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Comparative effectiveness of phosphate-enriched compost and single superphosphate on yield, uptake of nutrients and soil quality under soybean–wheat rotation

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SUMMARY

Low organic matter concentration coupled with low native soil phosphorus (P) concentrations is a major constraint limiting the productivity of a soybean–wheat system on Vertisols in the Indian semi-arid tropics. In a 3-year field study (1996–99), the performance of four different composts obtained from legume straw (*Glycine max* Merr.L), cereal straw (*Triticum aestivum*), oilseed straw (*Brassica juncea* L.) and city rubbish were compared, and also with chemical fertilizers in terms of degree of maturity, quality of compost, improvement in soil organic matter, biological activities of soil and yields of soybean and wheat. Phospho-sulpho-nitrocomposts (phosphocomposts) were prepared containing approximately 2·5 to 4·2% P and 1·4 to 2·3% N, in an aerobic decomposition process for 4 months by adding an aqueous slurry of 1:1 (dry weight) cow dung, 2·2% P in the form of low grade Mussorie phosphate rock (7·5% P), 10% pyrite (S, 22·2%) and 0·5% urea N, and bioinoculums such as the cellulose decomposers *Paecilomyces fusisporus* and *Aspergillus awamori*, and P-solubilizing organisms i.e. *Bacillus polymyxa* and *Pseudomonas striata*. The maturity indexes were strongly associated with the source of materials, chemical composition and degree of decomposition. The matured composts had lower C/N ratios (8·2 to 21·7) and water soluble carbohydrates (0·23 to 0·43%) and larger ratios of cation exchange capacity/total organic carbon (CEC/TOC) and lignin/cellulose than the initial. The matured compost increased total P, water soluble P, citrate soluble P, total N and NO_3-N and the application of phosphocompost at the rate of 10 t/ha gave plant growth dry matter accumulation, seed yield and P uptake by soybean equivalent to single superphosphate at 26·2 kg P/ha. The continuous turnover of enriched phosphocompost increased soil microbial biomass C and the activity of enzymes compared to application of chemical fertilizer.

INTRODUCTION

Soil organic matter with associated microbial activity plays a major role in the nutrient cycling process in soil leading to enhanced nutrient availability. Increasing plant biomass production per unit cropped area, increasing biomass return per unit to cropped area and decreasing soil organic matter loss have been identified as the major considerations to maintain the soil organic matter balance. Thus, low input sustainable agriculture and the reduced chemical input concept focus on the reconsideration of agricultural practices such as burning crop residues and organic matter recycling into soil, in order to maintain and preserve soil organic matter at an adequate level and to sustain arable land (Grubinger 1992). Farm yard manure (FYM) contains very small amounts of major nutrients (NPK). It is, however, difficult to obtain sufficient FYM, considering the fast growing urban population in India, and the cost of transportation is high. Farm residues, city rubbish and agro-based industrial wastes could be used as alternatives to FYM to maintain soil physical, chemical and biological quality (Swarup *et al*. 2000) and to sustain crop productivity.

The climate in semi-arid and subhumid regions is characterized by long cold winters, which are interrupted frequently by short, often dry summers. Thus, the soils are usually almost dry from October

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Table 1. *Treatment details for the soybean and wheat*

Treatments	Sources of waste	Compost applied to soybean (t/ha)	Nutrients supplied as chemical fertilizers: Soybean N	Soybean P (kg/ha)	Soybean K	Wheat N	Wheat P (kg/ha)	Wheat K
T_1	Soybean	10	—	—	—	60	13·1	16·7
T_2	Wheat	10	—	—	—	60	13·1	16·7
T_3	Mustard	10	—	—	—	60	13·1	16·7
T_4	City rubbish	10	—	—	—	60	13·1	16·7
T_5		NPK	25	17·4	16·7	120	17·4	33·3
T_6		NPK	25	21·8	16·7	120	21·8	33·3
T_7		NPK	25	26·2	16·7	120	26·2	33·3

Values are expressed on an oven dry weight basis.

until April. The average temperatures from April to June were exceptionally high (37–43 °C) with a mean of 40·6 °C and precipitation was exceptionally low. Thus, direct application of crop residues is possible only in the presence of sufficient soil moisture for rapid decomposition. Therefore, composting is an alternative in semi-arid and subhumid regions.

