiency and soil carbon (C) sequestration. A higher paddy, straw yield and total dry matter production of 5.00, 6.24 and 11.24 t ha^{-1} in WB-SMC at 5 t ha^{-1} with fertilizer N at 90 kg ha^{-1} and 5.26, 6.80 and 12.05 t ha^{-1} in WB-SMC at 5 t ha^{-1} with fertilizer N at 120 kg ha^{-1} confirmed the superiority of the WB-SMC over OY-SMC, which produced 3.57, 4.62 and 8.18 t ha^{-1} with fertilizer N at 90 kg ha^{-1} and 4.17, 5.32 and 9.48 t ha^{-1} with fertilizer N at 120 kg ha^{-1} respectively. When WB-SMC was applied at 5 t ha^{-1} it enhanced the recovery efficiency of 19.62 and 15.56 % compared to fertilizer N at 90 and 120 kg ha^{-1} respectively. Physiological efficiency due to luxury uptake of N with the use of WB-SMC and fertilizer N at 120 kg ha^{-1} gave evidence that N addition through the combined use of WB-SMC and fertilizer N was excessive. Agronomic efficiency of added N by the rice crop was improved by the incorporating WB-SMC at 5 t ha^{-1} and fertilizer N at 90 kg ha^{-1}. Despite a wider C:N ratio, OY-SMC gave higher soil C sequestration in flooded rice than WB-SMC in the presence or absence of fertilizer N.

Key Words: *C:N ratio; composts; nitrogen use efficiency; carbon sequestration.*

INTRODUCTION

In recent years, fertilizer cost and concern for sustainable soil productivity and ecological stability in relation to chemical fertilizer use has emerged as an important issue (Aulakh and Pasricha, 1997a; Aulakh and Singh, 1997). There is renewed interest in the use of organic manures, such as farmyard manure, compost and green manure as sources of plant nutrients (Singh et al., 1988; Aulakh, 1994).

Information on the benefits of integrating fertilizer nitrogen (N) with organic manures or its use as an alternative nutrient source will contribute to development of sustainable agricultural management systems in the subtropics. Organic manures are a natural resource for conserving and sustaining soil productivity. They are a primary substrate for replenishment of soil organic matter, which, on mineralization, supply essential plant nutrients (Walters et al., 1992). Additionally organic manure incorporation can improve soil physical and biological conditions and prevent soil degradation (Nyborg et al., 1995).

Spent mushroom compost, a waste product of mushroom production, has traditionally been discarded as waste creating an environmental nuisance. Mushroom compost is made by blending natural products that can include poultry manure, wheat straw, paddy straw, cottonseed hulls and gypsum. In addition to these ingredients composters add a variety of protein concentrates and NPK fertilizers. Although spent mushroom compost is not economical for subsequent use in mushroom growing it is potentially a valuable soil amendment and a source of nutrients for field crops. Spent mushroom compost adds organic matter to the soil which increases soil water and nutrient holding capacity and improves soil structure (Levanon and Danai, 1995).

Mushroom production has increased dramatically in the worlds twenty largest mushroom producing countries to 3,213,796 t (FAOSTAT, 2005). Indian mushroom growers generate approximately 600,000 t of spent mushroom compost yearly. Increased demand for organic residues and compost provides a potential outlet for spent mushroom compost, thus generating more income for mushroom growers and increasing crop production and improving soil quality (Wang et al., 1984).

Organic matter with different C:N ratios and biochemical composition releases nutrients at different rates. There is little published information on the use of spent mushroom composts of varying C:N ratios as an organic amendment and provider of soil essential nutrients. Hence there is a need to create awareness of the potential of this organic waste and to explore its potential, discover its complexities, evaluate its behavior, assess its benefits and learn how to adopt it for greater benefits, profitability and sustainability over large areas and on more crops.

