Nutr Cycl Agroecosyst (2011) 89:15–30
DOI 10.1007/s10705-010-9372-6

RESEARCH ARTICLE

Nutrient recycling potential of rock phosphate and waste mica enriched compost on crop productivity and changes in soil fertility under potato–soybean cropping sequence in an Inceptisol of Indo-Gangetic Plains of India

D. R. Biswas

Received: 16 October 2009 / Accepted: 29 April 2010 / Published online: 12 May 2010

Abstract This manuscript focuses on the nutrient recycling potential of enriched compost prepared using rice straw, low-grade rock phosphate (RP) and waste mica along with *Aspergillus awamori* and their effect on crop productivity and changes in soil fertility under potato–soybean cropping sequence in an Inceptisol of Indo-Gangetic Plains of India. Enriched composts had higher total as well as bioavailable P and K content than ordinary compost. Data emanated from the field study revealed that yield and uptake of N, P and K by potato tubers were significantly increased due to application of inorganic fertilizer and enriched compost over control. Application of 50% recommended dose of NPK fertilizers (RDF) along with 4.0 Mg ha^{-1} of enriched compost product-C prepared by rice straw + RP @ 4% P + waste mica 4% K + *Aspergillus awamori* resulted in 43.3% additional yield and 102.3, 67.0 and 62.2% additional N, P and K uptake by potato over control, respectively. Significant increase in yield and uptake of N, P and K by soybean grown on residual fertility were also observed over control. Post-harvest soil analysis indicated a significant build-up in soil organic C, available N, P and K due to application of enriched compost in combination with inorganic fertilizer over 100% RDF. The results clearly showed that enriched compost could be an alternative and cost effective option to prepare a value added product using agricultural wastes and low-grade minerals like RP and waste mica in place of costly chemical fertilizer for crop production and maintaining soil fertility.

Keywords Rock phosphate · Waste mica · Rice straw · Enriched compost · Crop productivity · Soil fertility · Potato · Soybean

D. R. Biswas (✉)
Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute, New Delhi 110 012, India
e-mail: drb_ssac@yahoo.com

Introduction

Recycling of organic wastes for increasing soil fertility has gained importance in recent years due to high cost of fertilizers. An estimated 250 million Mg of residues is produced annually in rice–wheat cropping systems in the Indo-Gangetic Plains of India (Gupta et al. 2004). Wheat residue after grain harvest is valued for animal feed and there is no difficulty in its removal from the field and subsequent management. Rice residues on the other hand, are generally not used for animal feed in northern India though they are used as cattle feed in eastern and southern parts of India. Consequently, rice residues are usually burnt on a large scale in the fields to save labour and to enable tillage and seeding machinery to work efficiently in order to sow the next crop without loss of time. Thus, the lack of alternative uses for crop residues and lack of appropriate mechanization to handle increasing quantities of residue have driven most of the farmers to burn them as a method of disposal (Singh et al. 2005). Estimation showed that about 40% of N, 30–35% of P, 80–85% of K, and 40–50% of S absorbed by rice remained in the vegetative parts (residue) at maturity, making them viable nutrient sources (Singh et al. 2005). At present three quarters of the crop residues are disposed of by burning. As a result of burning, considerable amounts of both organic C and nutrients are lost, and there is environmental pollution from the emissions of toxic and greenhouse gases like CO, CO_2 and CH_4. These pose a threat to human and ecosystem health. It has been estimated that for the year 2000 the emission of CH_4, CO_2, N_2O and NO_x was 110, 2306, 2 and 84 Gg, respectively, from the field-burning of rice and wheat straw in India (Gupta et al. 2004). Burning also resulted in a decrease in soil biota and reduced total N and C in the top layer of soil. The alternative means to utilize these large quantities of nutrient-rich biomass and to recycle them back to the field is to convert them into a value added product known as compost. Composting is recognized as an economical and sustainable option for waste management as it is easy to undertake and can be conducted in the local site of the produce (Singh and Amberger 1998; Biswas et al. 2009). However, traditional composts prepared from farm wastes have low nutrient content, particularly P and K and these nutrients need to be enriched in some way.

India ranks third and fourth as far as consumption of phosphorus and potassium fertilizer, respectively, in the World is concerned (FAI 2008). At present 160 million Mg of rock phosphate (RP) is available in India, most of which are unsuitable for commercial manufacture of P-fertilizers because of low P content as well as low reactivity (Narayanasamy and Biswas 1998) and majority of RPs for commercial use are imported. Similarly, the entire requirement of K is imported either in the form of muriate of potash or sulphate of potash, which require large amounts of foreign exchange because K-rich minerals are not available in India. India is fortunate in having the world's largest deposit of mica, a K-bearing mineral, located in the Koderma, Giridih and Hazaribagh districts of Jharkhand (Nishanth and Biswas 2008). Thus, there is an ample opportunity to explore the possibility of its use as a source of plant-K, if modified by chemical and/or biological means. Bio-intervention of waste mica with *Bacillus mucilaginosus* could be an alternative and viable technology to solubilize insoluble K into plant available pool and used efficiently as a source of K-fertilizer for sustaining crop production and maintaining soil potassium (Basak and Biswas 2009). Another possible means of improving the effectiveness of waste mica is through composting technology along with low-grade RP (Nishanth and Biswas 2008). However, there is no experimental work on the preparation of enriched compost using low-grade RP and waste mica and its application in soils under field conditions in intensive cropping sequence.

Soil organic C (SOC) is important for cycling plant nutrients and improving the physical, chemical and biological properties of a soil to sustain crop productivity (Campbell et al. 1996) as well as soil and environmental quality (Doran and Parkin 1994). The nutrients turn-over in soil–plant system is considerably high in intensive agriculture like potato–soybean cropping system and therefore decline in soil nutrients status, particularly SOC, is a great concern. Thus, any management system that improves and maintains the organic C and nutrient contents of the soil of such high intensive cropping system is the need of the day. In this context, it is necessary to give priority through recycling of crop residues for agricultural production and sustainable soil quality. Preparation and use of enriched compost may not only improves crop yield but also increases nutrient uptake besides improving the physical, chemical and biological properties of the soil, thereby provides better soil environment for growth and development. However, very limited information is available on preparation of enriched compost using crop residues mixed with RP and waste mica along with microbial inoculation to enhance biodegradation process of organic matter as well as improving the quality of product which requires thorough investigation. Hence, it is important to develop not only suitable technique for preparation of good quality of compost in the shortest possible time, but also evaluate its effectiveness as source of nutrients for crop production under intensive cropping system and the capacity to improve soil health.