Decomposed manures which have a high degree of humification and so contain less phytotoxic materials and pathogens are safe and efficient in crop production (Bernal *et al*. 1998). A review of past work concluded that adequate decomposition of organic materials is essential for obtaining better quality of organic matter, not only by way of crop nutrition but also to improve soil quality and productivity (De Nobili *et al.* 1986; De Nobili & Petrussi 1988; Inbar *et al*. 1992; Beca *et al*. 1995) Hence, it is important to develop a suitable technique for preparation of mineral enriched compost in the shortest possible time and evaluate its quality and maturity. Only a few investigations examined the effects of chemical amendments and bioinoculums on decomposition of organic materials under semi-arid and subtropical climatic growth conditions in India (Gaur 1987; Hajra *et al*. 1992, 1994; Manna *et al*. 1997). Soybean is one of the major cash crops in semi-arid and subhumid regions of central India where its residues are not used for cattle feed. During winter (dry season) either cereals, mainly wheat or oilseeds, follow soybean in the crop rotation. Burning of these crop residues is common in India, which hastens the decline in soil organic matter content, lowers biological activity and destroys soil structure. There is evidence that soybean is an exhaustive crop like wheat (Swarup *et al*. 2000). The adoption of mineral enriched compost in semi-arid and subhumid regions aims at maximizing grain yield, minimizing environmental side-effects and requiring the development of techniques of consistent crop management systems.

The nutrient turnover in the soil–plant system is very high in soybean–wheat rotation, and decline in nutrient status of the soil, particularly organic matter is a great concern. Thus, any management system which improves and maintains the organic matter of the soil of such high intensive cropping is the need of the day. In this context, it is necessary to give priority through recycling of these wastes for sustained production and soil quality. Since organic manures often have profound residual effects, their recommendations need to be generated on a cropping system basis, as far as possible. The present study, therefore, has been initiated to (i) monitor the quality of matured compost continuously through simple chemical parameters, (ii) to evaluate the comparative effectiveness of compost and inorganic fertilizer on yield and uptake of nutrients, and (iii) to assess the quality of soil by repeated application of compost and chemical fertilizer under soybean–wheat rotation.

MATERIALS AND METHODS

Preparation of phosphate enriched phosphocompost

Phosphocompost was prepared for three consecutive years (1996–99) using three different crop residues (soybean, wheat and mustard straw) and city rubbish separately. Forty kg of each waste (5–6 cm length) were mixed with equal quantity of fresh cow dung. Cheap mineral amendments, such as rock phosphate (Mussorrie phosphate, 100 mesh) and pyrite were added in the mixture. Nitrogen was also added to stimulate the microbial activity at a narrow C:N ratio because the organism's proliferation is maximum at a C:N ratio of 30:1 to 40:1 (Bernal *et al*. 1998). Pyrite was added to acidify the mixtures during composting so as to prevent the volatilization loss of nitrogen and also to progressively increase phosphorus solu-

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bilization. The indigenous rock phosphate, pyrites and nitrogen were added at the rate of 2·2% P, 10% (w/w) and 0·5% urea N, respectively, and mixed throughly with fresh cow dung slurry (60–70% moisture). The multibioinoculum such as cellulose decomposers (*Paecilomyces fusisporus* and *Aspergillus awamori*), P-solubilizers (*Bacillus polymyxa* and *Pseudomonus striata*) etc. were added at 5 and 30 days of decomposition to hasten the decomposition process and phosphorus solubilization from insoluble rock phosphate as well. Fungal culture was added at 500 g mycelial mat per tonne of materials whereas bacterial culture was added at 50 ml/kg of materials having 10^8 viable cell/ml. Initially for 1–3 days, bioinoculum was added twice in the mixture owing to a high initial temperature (55 to 70 °C) and thereafter the frequency of addition of inoculum decreased gradually. The mesophillic cultures were added after 30 days of composting when the temperature was below 35 °C. The materials were allowed to decompose for a period of 120 ± 10 days in the cemented pits (1 m × 1 m × 1 m), inserted with polyvinyl chloride tubes vertically as well as horizontally, for sufficient aeration throughout the decomposition period. The filled pits were covered with polythene sheets to maintain temperature, moisture and also to prevent entry of rain water and insects etc. The chemical characteristics of matured compost e.g. total organic carbon (TOC), C/N ratio, water soluble carbohydrate (Brink *et al.* 1960), cation exchange capacity (CEC), CEC/TOC and lignin/cellulose ratio were determined and used as significant criteria to evaluate maturity and quality index of compost. The carbon and nitrogen were estimated by CHNS-analyser, CEC by the method of Lax *et al.* (1986), lignin and cellulose by the method of Rowland & Roberts (1994). Citrate soluble P, water soluble P, available nitrogen and P and N content of compost were estimated as described by Jackson (1973).