With increased demand for food and fiber to support growing populations, coarse textured soils in subtropical and semiarid regions although having very high percolation rates are now used for raising both dryland crops and wetland rice (Aulakh and Singh, 1997; Aulakh and Pasricha, 1997b). The benefit of sequestering soil organic carbon (C) to sustain crop production by applying organic nutrients is well documented (Aulakh et al., 2001). Inadequate or imbalanced nutrient management and decreased soil organic matter are probably factors in declining yield and productivity of these porous soils.

A two-year field study with irrigated rice on a subtropical porous sandy loam soil was undertaken

(i) to investigate the individual and combined effect of different types of spent mushroom compost of varied C:N ratios with fertilizer N on yield response and N use efficiency and

(ii) to quantify soil C sequestration using spent mushroom compost of varied C:N ratios and/or with fertilizer N incorporation.

MATERIALS AND METHODS

Field experiments were conducted in 2004 and in 2005 on a subtropical irrigated alluvial sandy loam soil (Typic Ustochrept) Allahabad, India. Allahabad is situated at 25° 57′ N and 87° 17′E. Total annual rainfall during the study years was 1075 and 1345 mm for 2004 and 2005 respectively. About 80% of this rain falls during the South West monsoon (July-October). The characteristics of the alluvial sandy loam soil (0-15 cm) and the spent mushroom composts used in this experiment are presented in Table 1.

The treatments were

(i) three fertilizer N rates at 0, 90 and 120 kg ha^{-1} and

(ii) three levels of spent mushroom compost (0 spent mushroom compost control, 5 t ha^{-1} spent white button mushroom compost, and 5 t ha^{-1} spent oyster mushroom compost).

Treatments were arranged in a 3^2 factorial randomized block design with three replicates. The spent mushroom composts used in this study were spent white button mushroom compost (WB-SMC) which is residual material after the final harvest of *Agaricus bisporus* mushrooms and oyster spent mushroom compost (OY-SMC) which is the residue after final harvest of *Pleurotus ostreatus* mushrooms. Depending on treatment compost was incorporated thoroughly into the soil plough layer 10 d before transplanting rice.

Healthy 25 d old rice seedlings were transplanted, (3 seedlings hill^{-1}) during the third week of July. Rows were 20 cm apart and the plant spacing was 15 cm. Individual plots were 2.0 by 3.0 m. Half of the fertilizer N rate, as urea, was applied as a basal dressing. The remaining half was applied in two equal splits at tillering and at panicle initiation.

The crop was irrigated daily for the first 40 d and thereafter as needed to prevent the soil surface not having overlying water for more than 2 d. At maturity, the rice crop was harvested during the fourth week of November. Rice yield is expressed on 14% moisture basis. At the end of the study, soil bulk density was determined using a steel core sampler of 15 cm with open ends to 15 cm depth by collecting and combining two cores from each plot. Soil samples were air-dried, crushed to pass through a 2 mm sieve and analyzed for soil organic C. Mean bulk density values for each treatment were used to convert soil organic C concentration in mg C kg^{-1} soil to kg C ha^{-1}.

Nitrogen use efficiency and organic C sequestration were calculated using the following formulae.

Recovery efficiency (RE) of added N was calculated (Dilz, 1988):

$$\mathrm{RE} = \frac{\text{Total N uptake (kg N ha}^{-1}\text{) treatment} - \text{Total N uptake (kg N ha}^{-1}\text{) control}}{\text{Applied N(kg N ha}^{-1}\text{) treatment}} \times 100 \quad (1)$$

Physiological efficiency (PE) of N was calculated (Isfan, 1990)

$$\mathrm{PE}\,(\text{kg grain kg N uptake}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1}\text{) treatment} - \text{Grain yield (kg ha}^{-1}\text{) control}}{\text{Total N uptake (kg N ha}^{-1}\text{) treatment} - \text{Total N uptake (kg N ha}^{-1}\text{) control}} \quad (2)$$