Considering all these factors, there is a need to develop a cost effective eco-friendly sustainable system where the supply of nutrients to plants can be ensured. In this respect development of enriched compost using crop residue mixed with low-grade rock phosphate and waste mica inoculated with microbial culture through composting holds a lot of promise in India. The present study, therefore, have been initiated to (1) prepare enriched compost using rice straw mixed with rock phosphate and waste mica, (2) to evaluate the effectiveness of enriched compost and inorganic fertilizers on yield and uptake of nutrients by potato and soybean grown under potato–soybean rotation, and (3) to assess the changes in soil organic carbon and available N, P and K contents due to application of enriched compost and inorganic fertilizers under potato–soybean cropping sequence in an Inceptisol in Indo-Gangetic Plains of India.

Materials and methods

Raw materials

Low-grade rock phosphate (RP) from Rajasthan State Mines and Minerals Ltd, Udaipur (Rajasthan), India, was collected. The powder RP (100-mesh) contained 8.62% total P, 0.002% water soluble P, 1.26% citrate soluble P, 7.36% citrate insoluble P, 6.4% Ca and 5.64% Mg. Waste mica, a K-bearing mineral, was obtained from the surroundings of mica mines located at Koderma district of Jharkhand, India. It belongs to muscovite mica (white mica), which has the theoretical composition of $(OH)_4K_2(Si_6Al_2)Al_4O_{20}$. The ground (2-mm sieve) mica contained 10.0% total K and trace amounts of water soluble K (30 mg kg^{-1} of water-soluble K), while the amounts of exchangeable and non-exchangeable K were 158 and 260 mg kg^{-1}, respectively. Rice straw (RS) was obtained from the experimental farm, Indian Agricultural Research Institute (IARI), New Delhi, India. On dry (65 ± 1°C) weight basis, it had 43.1% total C, 0.5% N, 0.04% P, 0.92% K, 0.86% Ca, 0.43% Mg and 58, 25, 389 and 1346 mg kg^{-1} of Zn, Cu, Mn and Fe, respectively, and the C/N ratio was 86.2.

Preparation of enriched compost

Three enriched compost were prepared using rice straw, RP and waste mica along with *A. awamori* as per treatments:

1. Product-A: Ordinary compost-A (RS alone + *A. awamori*);
2. Product-B: Enriched compost-B (RS + RP @ 2 kg P per 100 kg RS + mica @ 2 kg K per 100 kg rice straw + *A. awamori*), and;
3. Product-C: Enriched compost-C (RS + RP @ 4 kg P per 100 kg RS + mica @ 4 kg K per 100 kg rice straw + *A. awamori*).

The protocol as outlined by Biswas and Narayanasamy (2006) was employed for the preparation of enriched composts. Chopped rice straw (5–6 cm size, 15 kg on air-dry weight basis, 30 ± 1°C), soaked in water for 24 h, was mixed thoroughly on a polythene sheet with required quantities of RP and waste mica as per the above treatment. A uniform dose of urea solution @ 0.25 kg N per 100 kg of rice straw (air dry weight basis, 30 ± 1°C) was added to reduce the C/N ratio, while fresh cow dung @ 10 kg per 100 kg of rice straw was made into slurry and added to each product as natural inoculants. A uniform dose of *Trichoderma viride* @ 50 g per 100 kg of rice straw (on fresh mycelia weight basis) was added to each product in order to hasten the composting period. Phosphate solubilizing microorganism viz., *Aspergillus awamori* @ 50 g per 100 kg of rice straw (on fresh mycelia weight basis) was also added in each treatment. Whole of the composting mass was mixed thoroughly and put in the cemented pits of 100-l capacity each. The composting pits were covered with polythene sheets to avoid excessive wetting by rain. Turning was performed after 15, 30, 60 and 90 days of composting to provide adequate aeration and moisture was maintained to 60% of water holding capacity throughout the experiment. The composting was continued for 120 days.

Characterization of enriched compost

At maturity (after 120 days), the composts were drawn from each pit. A representative sample was drawn from each product, divided into two portions. One portion was kept in a refrigerator at 4°C and used subsequently for analysis of total N and mineralizable N (NH_4^+-N and NO_3^--N). The other portion was first air-dried (30 ± 1°C) and then oven-dried (65 ± 1°C) for 24 h, crushed to pass through a 2-mm sieve, thoroughly mixed and used for analysis of total C, P, K as well as bio-available P and K. Three replicates were used for analysis of each parameter from different treatments. Sub-samples were also drawn from each product and moisture content of the fresh samples was determined so as to express the data on dry weight basis.

Total C content was determined by ignition method (Jackson 1973). Total N was determined by digesting the sample with H_2SO_4 using a digestion mixture (K_2SO_4:$CuSO_4$::10:1) in a micro-Kjeldahl method (Bremner and Mulvaney 1982) followed by distillation of NH_4^+-N in a semi-automatic micro-Kjeldahl distillation assembly (Model: Gerhard, Vepodest 30). For estimation of total P and K content, samples were digested with di-acid mixture (HNO_3:$HClO_4$::9:4). Total P (TP) content in the acid digest was then determined by spectrophotometrically using vanadomolybdo phosphoric yellow colour method in HNO_3 medium (Jackson 1973). Total K content in the acid digest was estimated by a flame photometer. Bio-available P consisting of water soluble P (WSP) and neutral 1 N ammonium citrate soluble P (CSP) was determined as per the procedure outlined by Fertiliser (Control) Order (FCO 1985). Sample of enriched compost (1 g) was leached with 100 ml distilled water and WSP content in the leachate was determined by spectrophotometrically. The residue left after removing WSP was then extracted with neutral 1 N ammonium citrate solution (100 ml) on a water bath for 1 h and filtered through a Buckner funnel using Whatman No. 42 filter paper. The residue left was used for determination of citrate insoluble P (CISP) as in case of total P by digesting the sample with mineral acids (HNO_3 and $HClO_4$) and estimating the P content spectrophotometrically. Citrate soluble P was then obtained by subtracting the sum of WSP and CISP from total P content (CSP = TP − WSP − CISP). Bio-available K consisting of water soluble K (WSK) and 1 N NH_4OAc extractable K (NH_4OAc-K) was extracted by successive extractions of the sample (5 g) with distilled water (25 ml) and 1 N NH_4OAc solution (25 ml) followed by determination by a flame photometer.