Field experiment

Experimental site

Field experiments were conducted at the Indian Institute of Soil Science, Bhopal during wet and dry seasons (1996–99). The experimental site is located in a semi-arid, subtropical climate with a mean annual rainfall of 1208 mm, of which 80–85% falls during June–September. In January temperature falls to a minimum of 10 °C and the maximum is 42 °C in May. The soil is classified as Typic Haplustert, medium black (21% sand, 34% silt and 45% clay) with a pH of 8·2, low in available nitrogen (169 kg/ha) and available P (5·8 kg/ha).

Experimental and crop culture

During the wet season, soybean cv. 'J10' was sown in the first fortnight of June in a row spacing of 45 cm at a depth of 5–6 cm with 120 kg/ha of seed. The plot size of 8 m × 4·5 m was maintained. The enriched compost was applied at the rate of 10 t/ha on soybean crop (Table 1). No chemical fertilizer was applied to the soybean crop in the compost treated plots (T_1–T_4). The effect of phosphocomposts were compared with three doses of inorganic phosphate: 17·4, 21·8 and 26·2 kg P/ha (T_5 to T_7). The treatments comprised four composts and three rates of inorganic phosphorus (T_1–T_7). All treatments were tested in a completely randomized block design with three replicates (Table 1). Soybean was harvested in the first fortnight of October.

After the harvest of soybean, wheat cv. WH-147 was sown in the first fortnight of November with a row spacing of 23 cm in each plot. The crop received fertilizers as shown in Table 1. Wheat received 60, 13·1 and 16·7 kg N, P and K/ha in the plots where only compost was applied to soybean (T_1–T_4), and compared with three doses of inorganic phosphates along with 120 kg N as urea and 33·3 kg/K as muriate of potash.

Phosphorus and potassium as single superphosphate and muriate of potash, respectively, were broadcast to both the crops just before sowing of seeds whereas nitrogen in the form of urea was applied in two splits in soybean (1/2 basal and 1/2 at 30 days after sowing) and three splits in wheat (1/2 basal, 1/4 at crown root initiation stage and 1/4 at active tillering stage). Other recommended cultural practices were followed to establish good crops.

Plant sampling and analysis

Plant samples were taken at 15 days interval each year to study the comparative effectiveness of enriched compost and chemical fertilizers in the production of plant biomass. The nitrogen and phosphorus concentration in soybean seed and wheat grain at harvest were determined and N and P uptakes calculated. Harvest index in soybean was calculated as: (economic yield)/ (biological yield) and expressed as a percentage (Donald 1962).

Soil chemical and biological analysis

The post harvest soil samples were taken from 0–15 cm depth each year in soybean–wheat rotation, air-dried for 3 weeks, and analysed for organic C contents, soil available N and P contents using standard method (Jackson 1973).

Soil microbial biomass (SMBC) was estimated from moist soil samples after harvest of each successive crop rotation by the chloroform-fumigation incubation method of Jenkinson & Powlson (1976). Composite soil samples of each replication

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Table 2. *Chemical characteristics of the waste materials used for microbial-enriched phosphocompost*

Parameters	Fresh cow dung	Soybean straw	Wheat straw	Mustard straw	City rubbish
Organic C (%)	35·1	50·00	48·9	46·8	23
Total N (%)	0·47	1·12	0·52	0·56	0·34
C/N ratio	74·7	44·6	94·0	54·6	53·5
Ash (%)	43·5	10·7	10·0	10·3	49·1
ADF (%)	—	58·3	52·5	57·9	60
Lignin (%)	—	11·8	6·8	8·9	7
Cellulose (%)	—	37·3	32·3	36·9	21
Lignin/cellulose ratio	—	0·32	0·21	0·24	0·33
Initial C/N ratio of the mixture	—	30·8	47·9	44·2	27·4

Values are expressed on an oven dry weight basis.

Table 3. *Chemical composition of microbial-enriched phosphocompost prepared from farm and city wastes based on mean of 3 years (1996–1999)*