Agronomic efficiency (AE) of added N was calculated (Novoa and Loomis, 1981)

$$\mathrm{AE}\,(\text{kg grain kg N uptake}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1}\text{) treatment} - \text{Grain yield (kg ha}^{-1}\text{) control}}{\text{Applied N (kg N ha}^{-1}\text{) treatment}} \quad (3)$$

Carbon added in soil organic C (SOC), (Aulakh, 2001)

$$\text{Cadded in SOC} = \frac{\text{SOC (Mg C ha}^{-1}\text{) treatment} - \text{Organic C (Mg C ha}^{-1}\text{) control}}{\text{Added C (Mg C ha}^{-1}\text{) treatment}} \times 100 \quad (4)$$

Organic C Sequestration, (Aulakh, 2001) was

$$\text{Organic C sequestration} = \frac{\text{SOC (Mg C ha}^{-1}\text{) treatment} - \text{SOC (Mg C ha}^{-1}\text{) control}}{\text{Added C (Mg C ha}^{-1}\text{) control}} \times 100 \quad (5)$$

Table 1. Characteristics of soil and spent mushroom composts used in this study.

Characteristics	Spent mushroom composts		Soil	Method used
	WB-SMC	OY-SMC		
pH	7.27	7.43	7.80	Digital pH meter
Organic carbon (g kg^{-1})	170.00	197.30	4.20	Walkely & Black method (Jackson, 1973)
Total N (g kg^{-1})	11.20	5.25	0.65	Chappman & Pratt, 1961
Total P (g kg^{-1})	7.85	1.57	0.57	Jackson, 1973
Total K (g kg^{-1})	20.35	12.05	3.40	Chappman & Pratt, 1961
C/N ratio	15.18	37.58	5.25	-
CEC [cmol (P+) kg^{-1})]	60.60	40.70	21.40	Jackson, 1973
Bulk density (Mg m^{-3})	0.25	0.20	1.58	Core soil sampler (Blacke and Hartage, 1986)
Texture	-	-	Sandy loam	Pipette method (Piper, 1950)

RESULTS AND DISCUSSION

YIELD AND DRY MATTER PRODUCTION

Paddy, straw yield and total dry matter (TDM) production were significantly higher (P < 0.05) in plots treated with 120 kg of N fertilizer ha^{-1} followed by plots given 90 kg fertilizer N ha^{-1}. The two-year mean paddy, straw yield and TDM production with application of 90 kg ha^{-1} of fertilizer N were 3.87, 4.90 and 8.77 t ha^{-1} whereas with 120 kg of N fertilizer ha^{-1} the paddy, straw yield and TDM production were 4.61, 5.91 and 10.51 t ha^{-1} respectively. The beneficial effects of N in increasing straw, paddy yield and hence the TDM production can be explained on the basis that N improved the growth of the plant and enhanced the uptake of other nutrients which might have increased the photosynthesis and photosynthates translocated to different parts for promoting meristematic development and consequently increased the yield of crop. Similar results were observed by Deshmukh and Tiwari (1996) and Om et al. (2000).

With no N fertilizer, 5 t ha^{-1} WB-SMC increased grain, straw yield and TDM production (P < 0.05) over the control. The grain, straw yield and TDM production with 5 t ha^{-1} WB-SMC were 3.41, 4.28 and 7.69 t ha^{-1} respectively (Table 2). This is understandable as organic matter improves soil physical, chemical and biological properties as well as supplying additional plant nutrients (Wang et al., 1984; Kaddous and Morgans, 1986). Maynard (1994) also reported that well composted organic amendments with a narrow C:N ratio might release nutrients in better synchrony with plant growth demand and give higher yields. On the contrary, treatment with OY-SMC (5 t ha^{-1}) gave lower grain, straw yield and TDM production than the control. This might have been due to immobilization of soil N in this treatment because of the wider C:N ratio (37.58) of OY-SMC.

