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Economizing the use of nitrogen fertilizer in wheat production through enriched compost

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Abstract

Manipulation of organic wastes and their composts as a source of organic matter (OM) and nutrients is imperative for sustainable agriculture. Further, the fortification of composts with chemical fertilizer enhances agronomic effectiveness of both by reducing the amount of fertilizer and improving the quality of compost. The present study aimed to explore the potential of organic and chemical nutrient sources with their optimal application and integration for sustainable wheat production. Accordingly, waste fruits and vegetables were collected, dried, ground and processed in a composting vessel. During the enriched composting, waste material (300 kg) was fortified with 30 kg N, i.e. 25% of the standard rate (120 kg N ha^{-1}) of N fertilizer. Treatments for both greenhouse and field experiments using wheat (*Triticum aestivum* L.) included: control (without any compost or N fertilizer), compost (non-enriched), fertilizer N 120 (120 kg N ha^{-1}), nitrogen-enriched compost (NEC), NEC + N 30 (30 kg N ha^{-1}) and NEC + N 60 (60 kg N ha^{-1}). Application rate of composts (non-enriched or enriched) was 300 kg ha^{-1} in the respective treatments. Phosphorus and potassium fertilizers were applied at 90 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}, respectively in all treatments. The crop was grown to maturity, and data on wheat growth and yield attributes were recorded. Application of NEC significantly improved the growth, yield and N, P and K contents of wheat compared with compost and control treatments. The performance of NEC + N 60 was statistically similar to that of fertilizer N 120. Economic analysis also revealed the superiority of NEC + N 60 over other treatments in terms of net return and relative increase in income; however, the value/cost ratio was highest with NEC alone. For effective and economical use of N fertilizer, it is suggested to integrate N fertilizer at reduced rates with NEC. Through enriched compost, application rates can be decreased from tonnes to kilograms per hectare, and dependence on chemical fertilizer can be reduced to a certain extent. So the approach is farmer friendly as it lowers compost application rates, and is economically acceptable as it saves N fertilizer. It is also environmentally sustainable due the recycling of organic waste and possible reduction of N losses to the environment. Thus, the study has wide application in the global environment and fertilizer market.

Key words: organic wastes, fortified compost, growth and yield, nutrient uptake, economics, environmental pollution

Introduction

Massive waste (agricultural, industrial, urban) generation, increased management costs and heightened public awareness about the environment and health safety have compelled agricultural, industrial and municipal sectors towards safe disposal of organic residues. Huge amounts of organic materials are in the form of farm waste, city waste, sewage sludge, poultry litter and agro-industrial wastes[1,2]. In urban areas of Pakistan, less than 60% waste is collected as no city has a proper waste collection and disposal system[3]. Improper handling of these wastes results in several environmental risks such as pollution of soil, water and air[4]. Composting, compared with other management strategies like landfilling, incineration and dumping in water channels, is a more economical and ecologically acceptable way to tackle the problem[5,6]. It helps to dispose of waste hygienically and also conserve the valuable plant nutrient source for safe use in agriculture[5].

Table 1. Analysis of raw and composted fruit and vegetable wastes.

Material/ Contents	Carbon (C)	Nitrogen (N)[1]	Phosphorus (P)	Potassium (K)	Zinc	Copper	Iron	Manganese	C/N ratio	C/P ratio	C/K ratio
	----------	---------- %	----------	----------	----------	---------- µg g^{-1}	----------	----------			
Raw waste	32.4	1.39	0.26	1.19	38.6	1.14	368	43.1	23.3	125	27.2
Compost	23.2	2.41	0.39	1.72	48.4	1.37	598	57.8	9.60	60	13.5

[1] Nitrogen content of enriched compost was 12.0%.

Composting is a biological process that converts heterogeneous organic wastes into stable and humified organic material by mixed microbial population under controlled optimum conditions of moisture, temperature and aeration. Organic matter (OM) thus biodegraded during composting can be handled, stored and applied to land without any environmental impact[6–9]. Composted organic material can be used as a source of OM and plant nutrients for sustainable crop productivity. The composted organic wastes not only act as a supplement to chemical fertilizers, reducing the need of inorganic fertilizers, but may also improve the OM status and physico-chemical properties of soil[10–12].