Chemical parameters	Soybean straw	Wheat straw	Mustard straw	City rubbish	S.E. (18 D.F.)
Maturity Index					
Total organic C (%)	28	24	32	13	1·10
Total N (%)	2·32	1·93	1·47	1·58	0·05
C/N ratio	12·1	12·4	21·7	8·2	—
CEC C mol (p+)/kg	68	113	53	66	1·23
CEC/TOC	2·32	4·70	1·65	6·0	—
Lignin (%)	31	37	30	13	1·91
Cellulose (%)	10	11	12	4	0·70
Lignin/cellulose ratio	3·1	3·4	2·5	3·2	—
Water soluble carbohydrates (%)	0·30	0·23	0·43	0·23	0·02
Available nutrient status					
Available NH_4-N (g/kg)	0·54	0·45	0·26	0·12	0·02
Available NO_3-N (g/kg)	0·76	0·88	0·35	0·28	0·01
Water soluble-P (g/kg)	0·88	0·82	0·48	0·31	0·01
Citrate soluble-P (g/kg)	7·85	8·83	3·15	2·31	0·02
Total-P (%)	4·13	4·25	3·43	3·23	0·17

(50 g, 60% field capacity) were fumigated with ethanol-free chloroform for 24 h. Non-fumigated controls were incubated for 10 days at 25 °C in air-tight jars along with a beaker containing 10 ml 0·5 M NaOH to determine soil respiration. The evolved CO_2 was measured by titration of excess NaOH with 0·25 N HCl after addition of $BaCl_2$ to precipitate CO_3 ions. The concentration of CO_2-C was expressed as mg CO_2-C/kg/10 d on a soil dry weight basis. The SMBC was calculated by using the following equation: SMBC = [(mg CO_2-C/kg soil/10 d) fumigated −(mg CO_2-C/kg soil/10 d) non-fumigated]/k, where $k_c = 0{\cdot}45$ (Jenkinson & Ladd 1981). Dehydrogenase activity was measured by the method of Casida *et al.* (1964). Moist soil samples (4 g) were placed in test tubes to which were added 1 ml of 3% aqueous solution of triphenyl tetrazolium chloride, 40 mg Ca CO_3 and 2·5 ml distilled water. The contents of each tube were then mixed with a glass rod and incubated for 24 h at 37 °C. Triphenyl formazan (TPF) was extracted by transferring the soil with the aid of methanol from each tube and the colour intensity was determined in a spectrophotometer. The dehydrogenase activity was expressed as µg TPF/g/24 h on dry weight basis. Soil alkaline phosphatase was assayed by the method of Tabatabai & Bremner (1969) and the phosphatase activity was expressed as µg p-nitrophenol phosphate (PNP) released/g/h on a soil dry weight basis.

Statistical analysis

Data collected for various studies were subjected to the analysis of variance appropriate to the design as given by Snedecor & Cochran (1967). Test of significance of the treatment differences was done on the basis of *t*-test. The significant differences between treatments were compared with the critical difference at 5% level of probability.

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Table 4. *Growth dynamics and yield attributes of soybean as influenced by different treatments in 1996–1999*

Treatments	Plant height (cm) 30 days	60 days	90 days	*No. of branches	*Pods/plant (No.)	*Seeds/pod (No.)	*100-seed weight (g)	*Harvest index (%)
Compost (t/ha)								
T_1: Soybean straw	18·1	42·1	54·3	3·8	28·6	1·7	12·5	47·0
T_2: Wheat straw	17·3	44·2	57·5	4·2	30·4	1·8	13·0	49·3
T_3: Mustard straw	16·5	42·0	53·5	2·8	29·4	1·6	12·2	46·8
T_4: City rubbish	18·1	43·5	56·8	3·0	29·9	1·7	12·9	49·1
P rates (kg/ha)								
T_5: 17·4	18·2	43·7	56·9	3·1	30·1	1·7	12·9	49·1
T_6: 21·8	18·4	44·8	57·0	3·3	30·3	1·7	13·0	50·1
T_7: 26·2	18·7	46·7	58·7	4·5	32·7	1·8	13·3	51·1
Mean	17·9	43·8	56·4	3·5	30·2	1·7	12·8	48·9
S.E. (12 D.E.)	0·37	0·45	0·66	0·46	0·26	0·24	0·36	0·74

* Yield attributes data were recorded at harvest (means of three years, 1996–99).