The use of fertilizer N with WB-SMC at 5 t ha^{-1} had a significant (P < 0.05) synergistic effect on grain, straw yield and TDM production in both the years over the control or N alone. The two year mean grain, straw yield and TDM production for N90 WB-SMC5, N90 OY-SMC5, N120 WB-SMC5 and N120 OY-SMC5 were 5.01, 6.24 and 11.24, 3.57, 4.62 and 8.18., 5.26, 6.80 and 12.05, and 4.17, 5.32 and 9.48 t ha^{-1} respectively. Grain, straw yield and TDM production response to WB- SMC5 was greatest when it was combined with 120 kg fertilizer N, which yielded 14.0, 15.07 and 14.65% more paddy, straw and TDM production than fertilizer N at 120 kg ha^{-1}. Application of N90 WB-SMC5 was more effective than FN120 in enhancing grain, straw yield and TDM production. Integration of OY-SMC5 with FN90 or FN120 did not increase grain, straw yield and TDM production over the sole application of

FN90 or NF120. The lack of response to OY-SMC5, even when applied with fertilizer N, may have been because of the wider C:N ratio of the OY-SMC and slow decomposition of the OY-SMC in coarse textured soils. These findings are in agreement with those of Sangwan et al. (2002).

Table 2. Paddy, straw yield and total dry matter production as affected by incorporation of spent mushroom compost with or without fertilizer nitrogen (2-year pooled data).

Treatments	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Total dry matter production ($t\ ha^{-1}$)
FN_0 $WB\text{-}SMC_0$ $OY\text{-}SMC_0$[a]	2.640	3.100	5.740
FN_0 $WB\text{-}SMC_0$ $OY\text{-}SMC_5$	2.222	2.535	4.757
FN_0 $WB\text{-}SMC_5$ $OY\text{-}SMC_0$	3.410	4.280	7.690
FN_{90} $WB\text{-}SMC_0$ $OY\text{-}SMC_0$	3.875	4.900	8.775
FN_{90} $WB\text{-}SMC_0$ $OY\text{-}SMC_5$	3.570	4.615	8.185
FN_{90} $WB\text{-}SMC_5$ $OY\text{-}SMC_0$	5.005	6.240	11.245
FN_{120} $WB\text{-}SMC_0$ $OY\text{-}SMC_0$	4.610	5.905	10.515
FN_{120} $WB\text{-}SMC_0$ $OY\text{-}SMC_5$	4.165	5.320	9.485
FN_{120} $WB\text{-}SMC_5$ $OY\text{-}SMC_0$	5.255	6.795	12.050
Standard errors			
FN	0.0748	0.0879	0.1039
SMC[b]	0.0748	0.0879	0.1039
FN x SMC	0.1151	0.1354	0.1732
ANOVA results**			
FN	S	S	S
SMC	S	S	S
FN x SMC	S	S	S

OY-SMC = Spent oyster mushroom compost (subscript is tones ha^{-1}).
[a] FN = Fertilizer nitrogen (subscript is $kg\ ha^{-1}$); WB-SMC = spent white button mushroom compost (subscript is tones ha^{-1});
[b] SMC = Spent mushroom compost i.e. WB-SMC and OY-SMC.
** Significance at 0.05 probability level.

NITROGEN USE EFFICIENCY

Recovery efficiency (RE) of added N (from all sources) in rice was highest when WB-SMC at 5 t ha^{-1} was combined with fertilizer N at 120 kg ha^{-1}, followed by application of WB-SMC at 5 t ha^{-1} combined with fertilizer N at 90 kg ha^{-1}. It was lower with of OY-SMC when used alone or combined with fertilizer N (Table 3). When WB-SMC was applied at 5 t ha^{-1} it had a higher RE compared with fertilizer N at 90 or 120 kg ha^{-1}. Nitrogen in WB-SMC was probably taken up, by the rice, more efficiently than urea N due to slower release from mineralization and lower gaseous N losses. The RE of 59.1% in N120 WB-SMC5 compared with 48.05% in N120 OY-SMC5 suggests that mineralization of compost N was accelerated by incorporation of WB-SMC and/or that some of the urea N in FN120 OY-SMC5 could have been immobilized by microbes decomposing the OY-SMC because of its wider C:N ratio. Similar findings were observed by Norman et al. (1990) who observed that rice recovered 3 to 37% of added crop residue N.