No doubt, use of chemical fertilizers provides essential nutrients for crop improvement to obtain higher yields and composted organic materials improve soil health, but during recent decades the yields have become almost static, for example in India and China[13]. It is more likely that the fortification of composted organic materials with chemical fertilizers may be an effective alternative approach for improving crop yields beyond existing levels. The quality of compost as well as the efficiency of chemical fertilizer was improved through enrichment of composted organic materials with urea N fertilizer during composting[14,15]. Incorporation of an appropriate rate of urea-N also reduced the quantity of applied organic waste substantially, contrary to the use of tonnes ha^{-1} for improvement of crop productivity as reported by many scientists[16–18]. Organic fertilization has advantages from both environmental and economic perspectives, and with appropriate application rates, chemical fertilizers could be reasonably avoided or minimized, lowering the production costs and reducing groundwater pollution without decreasing yields[19]. Organic production produces beneficial impacts on social and environmental issues, in addition to high prices fetched by the organic produce[20].

In this study, waste fruits and vegetables were composted and fortified with urea fertilizer to make nitrogen-enriched compost (NEC). Lower rates of N fertilizer were applied along with NEC to enhance the N fertilizer efficiency and to improve growth, yield and nutrient uptake of wheat. Further, economic evaluation of these nutrient sources was undertaken as it is an essential basis for farmer adoption of compost use. The focus was to optimize the use of both the compost and N fertilizer, so that any environmental pollution potential could be reduced without lowering crop yields and soil productivity.

Materials and Methods

This study comprises two phases; enriched compost was prepared in the first phase, and wheat crop was grown with compost and N fertilizer during the second phase. Two parallel experiments on wheat crop production with the same treatments were performed, one in the greenhouse and the other in the field at the Agronomy Field Station of Ayub Agriculture Research Institute (AARI), Faisalabad, Pakistan during 2004–2005.

Preparation of enriched compost

Compost was prepared by using a locally fabricated composter consisting of a drier, crusher/grinder and a processor. Organic material containing fruit and vegetable wastes was collected from various locations (fruit and juice shops, fruit and vegetable markets, etc.) of Faisalabad city. The collected organic waste material was air-dried for 24 h to remove the excess moisture and sorted to remove all unwanted substances (plastic bags, glass material and stones, etc.) in the organic waste. The organic material was then oven-dried at $60 \pm 5°C$ for 24 h and crushed in the crushing unit of the composter to convert raw forms of the waste into a finer form (< 2 mm). The crushed material was put in the composter (processing unit; a vessel of 500 kg capacity) to convert organic waste materials into compost. A moisture level of 40% (v/w) of the compost was maintained during the composting process. Composting was done for 6 days under controlled temperature and aeration (shaking at 50 rpm). The temperature rose up from 30 to 70°C in the composting unit during 2nd and 3rd day of composting and then reduced gradually to 30°C after 5th day process.

Composted material (300 kg) was fortified with 25% of the recommended rate (120 kg ha^{-1}) of N fertilizer for wheat in the form of urea. Thus, the 300-kg batch of compost received 30 kg N for the wheat crop. After enrichment, the organic product was passed through a grinder to make granules of the product. The enriched compost was packed in gunny bags and stored for a few days prior to use.

Both raw (non-composted) and composted organic waste materials were analyzed on a dry weight basis (Table 1) for carbon content[21], and macro- and micronutrients[22]. The C/N, C/P and C/K ratios were determined.

Table 2. Effect of different nutrient sources on growth and yield of wheat in the greenhouse.

Treatments	Plant height (cm)	Tiller (no.) ($plant^{-1}$)	Spike length (cm)	Straw yield (g pot^{-1})	Grain yield (g pot^{-1})	1000-grain weight (g)
Control	54.3 c*	2.0 d	7.9 d	14.3 d	6.9 d	35.3 d
Compost	55.6 c	2.0 d	8.1 cd	17.2 c	7.8 d	37.2 c
Fert N 120	61.0 a	4.1 a	9.2 ab	24.0 a	12.0 a	40.4 a
NEC alone	57.1 b	2.6 c	8.5 bc	19.0 bc	9.5 c	39.2 b
NEC + N 30	60.6 a	3.4 b	8.8 b	20.6 b	10.6 b	40.0 b
NEC + N 60	61.5 a	4.2 a	9.6 a	23.6 a	12.2 a	41.0 a

* Values sharing the same letter(s) in a column do not differ significantly at $P < 0.05$.