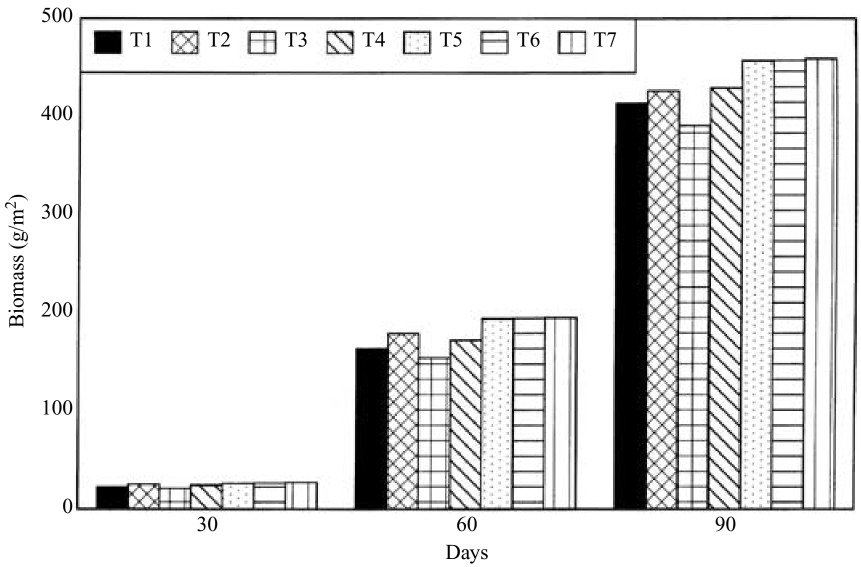

Fig. 1. Effect of enriched compost and chemical fertilizers on biomass production of soybean at different growth stages of the crop (1996–99).

RESULTS AND DISCUSSION

Characterization of different waste materials

Nitrogen concentration for the legume straw was as high as 1·12% and it was lowest (0·34%) in the city rubbish. City rubbish also contains low amounts of organic matter mainly due to the presence of non-decomposable materials in solid waste. Lignin content ranged from 6·8 to 11·8% in the materials used (Table 2) and there were no significant correlations between nitrogen and lignin percentages. This observation resembles the earlier findings of Palm & Sanchez (1995).

Chemical composition of enriched phosphocompost

There were significant differences in chemical composition of composts due to different waste materials used (Table 3). The maturity characters e.g. total organic C, C/N ratio, water soluble carbohydrates decreased from their respective initial values during composting whereas cation exchange/total organic carbon and lignin/cellulose ratio increased significantly ($P < 0·05$) above initial value in all the sources of compost. These index values indicated that the humified materials of the composts were more stable and are suitable for field application. City rubbish

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Table 5. *Growth dynamics and yield attributes of wheat as influenced by different treatments in 1996–1999*

	Plant height (cm)				No. of tillers (35 days after sowing)	*Grain weight/ spike (g)	*1000-grain weight (g)	*Grain to straw ratio
	30 days	60 days	90 days	120 days				
Compost (t/ha)								
T_1: Soybean straw	20·1	63·1	72·8	76·3	7·8	1·4	42·5	0·50
T_2: Wheat straw	20·5	64·5	73·1	78·5	8·1	1·4	43·4	0·54
T_3: Mustard straw	19·3	63·0	72·0	75·4	7·2	1·4	42·6	0·47
T_4: City rubbish	20·5	64·2	73·4	76·9	7·9	1·4	42·9	0·51
P rates (kg/ha)								
T_5: 17·4	20·7	64·5	75·4	78·3	8·0	1·4	43·0	0·52
T_6: 21·8	20·8	65·1	75·6	80·1	8·2	1·4	43·1	0·54
T_7: 26·2	21·2	65·8	76·6	82·0	8·5	1·5	43·4	0·57
Mean	20·4	64·3	74·1	78·2	7·9	1·4	42·9	0·50
S.E. (12 D.F.)	0·27	0·89	1·23	1·07	0·24	0·03	0·46	0·36

* Yield attributes recorded at harvest.

Table 6. *Effect of enriched phosphocompost and inorganic fertilizer on grain yields (t/ha) of soybean and wheat in Typic Haplustert in 1996–1999*

Treatment	Soybean			Mean 1996–99	Wheat			Mean 1996–99
	1996/97	1997/98	1998/99		1996/97	1997/98	1998/99	
Compost (t/ha)								
T_1: Soybean straw	2·84	2·71	2·43	2·66	4·53	4·42	4·22	4·39
T_2: Wheat straw	2·91	2·73	2·54	2·72	4·62	4·51	4·43	4·52
T_3: Mustard straw	2·52	2·52	2·13	2·39	4·23	4·09	4·08	4·13
T_4: City rubbish	2·72	2·73	2·51	2·65	4·45	4·42	4·23	4·37
P rates (kg/ha)								
T_5: 17·4	2·86	2·79	2·55	2·73	4·88	4·93	5·03	4·95
T_6: 21·8	2·88	2·80	2·56	2·75	4·97	5·23	5·11	5·10
T_7: 26·2	2·94	2·85	2·62	2·80	5·09	5·35	5·13	5·19
Mean	2·87	2·73	24·7	2·67	4·68	4·70	4·60	4·66
S.E.	0·068	0·058	0·075	0·065	0·12	0·15	0·16	0·14