Experimental site and soil

A field study was conducted during 2005 to 2006 at the experimental farm, Indian Agricultural Research Institute (IARI), New Delhi, India. It is located in the Indo-Gangetic Plain at (28°37′–28°39′ N latitude and 77°9′–77°11′ E longitude, at an altitude of 220 m above mean sea level. The climate of the study area is semi-arid subtropical region showing hot summers (May–June) and cold winters (December–January) with an annual average maximum and minimum temperature of 40.5 and 6.5°C, respectively, and the average annual rainfall of 760 mm occurring mostly during the months of July to September.

Composite surface soil (0–15 cm depth) was collected from the experimental field for initial properties. The soil belongs to Inceptisol, member of coarse loamy, non-acid, mixed hyperthermic family of Typic Haplustept (Soil Survey Staff 1999). Some of the physicochemical properties of the experimental soil were: texture sandy loam with sand 68%, silt 20% and clay 12% (Bouyoucos 1962); pH_w (1:2, soil:water) 8.25; electrical conductivity (EC_w 1:2, soil:water) 0.12 dS m^{-1}; CEC 10.8 cmol (p^+) kg^{-1} soil (Jackson 1973); organic C 3.1 g kg^{-1} (Walkley and Black 1934); available N 150.6 kg ha^{-1} (Subbiah and Asija 1956): 0.5 M $NaHCO_3$-extractable P 10.9 kg ha^{-1} (Olsen et al. 1954) and neutral 1 N NH_4OAc-extractable K 210.8 kg ha^{-1} (Hanway and Heidel 1952).

Experimental design and treatments

The effectiveness of rock phosphate and waste mica enriched composts were evaluated through a field experiment in a potato–soybean cropping sequence. Following eight treatments were used: T_1: Control; T_2: 100% recommended dose of fertilizer (RDF) (100:80:120 kg NPK ha^{-1}); T_3: 75% RDF + 2.0 Mg ha^{-1} of ordinary compost-A (Product-A); T_4: 50% RDF + 4.0 Mg ha^{-1} of ordinary compost-A (Product-A); T_5: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-B (Product-B); T_6: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-B (Product-B); T_7: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-C (Product-C); T_8: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-C (Product-C). The experiment was laid out in a randomized block design with three replications and plot size of 6 m × 5 m each.

Potato (*Solanum tuberosum* L.) var. *Kufri Badshah* was grown as the first crop. The recommended doses of nitrogen (100 kg N ha^{-1}), phosphorus (80 kg P_2O_5 ha^{-1}) and potassium (120 kg K_2O ha^{-1}) as well as other treatments were computed as per the treatment combinations. Urea and diammonium phosphate (DAP) were used as the source of nitrogen, while DAP and muriate of potash (MOP) were used as the source of phosphorus and potassium, respectively. The rates of NPK fertilizer and compost application for each treatment in the present field experiment are given in Table 1. Before the potato planting, the plots were plowed four times with the help of a tractor drawn disk to a depth of 15 cm followed by with a cultivator once and then ridges were made using a ridge maker and ridge packer. The whole quantities of enriched composts and inorganic fertilizers were applied before last ploughing and incorporated into soil. Potato seed tubers (one mm sprouted material) were planted during *rabi* season 2005–2006 by maintaining optimum plant population of 1.48×10^5 at a spacing of 45 cm × 15 cm. Soybean (*Glycin max*) was grown as the succeeding crop during *kharif* season in 2006 to study the residual effect of the composts and the fertilizers, if any. Before sowing of soybean, the plots were disked to a depth of 15 cm twice and then ridges were made using a ridge maker and ridge packer. Soybean was sown in the first week of July 2006. Necessary package of practices like weeding, application of herbicide, earthing-up of potato was taken care off. Adequate irrigations were given to potato and soybean as and when required with ground water and an irrigation of about 7.5 cm was applied to each crop.

Plant and soil analysis

Potato tuber was harvested manually in the second week of March 2006 and the yield was recorded. For analysis of potato tuber, samples were cut into small pieces, dried initially at room temperature (25–28°C) and then at 65 ± 1°C in an oven and ground to powder form. The ground samples were then analyzed for their N, P and K contents. Nitrogen content in potato tuber was determined by micro-Kjeldahl method (Jackson 1973). Total P and K were determined by di-acid digestion followed by spectrophotometrically and flame photometric method, respectively. A sub-sample of potato tuber was drawn, cut into small pieces and dried at 65 ± 1°C in an oven for determination of moisture content in fresh tuber so as to express the data on dry weight basis. Soybean was also harvested manually at maturity in the middle of October 2006, the dry matter, grain (expressed at 12% seed moisture content) and stover yields were recorded and analyzed for their N, P and K content as per the procedure mentioned in case of potato.

Post-harvest soil samples (0–15 cm depth) were collected from each plot after each crop, air-dried, ground to pass through a 2-mm sieve using a wooden pestle and mortar and analyzed for organic C (Walkley and Black 1934), available N (Subbiah and Asija 1956), available P (Olsen et al. 1954) and available K (Hanway and Heidel 1952). The impacts of addition of enriched compost on crop productivity and changes in soil properties with different treatments were assessed.

Statistical analysis

The data obtained from the field experiments on the yields, nutrients uptake by crops as well as organic C, available N, P and K in soils were subjected to analysis

Table 1 Rates of NPK fertilizer and compost application for each treatment in the present field experiment

Treatments	Quantities of fertilizers and compost			
	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Compost (Mg ha^{-1})
T_1	–	–	–	–
T_2	100	80	120	–
T_3	75	60	90	2.0
T_4	50	40	60	4.0
T_5	75	60	90	2.0
T_6	50	40	60	4.0
T_7	75	60	90	2.0
T_8	50	40	60	4.0

T_1: Control; T_2: 100% recommended dose of NPK fertilizers (100% RDF); T_3: 75% RDF + 2.0 Mg ha^{-1} of ordinary compost-A; T_4: 50% RDF + 4.0 Mg ha^{-1} of ordinary compost-A; T_5: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-B; T_6: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-B; T_7: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-C; T_8: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-C of variance (ANOVA) using randomized block design as given by Gomez and Gomez (1984). Data were assessed by Duncan's multiple range tests (Duncan 1955) with a probability $P \leq 0.05$. Least significant difference (LSD) between the mean values was evaluated by a one-way analysis of variance by using SPSS version 10.0 (Levesque 2007). A Pearson's correlations matrix was used to evaluate the relationships between yields, nutrients uptake by potato and soybean and soil organic C, available N, P and K after each crop.