Greenhouse experiment

This experiment was conducted in pots in a greenhouse to assess the effect of enriched compost and chemical fertilizers on the growth and yield of wheat crop. Soil was collected from Agronomy Station fields of AARI, Faisalabad; it was air-dried, ground, sieved (2 mm) and analyzed for physical and chemical characteristics. The soil used for the pot trial was a sandy clay loam having pH 7.4; ECe 2.8 dS m^{-1}; OM, 0.71%; total N, 0.05%; available P, 6.9 mg kg^{-1}; and exchangeable K, 180 mg kg^{-1} soil. Each pot was filled with sieved soil (10 kg pot^{-1}), mixed with recommended P and K fertilizers at 90 and 60 kg ha^{-1}, respectively. Single super phosphate and sulfate of potash were used as a source of P and K. Both types of composts (non-enriched or enriched) were applied on a dry weight basis at the rate of 300 kg ha^{-1} by mixing it with the top 15 cm soil before filling the pots. A standard rate of N at 120 kg ha^{-1} for wheat was kept for comparison. Details of the treatments are given below:

(T1) Control (without any compost or N fertilizer)
(T2) Compost (non-enriched)
(T3) Urea fertilizer nitrogen applied at 120 kg N ha^{-1} (Fert N 120)
(T4) NEC alone
(T5) NEC + 30 kg N ha^{-1} (NEC + N 30)
(T6) NEC + 60 kg N ha^{-1} (NEC + N 60)

Eight seeds of wheat (*Triticum aestivum* L.) of the cultivar Inqulab-91 were sown in each pot containing 10 kg soil. After germination, four healthy and uniform plants were maintained in each pot. The pots were arranged in completely randomized design with four replications. An additional amount of N fertilizer (25 and 50%) was applied in solution as two split applications. The first and second applications were applied after thinning and at grain-filling stage. Canal water meeting the irrigation quality criteria[23] for crops was used for irrigation.

Field experiment

The field experiment was conducted to assess the effect of enriched compost and chemical fertilizers on the growth, yield and nutrient uptake of wheat, which was sown at 125 kg seed ha^{-1} with a hand-drill, with an inter-row distance of 25 cm, with individual treatment plots of 12 m^2 (4 m × 3 m). The soil had the same physico-chemical characteristics as in the pot trial. The treatment plan followed was the same as in the case of the green-house experiment. The experiment was laid out in randomized complete block design with four replications. The N, P and K fertilizers were applied at 120, 90 and 60 kg ha^{-1} as urea, single super phosphate and sulfate of potash, respectively.

Full amounts of P and K fertilizers were applied as a basal dressing at sowing time to all treatments, while N was applied in two split applications, i.e. in the 3rd week after germination and at the tillering stage, according to the treatment plan. The effectiveness of organic fertilizer (NEC) was assessed in the presence of 25 and 50% of full application of N fertilizer for wheat. Compost-based organic fertilizer was applied at 300 kg ha^{-1} as a side dressing to plants along with the first application of N fertilizer and was then irrigated with canal water.

The plants were harvested at maturity (both in pot and field trials) and the growth and yield data were recorded. The NPK contents in grain and straw were determined[22]. The total nutrient contents of wheat plants (uptake) were calculated. The data were processed statistically through analysis of variance[24]. Means were compared by the Duncan's Multiple Range test[25].

Economic analysis

Data on the expenditures and returns of various treatments were processed for their economic comparison by using the procedures given hereunder[26]: Net return = Value of increased yield obtained − Cost of nutrient sources; Value/cost ratio (VCR) = Value of increased yield obtained ÷ Cost of nutrient sources; Relative increase in income (RII) = (Net income/Income at control) × 100.

Results

Greenhouse experiment

NEC in combination with N fertilizer increased the yield and yield attributes of wheat significantly (Table 2). By comparison with the control and compost alone, application of NEC caused a significant improvement in plant height, with no differences between N application rates. Similarly, NEC increased plant tillers at the 50 and 100% N

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enrichment, while compost alone was no better than the control. The effect of the materials on spike length was similar to plant height and tillers, but the influence of N enrichment rate was inconsistent.

Straw and grain yield, the main parameters of concern, and 1000-grain weight of wheat were also affected significantly by the integrated use of NEC and chemical fertilizer. For both straw and grain yield, the order of the effects of the materials was as follows: control, compost alone, NEC, and the NEC with three levels of N. In each case, there was no significant difference between the second and third N application rates along with NEC. The effects on 1000-grain weight were similar, being 35.3 g (lowest) for the control and 41.0 g (highest) for the NEC along with 60 kg N ha^{-1}.

As expected, the NEC in the presence of N fertilizer caused significant increase in N, P and K contents over control (124.6, 153.7 and 102%, respectively), but did not differ significantly with full dose of N fertilizer alone (Table 3). The compost alone without any enrichment was not different from the control.