Degrees of freedom for the error term for each individual year analysis = 12, and pooled analysis of three years = 36.

was decomposed faster in a given time followed by wheat straw then soybean straw as was evident from maturity index traits. For mustard straw, however, more time was required to obtain a similar quality of compost because mustard straw is more slowly decomposed by microorganisms (Manna & Ganguly 1998). The content of water soluble carbon and carbohydrates have been considered as acceptable indicators of maturity (Chanyasak & Kubota 1981; Garcia *et al.* 1992). In this study water soluble carbohydrates ranged from 0·25 to 0·30%. The humification process produces functional groups, and increases oxidation of the organic matter leading to a rise in CEC. For that reason this parameter has been used to evaluate the maturity of phosphocompost. Harada & Inoko (1980) proposed CEC as an important index of compost maturity. It was observed that the content of CEC was maximum (113 meq/100 g) in the wheat straw compost. The lignin/cellulose ratio of the compost was highly and positively correlated with the CEC ($r = 0·78$, $P < 0·05$), as was expected considering the fact that the process was proceeding adequately.

Significant differences in the content of water soluble P, citrate soluble P and total P were observed in the different composts. Citrate soluble P content of

Table 7. *N and P uptake (kg/ha) by soybean and wheat as influenced by phosphocompost and inorganic fertilizers in 1996–1999*

Treatment	Soybean 1996/97	Soybean 1997/98	Soybean 1998/99	Soybean Mean 1996–99	Wheat 1996/97	Wheat 1997/98	Wheat 1998/99	Wheat Mean 1996–99
N uptake (kg/ha)								
Compost (t/ha)								
T_1: Soybean straw	173·2	158·5	155·8	162·5	60·5	59·2	51·4	59·1
T_2: Wheat straw	181·6	170·6	158·2	170·1	60·7	60·4	52·0	59·7
T_3: Mustard straw	151·2	153·7	130·1	145·0	51·2	51·0	51·0	52·8
T_4: City rubbish	169·7	169·2	156·9	165·3	58·7	58·4	51·2	55·3
P rates (kg/ha)								
T_5: 17·4	174·5	170·2	157·5	167·4	64·4	65·3	66·4	65·4
T_6: 21·8	178·6	176·4	159·8	171·6	66·1	70·1	68·5	68·2
T_7: 26·2	184·6	179·6	163·7	176·0	68·7	71·7	68·7	69·7
Mean	173·3	168·3	154·6	165·4	61·5	62·3	58·5	61·5
S.E.	3·5	4·5	3·6	4·1	1·8	1·6	1·5	1·9
P uptake (kg/ha)								
Compost (t/ha)								
T_1: Soybean straw	12·2	11·9	10·2	11·4	9·6	9·2	8·9	9·2
T_2: Wheat straw	12·2	12·0	10·7	11·6	10·6	10·4	9·3	10·1
T_3: Mustard straw	10·3	10·3	8·7	9·8	9·3	9·0	8·9	9·1
T_4: City rubbish	11·7	11·9	10·7	11·5	9·3	9·3	9·3	9·3
P rates (kg/ha)								
T_5: 17·4	12·3	12·3	10·9	11·8	9·8	10·4	11·1	11·1
T_6: 21·8	12·7	12·3	12·3	12·4	9·8	10·4	11·0	11·2
T_7: 26·4	12·5	12·3	11·0	11·9	11·7	12·3	11·8	11·9
Mean	11·9	11·8	10·6	11·5	10·0	10·0	10·0	10·3
S.E.*	0·3	0·2	0·4	0·2	0·5	0·6	0·5	0·7

* Degree of freedom for the error term for each individual year analysis = 12, and for pooled analysis of 3 years = 36.