Results

Composition of enriched compost

In general, total C content in the matured compost decreased substantially with RP and mica enrichment (Table 2). The mean total C content in product-A (ordinary compost-A) was 38.2%, while it decreased substantially to 34.0 and 25.6% in enriched compost product-B and product-C, respectively. Total N content was 1.67% in ordinary compost, which decreased to 1.41% in product-B and 1.00% in product-C, respectively. Irrespective of the treatments, all of the enriched compost products had markedly lower C/N ratios, compared to the raw rice straw which had a C/N ratio of 86.2 used for composting. It was also observed that ordinary compost had the lowest C/N ratio. However, C/N ratio increased in enriched product-B and product-C. As far as total P is concerned, ordinary compost had a lower P content (0.53%) than enriched compost product-B (2.29% P) and product-C (2.93% P). Total K content also increased substantially in enriched compost product-B (2.24% K) and product-C (2.62% K) due to addition of RP and waste mica compared to product-A (1.52% K). As far as bio-available P is concerned, enriched products had less WSP content than ordinary compost. However, a substantial improvement in CSP content in product-B and product-C was noticed compared to product-A. Increases in both the WSK and NH_4OAc-K occurred in enriched composts compared with ordinary compost.

Yield of potato and soybean

Significant ($P < 0.05$) increases in potato yields above the control (Table 3) were recorded with the application

Table 2 Characteristics of enriched composts prepared using rice straw, rock phosphate and waste mica inoculated with *Aspergillus awamori* (Mean ± standard deviation)

Treatments	Total nutrients (%)				C/N ratio	Bio-available nutrients (%)			
	Total C	Total N	Total P	Total K		WSP	CSP	WSK	NH_4OAc-K
Product-A	38.2 ± 0.47	1.67 ± 0.11	0.53 ± 0.05	1.52 ± 0.10	22.9 ± 0.80	0.046 ± 0.005	0.28 ± 0.01	0.41 ± 0.04	1.38 ± 0.03
Product-B	34.0 ± 1.00	1.41 ± 0.13	2.29 ± 0.11	2.24 ± 0.09	24.1 ± 0.67	0.027 ± 0.001	1.36 ± 0.11	0.53 ± 0.04	1.80 ± 0.03
Product-C	25.6 ± 0.87	1.00 ± 0.10	2.93 ± 0.09	2.62 ± 0.11	25.6 ± 0.73	0.031 ± 0.003	1.98 ± 0.39	0.85 ± 0.01	1.90 ± 0.04

Note: RS = rice straw; RP = rock phosphate; WSP = water soluble P; CSP = citrate soluble P; WSK = water soluble K; NH_4OAc-K = Ammonium acetate extractable K; Product-A = RS + *Aspergillus*; Product-B = RS + RP @ 2% P + mica @ 2% K + *Aspergillus awamori*; Product-C = RS + RP @ 4% P + mica @ 4% K + *A. awamori* of the recommended dose of fertilizer as well as different enriched composts in combination with chemical fertilizer than the control (11.41 Mg ha^{-1}). The recommended dose of NPK fertilizer (T_2) resulted in 17.9% higher yield over the control (T_1). While, treatment T_8 where 50% RDF was applied along with 4.0 Mg ha^{-1} of enriched compost (product-C) resulted in 43.3 and 21.5% higher tuber yield over control and treatment T_2, respectively. However, T_8 was statistically similar to treatments T_5, T_6 and T_7. Further, treatments T_5, T_6, T_7 and T_8 performed significantly higher yield than the treatments T_2, T_3 and T_4.

Significant ($P < 0.05$) increase in grain and stover yield of soybean (Table 3) was also noticed due to residual effect of fertilizer materials applied directly to first crop of potato compared to the control. The recommended dose of NPK fertilizer (T_2) resulted in 27.4 and 22.6% extra grain and stover yield of soybean, respectively, over their corresponding yields in the control. Integrated use of chemical fertilizers and enriched composts resulted in 27.6–46.9% increase in soybean grain yield. Similarly, stover yield increased by 21.3–33.8% over the control. Treatment T_8 was statistically at par with T_5, T_6 and T_7. While, T_8 recorded 15.3 and 9.1% extra grain and stover yield over T_2.

Nutrient uptake by potato and soybean

Combined application of inorganic fertilizers and enriched composts significantly ($P < 0.05$) increased uptakes of N, P and K by potato tuber (Table 4) compared to the control. The maximum uptake of N, P and K by potato tuber was obtained in plots where 50% RDF was applied along with 4.0 Mg ha^{-1} of product-C (T_8). Treatment T_2 resulted in 48.2, 26.1 and 27.1% higher uptake of N, P and K, respectively, over the control, while treatment T_8 resulted in 102.3, 67.0 and 62.2% additional uptake of N, P and K, respectively, over the control. Results revealed that integrated use of inorganic fertilizers (applied either 75% RDF or 50% RDF) along with enriched compost product-B and product-C (applied @ 2.0 or 4.0 Mg ha^{-1}) resulted in higher uptake of N, P and K by potato tuber than sole application of 100% RDF (T_2).

Application of fertilizer materials to the first crop also resulted in significant ($P < 0.05$) residual effect in soybean crop (Table 5) as evidenced by

Table 3 Effect of enriched composts on yield of potato and soybean in a potato–soybean cropping system, with percent increase over control

Treatments	Potato tuber yield		Soybean yield			
	Tuber yield (Mg ha^{-1})	% Increase over control	Grain yield		Stover yield	
			Yield (Mg ha^{-1})	% Increase over control	Yield (Mg ha^{-1})	% Increase over control
T_1	11.41c*	–	0.98 d	–	2.60 c	–
T_2	13.46 b	17.9**	1.25 c	27.4	3.19 b	22.6
T_3	12.79 bc	12.1	1.25 c	27.6	3.15 b	21.3
T_4	13.25 b	16.1	1.31 bc	33.8	3.17 b	22.2
T_5	15.33 a	34.4	1.36 ab	38.7	3.31 ab	27.5
T_6	15.68 a	37.4	1.37 ab	39.9	3.41 ab	31.3
T_7	15.18 a	33.0	1.39 ab	42.0	3.35 ab	29.1
T_8	16.35 a	43.3	1.44 a	46.9	3.48 a	33.8
LSD ($P = 0.05$)	1.42		0.098		0.241	

T_1: Control; T_2: 100% recommended dose of NPK fertilizers (100% RDF); T_3: 75% RDF + 2.0 Mg ha^{-1} of ordinary compost-A; T_4: 50% RDF + 4.0 Mg ha^{-1} of ordinary compost-A; T_5: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-B; T_6: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-B; T_7: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-C; T_8: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-C