Physiological efficiency was reduced with FN120 WB-SMC5 compared to FN120 OY-SMC5 and the other treatments except in WB-SMC and OY-SMC (Table 3). This suggests that N addition in FN120 WB-SMC5 was excessive and that luxury N uptake (162 kg ha^{-1} data not shown) occurred. This was 25.0 kg ha^{-1} more than the next best treatment.

The agronomic efficiency (AE) of added N by the rice was improved by incorporation of WB-SMC at 5 t ha^{-1} with N at 90 kg ha^{-1}, but not with fertilizer N application at 120 kg N ha^{-1}. The improved AE with WB-SMC at 5 t ha^{-1} reflected the greater RE compared with urea N alone or urea N with OY-SMC at 5 t ha^{-1} (Table 3). Incorporation of spent mushroom compost affected the loss of added N from the plant-soil system, indicating the importance of immobilization and re-mineralization of added urea N in the presence of the incorporated composts.

Integrated approaches of narrow C:N ratio organic and inorganic N management have shown increased efficiency of applied fertilizer N in rice. Similar findings were reported by Buresh and Datta (1991). The RE of applied N was quite close in the case of WB-SMC and inorganic N fertilizer compared to OY-SMC. This was because of minimal N loss and timely mineralization of WB-SMC because of its narrow C:N ratio which made N available to the crop for longer than with inorganic fertilizer N or with OY-SMC which immobilized native soil N because of its wider C:N ratio.

Table 3. Recovery, physiological and agronomic efficiency, as affected by incorporation of spent mushroom composts (WBS-MC and OY-SMC) with or without fertilizer nitrogen (2-year pooled data).

Treatments	Recovery efficiency (%)	Physiological efficiency (kg grain kg N uptake^{-1})	Agronomic efficiency (kg grain kg N applied^{-1})
FN_0 $WB\text{-}SMC_0$ $OY\text{-}SMC_0$	0.00	0.00	0.00
FN_0 $WB\text{-}SMC_0$ $OY\text{-}SMC_5$	-	-	-
FN_0 $WB\text{-}SMC_5$ $OY\text{-}SMC_0$	61.58	22.56	13.77
FN_{90} $WB\text{-}SMC_0$ $OY\text{-}SMC_0$	51.48	26.76	13.72
FN_{90} $WB\text{-}SMC_0$ $OY\text{-}SMC_5$	33.62	23.84	8.00
FN_{90} $WB\text{-}SMC_5$ $OY\text{-}SMC_0$	60.69	26.86	16.20
FN_{120} $WB\text{-}SMC_0$ $OY\text{-}SMC_0$	53.29	30.88	16.41
FN_{120} $WB\text{-}SMC_0$ $OY\text{-}SMC_5$	39.30	26.57	10.43
FN_{120} $WB\text{-}SMC_5$ $OY\text{-}SMC_0$	63.14	22.80	14.86
Standard errors			
FN	0.124	0.030	0.026
SMC	0.124	0.030	0.026
FN x SMC	0.192	0.052	0.045
ANOVA results**			
FN	S	S	S
SMC	S	S	S
FN x SMC	S	S	S

** Significance at the 0.05 probability level.

CARBON SEQUESTRATION

Soil bulk density was significantly reduced with both types of spent mushroom compost compared with urea N alone or the untreated control (Table 4). Application of N fertilizer and spent mushroom composts enhanced soil organic C concentration. The effect of OYSMC on soil organic C was greater than that of WB-SMC and masked the effects of the latter. In plots that did not receive spent mushroom composts soil organic C concentration decreased from the start of the experiment.