Field experiment

Application of NEC in combination with N fertilizer significantly increased the plant height, number of tillers m^{-2}, spike length, straw yield, grain yield and 1000-grain weight of wheat (Table 4). The response patterns for most parameters followed those observed in the greenhouse experiment. Grain and straw yields with the NEC plus the two higher N levels were 2–3 times higher than the control without any compost or nutrient addition. In each case, NEC with higher N levels was significantly superior to NEC alone with no difference between second and third N application rates. The same results were observed in the case of the control and compost alone.

The NEC in the presence of 50% N fertilizer caused significant increase in N, P and K contents (192.7, 220.5 and 188.3%, over the control, respectively) of wheat that differed non-significantly with full application rate (100%) of N fertilizer (Table 5). Application of non-enriched compost and control also had non-significant difference.

Table 3. Effect of different nutrient sources on nutrient uptake (mg pot^{-1}) by wheat in the greenhouse.

Treatments	Nitrogen	Phosphorus	Potassium
Control	154 d*	67 d	117 d
Compost	190 d	83 d	136 d
Fert N 120	355 a	165 a	239 a
NEC alone	245 c	110 c	170 c
NEC + N 30	296 b	133 b	201 b
NEC + N 60	346 a	170 a	237 a

* Values sharing the same letter(s) in a column do not differ significantly at $P < 0.05$.

Discussion

This study demonstrated the effectiveness of NEC combined with chemical fertilizer for promoting the growth, yield and nutrients (N, P and K) uptake of wheat under both greenhouse (pot) and field conditions. A relatively low application of NEC combined with standard application rates of fertilizer N was shown to increase N-use efficiency. With the application of 300 kg ha^{-1} organic fertilizer/enriched compost (compost enriched with 30 kg N), there was an overall ~25% (30 kg) saving of N. Other scientists[16,27,28] also reported N saving with the application of compost; however, most studies used larger amounts of compost as a complementary source to chemical fertilizer in contrast with our study. Thus, the actual N rate applied was the same as the full recommended application of chemical fertilizer, but part of the chemical fertilizer was substituted through the compost.

The novelty of our approach is that the NEC was applied just at 300 kg ha^{-1} as a soil amendment. Previously, farmers had to add compost in soil at several tonnes per hectare, largely because of the poor nutrient status of such compost. It is likely that N losses due to leaching or denitrification might have been reduced in soil by mixing N-fertilizer with organic compost, resulting in a better utilization of N by the plant[14,15]. Previous studies have also shown that composted organic materials enhance fertilizer use efficiency by releasing nutrients slowly and thus reducing the losses, particularly of N[16,29–31].

Recently, an incubation study revealed that carbon dioxide release from NEC-amended soil was much slower than recorded in the case of raw compost or raw compost

Table 4. Effect of different nutrient sources on the growth and yield of wheat in the field.

Treatments	Plant height (cm)	Tillers (number m^{-2})	Spike length (cm)	Straw yield (tonnes ha^{-1})	Grain yield (tonnes ha^{-1})	1000-grain weight (g)
Control	60.5 d*	324 d	8.2 d	2.65 d	1.93 d	39.7 d
Compost	67.4 cd	352 cd	8.5 cd	2.80 d	2.06 d	41.0 cd
Fert N 120	84.2 a	442 ab	9.9 a	6.02 a	3.95 a	45.5 ab
NEC alone	73.3 bc	380 c	8.8 c	4.48 c	3.25 c	42.6 c
NEC + N 30	79.2 ab	424 b	9.4 b	5.81 ab	3.69 b	44.4 b
NEC + N 60	87.1 a	460 a	10.1 a	6.25 a	4.0 a	46.2 a

* Values sharing the same letter(s) in a column do not differ significantly at $P < 0.05$.

plus urea-amended soil, indicating more stability of composted organic wastes over uncomposted organic wastes[32]. It was also reported that organic material rich in N is least decomposed/lost, adding more OM to the soil[33]. Since addition of organic fertilizer increases mobilization of P and microbial activities in soil[34], it might also be a contributing factor in improving P nutrition as well as improving the root system.

The results also revealed that application of non-enriched compost at 300 kg ha^{-1} without any N fertilizer had no significant effect on the growth and yield of wheat and was comparable with the un-amended control. This was probably due its poor nutrient content and slower decomposition rate. Application of immature compost (raw organic waste) at considerably higher application rates (tonnes) may even reduce the crop yield due to a wider C/N ratio, oxygen deficiency in plant roots and production of harmful organic compounds[18,34–36].