* For each parameter, different lowercase letters within the same column indicate that treatment means are significantly different at $P < 0.05$ according to Duncan's Multiple Range Test for separation of means

** Figures indicate percent increase in yields over control

Table 4 Nutrient uptake by potato tuber as affected by enriched composts in a potato–soybean cropping system, with percent increase over control

Treatments	Nutrient uptake by potato tuber					
	N uptake		P uptake		K uptake	
	N uptake (kg ha^{-1})	% Increase over control	P uptake (kg ha^{-1})	% Increase over control	K uptake (kg ha^{-1})	% Increase over control
T_1	115 f*	–	33.3d	–	184e	–
T_2	171 e	48.2**	42.0 c	26.1	234 d	27.1
T_3	187 d	62.1	43.5 c	30.6	259 c	40.8
T_4	175 e	51.7	42.6 c	27.9	241 d	30.9
T_5	214 c	86.2	49.8 b	49.5	281 b	52.5
T_6	226 b	96.4	51.5 ab	54.7	290 ab	57.4
T_7	224 b	94.5	50.8 ab	52.6	280 b	52.3
T_8	233 a	102.3	55.6 a	67.0	299 a	62.2
LSD ($P = 0.05$)	6.4		4.73		13.7	

T_1: Control; T_2: 100% recommended dose of NPK fertilizers (100% RDF); T_3: 75% RDF + 2.0 Mg ha^{-1} of ordinary compost-A; T_4: 50% RDF + 4.0 Mg ha^{-1} of ordinary compost-A; T_5: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-B; T_6: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-B; T_7: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-C; T_8: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-C

* For each parameter, different lowercase letters within the same column indicate that treatment means are significantly different at $P < 0.05$ according to Duncan's Multiple Range Test for separation of means

** Figures indicate percent increase in uptake over control

increased uptake of N, P and K as compared to the control. Data revealed that significantly higher nitrogen uptake by soybean grain was obtained in T_8 compared to all other treatments and this resulted in 50.7% greater N uptake over the control. Significant increases in P uptake by soybean grain and stover were recorded over the respective controls. Similar trend in increases in K uptake by soybean grain and stover were observed.

Changes in soil properties

Soil organic C

Data emanated from the present study clearly indicated that addition of enriched composts either alone or in combination with inorganic fertilizers significantly ($P < 0.05$) increased soil organic C (SOC) content over the control after potato and soybean harvest (Table 6). Significant ($P < 0.05$) increase in SOC (25.0% higher over control) was noticed in T_2 over the SOC status in control after the harvest of potato. Application of 50% RDF along with 4.0 Mg ha^{-1} of enriched product-C (T_8) had significantly higher SOC than other treatments after the harvest of potato (4.2 g kg^{-1}) except T_6 and T_7 as well as after soybean (3.9 g kg^{-1}) except T_4 and T_5. The improvement in enhancing SOC in treatment T_8 was 50.0% over unfertilized plot both after potato and soybean crops. It is also evident that SOC content increased significantly ($P < 0.05$) by 20 and 22% after potato and soybean, respectively, in treatment receiving enriched product-C along with 50% RDF than that in full dose of NPK treated plots (T_2).

Available N

It is evident that the available N improved significantly ($P < 0.05$) in all the fertilized plots receiving chemical fertilizers and enriched composts either alone or in combination than that of unfertilized, control plot (Table 6). Treatment T_2 resulted in significant build-up in available N by 47 and 38% over unfertilized plot after potato and soybean harvest, respectively. Whereas, application of 50% of RDF + 4.0 Mg ha^{-1} of enriched product-C (T_8) resulted in 68 and 54% increase in available N over unfertilized plot after potato and soybean harvest, respectively. Further, treatment T_6 and T_8 were at par in maintaining available N in soil after potato harvest,

Table 5 Nutrient uptake by soybean as affected by enriched composts in a potato–soybean cropping system, with percent increase over control

Treatments	Nutrient uptake by soybean											
	Grain N uptake		Stover N uptake		Grain P uptake		Stover P uptake		Grain K uptake		Stover K uptake	
	N uptake (kg ha^{-1})	% Increase over control	N uptake (kg ha^{-1})	% Increase over control	P uptake (kg ha^{-1})	% Increase over control	P uptake (kg ha^{-1})	% Increase over control	K uptake (kg ha^{-1})	% Increase over control	K uptake (kg ha^{-1})	% Increase over control
T_1	52.1 d*	–	19.9 d	–	7.2 d	–	4.8 f	–	16.5 c	–	43.9 d	–
T_2	63.9 c	22.6**	26.9 bc	35.2	8.6 c	19.4	5.9 e	22.9	21.5 b	30.3	55.2 c	25.7
T_3	66.4 bc	27.4	25.1 c	26.1	9.3 bc	29.2	6.3 dc	31.3	21.4 b	29.7	55.5 c	26.4
T_4	67.0 bc	28.6	25.5 bc	28.1	9.6 b	33.3	6.6 cd	37.5	22.9 ab	38.8	58.4 c	33.0
T_5	71.6 b	37.4	27.6ab	38.7	9.5 b	31.9	7.2 ab	50.0	23.1 ab	40.0	62.1 b	41.5
T_6	70.6 b	35.5	29.9 a	50.3	10.1 ab	40.3	6.9 bc	43.8	24.6 a	49.1	64.2 ab	46.2
T_7	70.2 b	34.7	26.8 bc	34.7	9.9 b	37.5	6.7 bcd	39.6	23.5 ab	42.4	62.2 b	41.7
T_8	78.5 a	50.7	29.9 a	50.3	10.8 a	50.0	7.7 a	60.4	25.3 a	53.3	65.8 a	49.9
LSD ($P = 0.05$)	4.94		2.26		0.79		0.55		2.29		3.30	

T_1: Control; T_2: 100% recommended dose of NPK fertilizers (100% RDF); T_3: 75% RDF + 2.0 Mg ha^{-1} of ordinary compost-A; T_4: 50% RDF + 4.0 Mg ha^{-1} of ordinary compost-A; T_5: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-B; T_6: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-B; T_7: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-C; T_8: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-C

* For each parameter, different lowercase letters within the same column indicate that treatment means are significantly different at $P < 0.05$ according to Duncan's Multiple Range Test for separation of means

** Figures indicate percent increase in uptake over control

Table 6 Changes in soil organic C and available N after potato and soybean as affected by enriched composts in a potato–soybean cropping system, with percent change over control