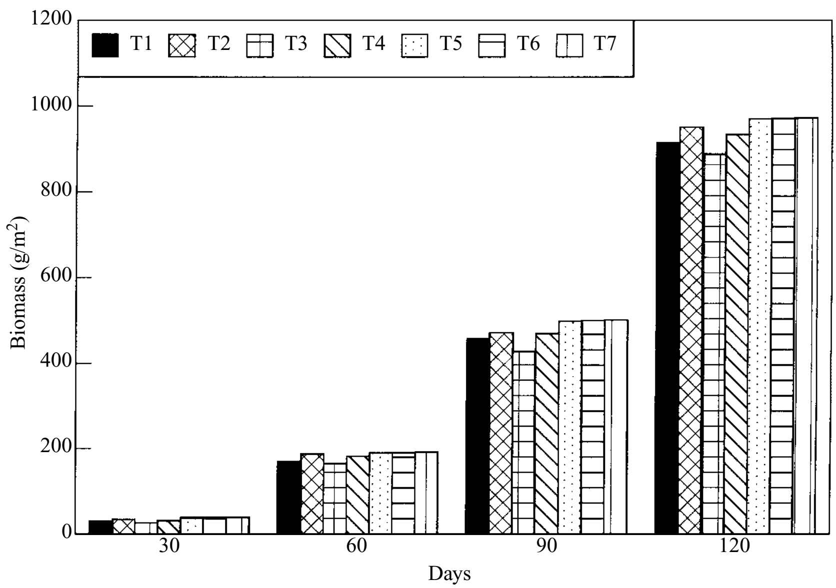

Fig. 2. Effect of enriched compost and chemical fertilizers on biomass production of wheat at different growth stages of the crop (1996–99).

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phosphocompost ranged from 0·23 to 0·88%, the highest being in wheat straw compost and the lowest in the city rubbish compost. The water soluble P was about 6 to 10-fold lower than citrate soluble P in all the composts. The results clearly indicated that the quality of residue is more important in a biochemical transformation of organic matter by microorganisms whose metabolic phase occurs in the water soluble phase. The water soluble carbon acted as a source of energy for heterotrophs and their high proliferation yielded higher production of organic acids that have improved the quality of citrate soluble P. The content of NH_4-N and NO_3-N varied from 0·12 to 0·54 and from 0·28 to 0·88 g/kg, respectively. The available nutrient status of city rubbish was relatively lower than even mustard straw compost possibly due to the low grade of compostable organic matter. Higher values of these traits were recorded in the compost prepared from wheat straw, which has been considered as a nutritionally better quality phosphocompost among all the sources of materials used, followed by soybean straw, city rubbish and mustard straw compost, respectively (Table 3).

Growth, yield and uptake of nutrients

Soybean

In general, the plots receiving chemical fertilizer (T_5–T_7) recorded higher plant height and more branches of soybean compared to compost at all the stages of crop growth (Table 4). Among composts, the wheat straw compost recorded significantly higher plant height and branches over mustard straw compost and city rubbish compost. Differences in dry matter accumulation at early stages due to treatments (both composts and inorganics) were not great. With the advancement of time, chemical fertilizer outclassed composts in dry matter production though it was on a par with wheat straw compost (Fig. 1). It appears that application of wheat straw compost could maintain optimum growth and development of soybean as it contained higher soluble P, total P and total N and released nutrients into the soil. Seed/pods and 100-seed mass of soybean were not affected by the treatments (Table 4). However, pods/plant and harvest index were significantly higher in the plots receiving chemical fertilizer at higher rates compared to compost treated plots. In all the three years chemical fertilizer consistently gave higher yield of soybean though on a par with wheat straw compost. The lowest grain yield of soybean was recorded with mustard straw compost which may be ascribed to the smaller amount of available plant nutrients in this compost (Table 3). Nitrogen and P uptake were also higher in the plots receiving chemical fertilizers and wheat straw compost. Wheat straw phosphocompost made favourable soil conditions for soybean with respect to biological and chemical properties of soil

Table 8. *Improvement of soil chemical and biological activities during three successive years (1996–1999).*

Treatment	OC (%)				Available N (mg/kg)				Available P (mg/kg)				SMBC (mg/kg)				Soil respiration (mg CO2-C/100 g/10 d)				DHA (µg TPF/g/24 h)				Phosphatase (µg PNP/g/h)			
	I	II	III	Mean	I	II	III	Mean	I	II	III	Mean	I	II	III	Mean	I	II	III	Mean	I	II	III	Mean	I	II	III	Mean
Compost (t/ha)																												
T1: SS	0·52	0·52	0·53	0·52	189	189	201	196	5·2	5·3	5·6	5·4	321	322	363	336	38	39	39	39	50	53	56	53	250	255	285	263
T2: WS	0·49	0·49	0·52	0·50	178	185	210	191	5·2	5·6	6·0	5·5	370	365	389	373	40	40	40	40	52	55	58	55	285	290	289	288
T3: MS	0·49	0·50	0·52	0·50	176	178	180	177	5·1	5·1	5·7	5·3	345	350	345	347	30	30	31	30	49	50	48	49	232	232	233	299
T4: CR	0·49	0·49	0·51	0·49	178	188	190	185	5·0	5·1	5·2	5·1	380	378	360	373	30	31	30	31	49	50	54	51	250	280	256	262
P rates (kg/ha)																												
T5: 17·4	0·49	0·48	0·50	0·48	180	187	191	186	5·0	5·3	5·5	5·2	185	189	200	191	20	25	26	24	42	45	44	44	220	230	230	227
T6: 21·8	0·49	0·49	0·50	0·49	180	188	191	186	5·1	5·3	5·5	5·2	190	190	205	195	20	25	27	24	42	44	44	43	222	228	235	228
T7: 26·2	0·48	0·49	0·50	0·49	188	188	190	189	5·2	5·5	5·8	5·4	190	188	221	200	22	27	27	25	42	43	44	43	230	230	235	232
S.E.*	0·004	0·01	0·005	0·003	4·1	4·5	5·3	2·6	0·13	0·24	0·4	0·15	8·3	10	4·8	4·6	1·2	1·6	1·7	0·9	1·5	1·9	2·5	1·2	4·6	4·5	6·7	3·1