Incorporation of OY-SMC sequestered more C into soil organic matter than WB-SMC or fertilizer N. This was due to the wider C:N ratio of the OY-SMC, which was negatively correlated with C mineralization and positively related to immobilization (Aulakh et al., 1991). Enhanced fertilizer N increased the amount of crop stubble, which ultimately contributed to increased soil organic C sequestration. The low C:N ratio of WB-SMC gave lower C sequestration of WB-SMC than OY-SMC due to more rapid mineralization i.e. CO_2 loss from the WB-SMC.

Table 4. Soil bulk density and the concentration and sequestration of soil organic carbon in surface soil (0 – 15 cm) as affected by the incorporation of spent mushroom compost with or without fertilizer nitrogen (two years pooled data).

Treatments		Soil organic carbon		
	Soil bulk density ($Mg\ m^{-3}$)	Concentration ($g\ kg^{-1}$ soil)	Amount Added($Mg\ ha^{-1}$)	Sequestration[a] (%)
FN^0 $WB\text{-}SMC^0$ $OY\text{-}SMC^0$	1.62	3.50	8.80	0.00
FN^0 $WB\text{-}SMC^0$ $OY\text{-}SMC^5$	1.53	4.82	11.44	30.14
FN^0 $WB\text{-}SMC^5$ $OY\text{-}SMC^0$	1.54	4.20	10.06	14.40
FN^{90} $WB\text{-}SMC^0$ $OY\text{-}SMC^0$	1.61	3.73	9.30	5.65
FN^{90} $WB\text{-}SMC^0$ $OY\text{-}SMC^5$	1.52	5.04	11.94	35.76
FN^{90} $WB\text{-}SMC^5$ $OY\text{-}SMC^0$	1.54	4.40	10.51	19.48
FN^{120} $WB\text{-}SMC^0$ $OY\text{-}SMC^0$	1.61	3.95	9.87	12.33
FN^{120} $WB\text{-}SMC^0$ $OY\text{-}SMC^5$	1.52	5.21	12.33	40.21
FN^{120} $WB\text{-}SMC^5$ $OY\text{-}SMC^0$	1.53	4.64	11.05	25.61
Standard errors				
FN	0.007	0.013	0.016	0.031
SMC	0.007	0.013	0.016	0.031
FN x SMC	0.011	0.020	0.028	0.053
ANOVA results**				
FN	NS	S	S	S
SMC	S	S	S	S
FN x SMC	NS	S	S	S

[a] Soil organic carbon sequestration, Equation (5)
** Significance at the 0.05 probability level

CONCLUSIONS

The results indicate that supplying plant nutrients through the integrated use of WB-SMC of a narrow C:N ratio and 90 kg fertilizer N ha^{-1} gave an advantage over the use of OY-SMC and/or fertilizer N. It gave a higher rice yield and reduced the need for fertilizer N. Use of WB-SMC alone, can give a farmer a rice yield comparable with that produced from 90 kg of fertilizer N ha^{-1}. Mineralization of WB-SMC was relatively rapid and gave similar, or enhanced, plant N-use efficiency to that with fertilizer N. However, excess fertilizer N use in conjunction with WB-SMC of narrow C:N ratio reduces fertilizer use efficiency and may lower crop yield due to lodging caused by excess vegetative growth. The OY-SMC, with a wider C:N ratio, reduced N recovery and agronomic N efficiency but its incorporation with fertilizer N can increase yield, recovery efficiency and agronomic efficiency compared with application of OY-SMC alone. The use of WB-SMC in rice cropping enhanced C sequestration but the effect due to OY-SMC with a wider C:N ratio compared to WB-SMC with a narrow C:N ratio was higher because of low mineralization and high immobilization of its C.

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