Treatments	Organic C (g kg^{-1})				Available N (kg ha^{-1})			
	After potato		After soybean		After potato		After soybean	
	Final	% Change	Final	% Change	Final	% Change	Final	% Change
T_1	2.8 e*	–	2.6 d	–	143 f	–	120 e	–
T_2	3.5 d	25.0	3.2 c	23.1	209 de	47	165 bcd	38
T_3	3.5 d	25.0	3.1 c	19.2	201 e	41	158 d	32
T_4	3.7 bcd	32.1	3.6 ab	38.5	211 de	48	160 cd	34
T_5	3.6 cd	28.6	3.7 a	42.3	219 cd	53	163 bcd	36
T_6	4.0 ab	42.9	3.3 bc	26.9	232 ab	63	167 bc	40
T_7	3.9 abc	39.3	3.1 c	19.2	226 bc	59	171 b	43
T_8	4.2 a	50.0	3.9 a	50.0	240 a	68	185 a	54
LSD ($P = 0.05$)	0.36		0.33		10.5		8.1	
Initial soil	3.1				151			

T_1: Control; T_2: 100% recommended dose of NPK fertilizers (100% RDF); T_3: 75% RDF + 2.0 Mg ha^{-1} of ordinary compost-A; T_4: 50% RDF + 4.0 Mg ha^{-1} of ordinary compost-A; T_5: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-B; T_6: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-B; T_7: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-C; T_8: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-C

* For each parameter, different lowercase letters within the same column indicate that treatment means are significantly different at $P < 0.05$ according to Duncan's Multiple Range Test for separation of means

while T_8 maintained significantly higher available N in soil after soybean harvest.

Available P

Significant ($P < 0.05$) increases in available P occurred in the soil after the potato harvest, and after the soybean crop grown on residual fertility, with the application of composts, compared with the unfertilized control treatment (Table 7). Significant increases in available P by 82% in T_3 to 138% in T_8 were noticed over control after potato harvest. Treatment T_8 maintained significantly higher available P than 100% RDF (T_2) after both potato and soybean crops. However, Treatment T_8 was statistically on par with T_6 and T_7 in maintaining available P after potato and soybean harvest.

Available K

Significant ($P < 0.05$) increase in available K in soil after potato and soybean were noticed in all the fertilized plots over unfertilized plot (Table 7). Data emanating from this study indicated that the available K concentrations in the soil, after the potato and the soybean crops, were significantly ($P < 0.05$) higher with the treatment T_8 receiving combined application of 50% RDF + 4.0 Mg ha^{-1} of product-C than available K concentrations for all other treatments.

Correlation matrix

Data on Pearson's correlation matrix (Table 8) revealed that tuber yield of potato was significantly and positively correlated ($P < 0.01$) with N uptake ($r = 0.97$), P uptake ($r = 0.98$), and K uptake ($r = 0.99$) by the crop. Significant and positive correlation ($P < 0.01$) was also observed between tuber yield and SOC ($r = 0.88$), available N ($r = 0.90$) and available P ($r = 0.86$) as well as between uptake of N, P and K by potato tuber with SOC, available N and P. Similarly, very good correlation between soybean yield with SOC ($r = 0.78$), available N ($r = 0.97$), available P ($r = 0.97$) and available K ($r = 0.96$) as well as between uptake of N, P and K by soybean with SOC, available N, P and K in soil after soybean harvest were observed.

Table 7 Changes in available P and available K after potato and soybean as affected by enriched composts in a potato–soybean cropping system, with percent change over control

Treatments	Available P (kg ha^{-1})				Available K (kg ha^{-1})			
	After potato		After soybean		After potato		After soybean	
	Final	% Change	Final	% Change	Final	% Change	Final	% Change
T_1	9.4 e*	–	8.7 d	–	160 d	–	149 d	–
T_2	19.6 bcd	109	17.9 bc	106	241 bc	51	228 b	53
T_3	17.1 d	82	15.7 c	81	233 c	46	214 c	44
T_4	18.3 cd	95	16.9 bc	94	245 bc	53	217 bc	46
T_5	19.0 bcd	102	16.8 bc	98	239 bc	49	219 bc	47
T_6	21.4 ab	128	18.9 ab	117	246 b	54	221 bc	48
T_7	20.0 abc	113	18.5 ab	113	246 b	54	228 b	53
T_8	22.4 a	138	20.7 a	138	261 a	63	239 a	60
LSD ($P = 0.05$)	2.4		2.2		11.5		10.8	
Initial soil	10.9				211			

T_1: Control; T_2: 100% recommended dose of NPK fertilizers (100% RDF); T_3: 75% RDF + 2.0 Mg ha^{-1} of ordinary compost-A; T_4: 50% RDF + 4.0 Mg ha^{-1} of ordinary compost-A; T_5: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-B; T_6: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-B; T_7: 75% RDF + 2.0 Mg ha^{-1} of enriched compost-C; T_8: 50% RDF + 4.0 Mg ha^{-1} of enriched compost-C

* For each parameter, different lowercase letters within the same column indicate that treatment means are significantly different at $P < 0.05$ according to Duncan's Multiple Range Test for separation of means

Discussion

Quality of enriched composts

Three enriched composts were prepared using rice straw mixed with low-grade minerals, namely RP and waste mica along with phosphate solubilizing microorganism viz., *Aspergillus awamori*. Compositions of the matured (120 days old) products revealed that total C content decreased, while total N content increased during composting process in all the products. The decrease in total C and increase in total N content in the matured compost is due to weight loss during composting through loss of C in respiration as CO_2. Similar results in decrease in total C and increase in total N content per unit of material during decomposition of different organic wastes were reported by other workers (Goyal et al. 2005; Nishanth and Biswas 2008). When RP and waste mica were added into the composting mass, total C as well as total N content decreased compared to rice straw compost. This occurred because materials like RP and waste mica contain negligible concentrations of C and N were added to rice straw rich in total C and N, resulting is the differential dilution of compost caused by addition of mineral matter. Moreover, when the rate of addition of RP and waste mica increased, the magnitude of N content per unit mass of the final product further decreased. Irrespective of the treatments, the C/N ratio of the matured products narrowed down which may be due to the fact that as the decomposition progressed, carbon content is lost mainly as CO_2, while N content per unit material increased. Similar results also observed in our earlier work (Biswas et al. 2009). The values of P and K content increased in product-C, which is attributed to the contribution of P from RP and K from waste mica. Significant improvements in bio-available P (particularly CSP) and K (both WSK and NH_4OAc-K) contents in enriched compost compared to ordinary rice straw compost may be attributed to mobilization of rock phosphate and waste mica during composting.