The economic analysis of the study (Table 6) indicated that this technology of N-amended compost is cost-effective, as collection and transportation of waste organic material are the government's responsibility by law. Raw material is available free of cost and application of a few hundred kilograms is quite feasible for farmers to use as soil amendments; also it does not create a demand–supply problem. This approach is not only cost-effective but also helps in saving chemical fertilizer and improving the soil OM status and thus soil quality. As the production cost of N fertilizer is considerable both in its environmental aspects (consumption of fossil fuel and emission of CO_2) as well as in currency terms, there is increasing demand from the global society and farmers, especially in developing countries, for optimal and profitable N-resource management practices. Nitrogen losses through leaching (nitrate) and in gaseous forms (nitrous oxide and ammonia) from agricultural lands, particularly from fertilizer N sources (ranging up to 60%), also have a negative environmental impact and an economic loss. This situation emphasizes the need to develop viable technologies and farm practices leading to enhanced N fertilizer use efficiency that centers on optimizing application and minimizing uncontrolled losses.

OM plays a pivotal role in stabilizing N through biological intervention so as to reduce its losses and improve its efficiency in crop production. Organic farming has a considerable potential to contribute to the global food supply, and also to reduce the harmful effects on environment from conventional agriculture[37]. With respect to biodiversity, atmospheric pollution and water contamination, the organic system was found to be superior to the integrated system, which in turn was better than the conventional method of olive farming[38]. Our study supports this dual objective. By introducing the NEC technology, the amount of N fertilizer could be reduced by at least 25% of the total required to sustain crop yields. With appropriate manure application, the advantages of organic fertilization were reflected in chemical fertilizers being reasonably avoided in sweet pepper cultivation, thus lowering production costs without decreasing fruit yield[19]. Thus organic production can have beneficial impacts on social and environmental issues, in addition to a potentially higher price for such produce[20].

Table 5. Effect of different nutrient sources on nutrient uptake (kg ha^{-1}) by wheat in the field.

Treatments	Nitrogen	Phosphorus	Potassium
Control	30.4 d*	14.1 d	39.4 d
Compost	33.6 d	15.6 d	47.0 d
Fert N 120	88.8 a	43.6 a	115.4 a
NEC alone	55.2 c	27.9 c	80.8 c
NEC + N 30	78.4 b	38.0 b	101.8 b
NEC + N 60	89.0 a	45.2 a	113.6 a

* Values sharing the same letter(s) in a column do not differ significantly at $P < 0.05$.

Table 6. Economics (in US$) of using different nutrient sources for wheat production in the field.

Treatments	Expenditure on nutrient sources[1]	Income from wheat[2] Grain	Straw	Total	Increased income over control	Net Return	Value/cost (VCR) ratio	Relative increase in income (RII)
Control	–	321.67	66.25	387.92	–	–	–	–
Compost	3.00	343.34	70.00	413.34	25.42	22.42	8.47	93.89
Fert N 120	43.48	658.35	150.50	808.85	420.92	377.44	9.68	183.72
NEC alone	17.29	541.68	112.00	653.68	265.75	248.46	15.37	148.48
NEC + N 30	28.16	615.01	145.25	760.26	372.34	344.18	13.22	172.68
NEC + N 60	39.03	666.68	156.25	822.93	435.01	395.98	11.15	186.92

[1] Expenditures on different nutrient sources were as follows:
- Price of N fertilizers (US$ kg^{-1}) = 0.36 (NFDC, 2006)[39].
- Cost of NEC includes electricity and labor charges for processing.
- Cost of enriched compost includes electricity and labor charges for processing, and cost of 30 kg N.

[2] Price of the wheat produce is as follows:
- Price of wheat grain = 166.67 US$ $tonne^{-1}$.
- Price of wheat straw = 25.00 US$ $tonne^{-1}$.

Conclusions

Organic waste materials can be converted into value-added organic fertilizer by composting and fortification with lower doses of urea N. It is possible to get higher yield levels with complementary use of organic and synthetic fertilizers, as against their sole application. The improvement in soil OM and reduction in piling up of organic wastes would be an additional incentive. Further, the reduced demand for mineral N fertilizers may lessen the consumption of a non-renewable energy source (natural gas) used as raw material for urea fertilizer production, and would keep down the pollution from emissions of greenhouse gases (CO_2 and nitrous oxide) and leaching of nitrates to groundwater. Also, the resource-poor farmers, especially in developing countries like Pakistan, could be less reliant on expensive mineral N fertilizers to support their livelihoods from their limited agricultural income.

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