SS, Soybean straw; WS, Wheat straw; MS, Mustard straw; CR, City rubbish.
* Degrees of freedom for the error terms for each individual years analysis = 12, and for pooled analysis of three years = 36, I = 1996/97, II = 1997/98, III = 1998/99. Samples were collected after harvest of each crop rotation (1996–1999).

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that could increase nutrient uptake and provided equivalent yields to chemical fertilizer. This was in accordance with the findings of Manna & Ganguly (1997). Data pooled over 3 years showed non-significant differences in grain yield of soybean due to chemical fertilizers (T_5–T_7), wheat straw compost (T_2) and soybean straw compost (T_1) (Table 6). Nitrogen and P uptake by soybean followed a similar trend (Table 7). Thus, it may be inferred that enriched wheat straw compost at the rate of 10 t/ha was an alternative to the recommended application rate of N and P for soybean. It was also observed that the size of nodules in soybean roots (data not presented) in composted plots were much higher than in chemical fertilizer plots possibly due to increased root biomass.

Wheat

The important growth characters such as plant height, number of tillers etc. and yield attributes of wheat such as grain weight/spike, 1000 grain weight and grain to straw ratio are presented in Table 5. The plant height of wheat was not affected by the treatments at any growth stage except at 60 days after sowing. Though dry matter (DM) of wheat were comparatively higher in T_2 and T_7, the treatment differences were significant at none of the stages (Fig. 2). This indicated that residual effect of compost did not contribute more to DM possibly due to less available nutrients remaining in the soil after soybean harvest. Application of chemical fertilizer to wheat (T_5) gave significantly higher grain yield of wheat each year over composts. However, differences in grain yield due to phosphate rates were not significant. This work was in accordance with the findings of Ghosh & Sharma (1996). Thus, it may be inferred that wheat straw compost was the next best nutrient management option for soybean–wheat rotation possibly due to release of nutrient from the compost at a later stage. Significant differences in grain yield of wheat were evident from significant and positive correlation with grain weight/spike ($r = 0·88$, $P < 0·05$) and 1000 grain weight ($r = 0·73$, $P < 0·05$). Nitrogen and P uptake by wheat also followed the similar trend. The higher yield obtained in the plot receiving chemical fertilizer clearly indicated that the residual effect of nutrient from even wheat compost was not sufficient to produce wheat grain on a par with the direct application of chemical fertilizer (Table 7).

Biological activity of soil

Application of enriched phosphocompost significantly ($P < 0·05$) increased soil respiration (SR), dehydrogenase activity (DHA) and soil microbial biomass carbon (SMBC) compared to their initial value but the magnitude of increase of these characters were less in the plots where only chemical fertilizer were applied (Table 8). In fact, SMBC increased by the application of composts about twofold more than with inorganics owing to the presence of easily water-soluble carbon which acts as a source of energy for soil organisms. Water-soluble carbon was positively correlated with soil microbial biomass carbon (McGill *et al.* 1986; Manna & Ganguly 1997). The phosphatase activity was highest in wheat straw compost and the lowest in the plots receiving chemical fertilizer.

Therefore, from the present study it is clear that crop residues which are not fed to animals or are in excess on the farm, if utilized effectively in the form of compost, may improve their quality in the shortest possible time, which, in turn, provides balanced nutrition to plants, improves biological activity of soils and ultimately sustains crop production. The study further suggests that to boost the total productivity of crops as well as in the system as a whole and to improve soil quality, application of enriched wheat straw compost to soybean may be supplemented with some quantity of inorganic fertilizers. In other words, to raise wheat crop on residual fertility of soybean, an integrated nutrient supply to soybean is a must.

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