Yield of potato and soybean

Increases in yields of potato and soybean occurred due to application of different enriched compost in comparison to the unfertilized control. This was obvious as the experimental initial soil was deficient

Table 8 Matrix of correlation coefficients between the yield and nutrient uptake of potato and soybean crops, and soil organic C, available N, P and K after the potato and soybean crops

Parameter	N uptake	P uptake	K uptake	Org. C	Avail. N	Avail. P	Avail. K
After potato							
Yield	0.97[b]	0.98[b]	0.99[b]	0.88[b]	0.90[b]	0.86[b]	0.81[a]
N uptake		0.95[b]	0.96[b]	0.93[b]	0.93[b]	0.91[b]	0.90[b]
P uptake			0.99[b]	0.92[b]	0.90[b]	0.85[b]	0.80[a]
K uptake				0.93[b]	0.92[b]	0.89[b]	0.83[a]
Org. C					0.97[b]	0.95[b]	0.92[b]
Avail. N						0.99[b]	0.97[b]
Avail. P							0.97[b]
After soybean							
Yield	0.98[b]	0.96[b]	0.99[b]	0.78[a]	0.97[b]	0.97[b]	0.96[b]
N uptake		0.98[b]	0.98[b]	0.84[b]	0.96[b]	0.94[b]	0.83[b]
P uptake			0.98[b]	0.84[b]	0.92[b]	0.90[b]	0.88[b]
K uptake				0.81[a]	0.94[b]	0.94[b]	0.92[b]
Org. C					0.77[a]	0.75[a]	0.75[a]
Avail. N						0.99[b]	0.99[b]
Avail. P							0.97[b]

[a] Correlation is significant at $P = 0.05$ level (2-tailed)

[b] Correlation is significant at $P = 0.01$ level (2-tailed)

in available P and K. Integrated use of chemical and enriched compost further increased the tuber yield of potato over sole application of chemical fertilizers due to the enhanced nutrient level in the compost and fertilizer, which leads to continuous availability of nutrients in available form to the plants. Significant residual effect of combined application of chemical and enriched composts to soybean crop grown on residual fertility after the first crop of potato was also observed compared to unfertilized (control) plots as well as plot receiving 100% recommended dose of NPK fertilizers. This type of positive results may be attributed as when organic manure was applied along with inorganic fertilizer more nutrient uptake happened in the plant system and so more plant biomass was recorded. The higher yields of crops obtained in enriched compost treated plots were possibly caused by other benefits of organic matter exceeding P and K supply, such as improvements in microbial activities, better supply of secondary and micronutrients, which are not supplied by 100% RDF, and lower losses of nutrients from the soil (Yadav et al. 2000; Singh et al. 2004). The improved soil physical properties in the enriched compost treated plots might have also contributed to the improvement in crop yields. Similar results in improving soil physical properties due to addition of organic amendments were reported by others (Hati et al. 2006; Gopinath et al. 2008).

Nutrient uptake by potato and soybean

Combination of chemical and enriched compost positively influenced the nutrient uptake by potato and soybean grown under potato–soybean cropping sequence compared to unfertilized plots as well as recommended dose of NPK fertilizers. This result indicated that integrated use of inorganic fertilizers and enriched composts, in general, performed better in enhancing nutrient uptake than sole application of inorganic fertilizers except K uptake by soybean grain. The increased uptake of nutrients by both the crops due to addition of rock phosphate and waste mica enriched composts may be attributed to greater availability of nutrients, particularly citrate soluble P in these products compared to product-A. This may be explained as during decomposition of organic matter lot of organic acids, namely citric, oxalic, tartaric, etc. are produced, which in turn, enhanced the dissolution of P from RP. The availability of P in RP also increased due to inoculation with phosphate solubilizing microorganisms, which are also known to produce organic acids, namely citric, oxalic, tartaric, acetic, lactic, gluconic, α-ketogluconic, etc. (Babana and Antoun 2006). These acids are the sources of H^+ ions that are considered the primary mechanisms attributed to solubilization of RP and make it available for the plant. Organic acid anions can also solubilize RP through chelation reactions (Hinsinger et al. 2003; Reyes et al. 2006; Vassilev et al. 2006). Acid phosphatases and phytases secreted by the microorganisms also have an important role in P solubilization of RP to available form (Singh and Amberger 1998; Varenyam et al. 2007). Moreover, during decomposition of organic matter CO_2 is evolved and results in the formation of weak carbonic acid, which further dissolves P from RP, thus increasing the availability of P in the enriched compost products. This result is consistent with our earlier reports (Biswas and Narayanasamy 2002, 2006).

Further, high amounts of organic P are produced, presumably during the decomposition of enriched compost process as well as in the soil in comparison of ordinary compost process, and this increases P uptake by the plants (Biswas and Narayanasamy 2002). Odongo et al. (2007) reported that P-enriched composting in the presence of wheat straw significantly increased P availability and increased plant growth. Higher nutrient uptake by potato and soybean due to enriched composts could possibly be attributed partly to the contribution of other plant nutrients and partly to a favourable effect on physical, chemical and biological properties of the soil which in turn, helps in higher biomass production as well as greater nutrient uptake by plant. These results corroborate the findings of others (Abdelhamid et al. 2004). Organic acids produced during composting also might facilitate the solubilization of K from waste mica or through the formation of metal–organic complexes by forming chelate with silicon ions present in rice straw, and therefore assisted the dissolution process of K from the mica, during the composting process (Biswas et al. 2009). Many other workers reported that organic acids can facilitate the weathering of minerals by directly dissolving K from rocks or through the formation of metal–organic complexes by forming chelate with silicon ions to bring the K into solution (Song and Huang 1988; Friedrich et al. 1991; Bennett et al. 2001). Moreover, increased availability of nutrients in enriched composts especially P would have enhanced root proliferation which helped in greater uptake of K by crops.

Changes in soil properties

Soil organic C

This study clearly indicated that SOC content in the unfertilized plots declined due to high intensive agriculture as in the present potato–soybean cropping sequence over initial SOC. Plots receiving 100% RDF showed a significant gain in SOC over unfertilized (control) plots, indicating the beneficial effect of a balanced fertilization in improving SOC. Combined application of chemical and enriched compost-C (RS + RP @ 4 kg P per 100 kg RS + mica @ 4 kg K per 100 kg rice straw + *A. awamori*) further increased SOC content over 100% RDF even after succeeding soybean crop, which may be explained by the greater root biomass (residue) left in the soil resulting from increased biomass production (larger yield). The results are consistent with the work done by others (Kundu et al. 2007). This may also be due to the contribution of carbon made through the addition of the composts themselves as they are a source of carbon besides the overall improvement in physical, chemical and biological properties of soil. The improvement in enhancing SOC in plot receiving 50% of RDF along with 4.0 Mg ha^{-1} of product-C may be attributed to balanced and integrated use of inorganic and organic sources of nutrients. The present results are in agreement with the work done by others (Majumder et al. 2008), where they found that the application of NPK along with FYM increased the SOC by 24.3% compared to control in a long-term fertilizer experiment which might be due to the addition of organics for several years as well as due to the continuous return of large amount of crop residues in the form of roots and stubbles to the soil (Janzen et al. 1998). It is reported that organic manure like FYM also conserves organic matter content of the soil (Gaur et al. 1984). Probably because of this advantage, yields of potato and soybean in the enriched compost treated plots were higher.

Available N

Significant ($P < 0.05$) build-up in available N due to combined application of inorganic fertilizers and enriched composts compared to the control clearly indicated the beneficial effect of balanced and integrated use of nutrients for sustaining crop production under potato–soybean cropping system. The positive balance in available soil N is likely attributed to the positive balance of total SOC and might have been partially due to a slow release of N from enriched compost products. The present results are in agreement with other workers (Yadav et al. 2000; Bhandari et al. 2002). In addition, the T_8 treatment produced more available N in the soil following the soybean crop than all other treatments (Table 6). It is mentioned that the more extensive root systems might have contributed to the increased levels of available N with the T_8 treatment. The positive SOC and available N build-up illustrate the importance of short-term additions of organic materials to soil for maintaining SOC and sustaining crop productivity.

Available P

Significant ($P < 0.05$) build-up in available P due to combined use of inorganic fertilizers and enriched composts clearly indicates the beneficial effect of integrated nutrient management in enhancing available P in soils after the first crop of potato. This may be attributed to increased availability of P (citrate soluble and organic P) in enriched compost product than ordinary rice straw compost (Biswas and Narayanasamy 2002, 2006). The released phosphate was then immobilized into the microbial cells as evidenced by higher water soluble, citrate soluble and organic P contents in the final product. This microbial P acts as a slow release fertilizer due to its slow rate of decomposition and provides available P to plants for a longer period instead of fixation and/or precipitation in soil minerals as in case of commercial water soluble P-fertilizer. Decline in available P content in soil after soybean in unfertilized plot was associated with SOC content which also declined. While, the available P balance after soybean harvest in plots receiving enriched compost was highly positive. This might be due to the fact that the major P fraction added through enriched compost is in the organic pool, which mineralized slowly with time (Singh et al. 2004). Increase in available P content in soil with P additions through inorganic fertilizer and enriched compost is expected because potato and soybean crops utilize only a fraction of the applied P and substantial amounts of P would be available in the soil after soybean. Moreover, organic materials used as manure also supplied sizeable amounts of P to the soil. Probably because of this, greater build-up of available P was observed in the plots treated with enriched composts compared to that treated with control and comparable with 100% RDF, indicating that enriched composts could substitute 50% of RDF and save 50% chemical fertilizers.

Available K

Significant ($P < 0.05$) decrease in available K in unfertilized plot over the initial available K in soil after potato was noticed. However, significant build-up in available K was registered due to addition of integrated use of inorganic and enriched compost. Available K content in soil after soybean harvest increased significantly in plots receiving 100% RDF over the control, suggesting that current dose of K application in the plots under 100% NPK treatment was sufficient to sustain soil K fertility under potato–soybean cropping system. Combined application of enriched composts and inorganic fertilizer showed further increase in available K after soybean harvest. The positive balance in available K may be attributed to the increased release of non-exchangeable K from the soils as enriched composts increased soil cation exchange capacity, which might have resulted in increased available K and K utilization by crops, besides its own K contribution. The present results corroborate the findings of others (Blake et al. 1999).

Correlation matrix

Significant correlation ($P < 0.01$) between yield and nutrients uptake by crops with soil properties indicate a beneficial effect of balanced and integrated use of inorganic fertilizer and enriched compost under potato–soybean cropping system. A strong relationship between crop yields and nutrients uptake by potato and soybean with SOC under potato–soybean cropping system indicated that the present findings do highlight the fact that with the integrated nutrient management approach, using NPK fertilizers and enriched composts, the crop performance (growth and nutrient uptake) is closely related to SOC, which in turn is closely related to the residual nutrient availability for the following crop. The benefits of balanced fertilization using crop residues, organic manure and green manuring in maintaining soil organic matter levels have been reported by other workers (Ladd et al. 1994). Similar effects of organic manure and chemical fertilizer application on SOC have also been reported elsewhere (Banger et al. 2009).

Conclusions

From the above discussion it may be concluded that rock phosphate and waste mica enriched compost, known as enriched compost or organic fertilizer, can be prepared using crop residue like rice straw, low-grade RP, waste mica and *Aspergillus awamori* which had higher total as well as bio-available P and K content than ordinary rice straw compost. Application of enriched composts along with differing amounts of NPK fertilizers under potato–soybean cropping sequence on an Inceptisol in Indo-Gangetic Plains resulted in significantly higher yield and nutrient uptake by both the crops over ordinary compost along with NPK fertilizers. The present results demonstrated that 50% recommended dose of NPK fertilizers could be substituted by application of enriched compost (4.0 Mg ha^{-1}), thereby 50% of costly chemical fertilizers could be saved. The overall results suggested that enriched compost maintained higher SOC, available N, P and K in soil. Thus, development of enriched compost could be an alternative and cost effective option to prepare a value added organic fertilizer and to utilize agricultural waste and low-grade materials such as RP and waste mica along with bioinoculant in place of costly chemical fertilizers for crop production and maintaining soil health. Further studies are needed to see the effect of the enriched compost on the soil physical, chemical and biological properties as well as quality of the crops under intensive and organic farming. An investigation into the economics of the enriched compost technology is also to be considered as a worthwhile topic for future studies.

Acknowledgments The author thanks the Indian Council of Agricultural Research, New Delhi, India, for financing this work through an *Ad-hoc* Research Project on "Development of Enriched Organo-mineral Fertilizers" and Head, Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute (IARI), New Delhi for providing facilities for successful completion of the research works.

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