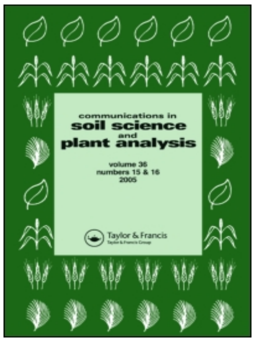

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Evaluation of Integrated Nutrient Management Interventions for Cotton (*Gossypium hirsutum*) on a Vertisol in Central India

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ABSTRACT

Phospho-compost (PC) and poultry manure (PM) were evaluated in field experiments to diversify integrated nutrient management (INM) for rain-fed cotton. Seed cotton yield in the PC (2501–2579 kg ha^{-1}) was similar to the recommended INM (2673 kg ha^{-1}) treatment and was significantly better than nitrogen, phosphorus and potassium (100% NPK) (2130 kg ha^{-1}) and farmers practice (FP) (1886 kg ha^{-1}). Yield was lower in the PM (2476–2617 kg ha^{-1}) than in the PC. Nutrient uptake was higher in all INM intervention plots due to an improvement in soil nutrient status compared with those receiving 100% NPK. Soil labile carbon values were higher in the INM treatments (333–452 mg kg^{-1}), with a greater magnitude in the PC-amended plots (402–452 mg kg^{-1}). Carbon management index (CMI) values were higher for the INM than treatments NPK and FP. Among INM interventions, PC plots had higher values than the PM.

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Carbon management index; farmyard manure; phospho-compost; poultry manure; soil organic carbon

Introduction

Cotton (*Gossypium hirsutum*) is the major commercial crop grown in central India. Vertisols supporting rain-fed cotton are generally low in organic carbon and available nutrient status, consequently resulting in low productivity (Singh et al. 2004). Presently, the resource-poor Indian farmers apply fertilizers at rates far below the recommended rates (Blaise, Bonde, and Choudhary 2005). Over the years, with mechanization and the replacement of animal power with tractors, the availability of organic manures, especially farmyard manure (FYM), has declined. Consequently, their application to fields diminished further. It is well established that sustained crop production is possible with management practices that enhance or maintain soil organic carbon (SOC) levels (Lal 2001). With regular addition of FYM, cotton productivity is stabilized at a higher level (Blaise, Ravindran, and Singh 2006). However, existing integrated nutrient management (INM) packages (5 Mg FYM ha^{-1} along with the recommended dose of fertilizers) have not found favor with farmers. Firstly, because of the short supply of FYM and, secondly, due to its competing uses and high fertilizer costs. Thus, the adoption rate of the INM practices is very low. Therefore, there is a need for evolving variable INM interventions based on farmers' access and availability of other organic resources.

In India, large amounts of phosphorus (P) and entire potassium (K) fertilizer are imported. These fertilizers are costly and farmers apply limited amounts though the soils have low P content. However, large reserves of rock phosphate exist (Rao, Srivastava, and Ganeshamurthy 2015), which can be utilized to prepare enriched phospho-compost (PC) (Manna 2006). Composting of straw-based farm wastes along with rock phosphate is a strategy to improve the value of the manure (Mahimairaja, Bolan, and Hedley 1995). By utilizing PC, Singh et al. (2009) reported a significant reduction in the requirement of fertilizer-P for the rice–wheat cropping system of north India (Singh et al. 2009). In Japan, Hellal, Nagumo, and Zewainy (2012, 2013)) reported enhanced productivity of maize with PC on red soils. Poultry manure (PM)

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is becoming more abundant because of the growing poultry industry (Amanullah, Sekar, and Muthukrishnan 2010). PM is a good source of nutrients, particularly nitrogen (N) and P, and its application to croplands provides an environmentally friendly way of disposing of large quantities of poultry litter produced on poultry farms (Nyakatawa, Reddy, and Mays 2000). Amending soils with PM was found to improve yield of cotton (Nyakatawa, Reddy, and Mays 2000; Reddy et al. 2007; Reddy, Nyakatawa, and Reeves 2004), maize and cowpea (Akande, Adediran, and Oluwatoyinbo 2005).

Thus, there is a likelihood of reduced dependency on fertilizers with inclusion of locally available organic sources such PC and PM. Notwithstanding this fact, less is known about the extent of nutrient reduction possible and their impact on cotton crop. In earlier studies, SOC was measured to assess the impact of nutrient management strategies on soil quality. However, high background levels make it difficult to detect small changes in SOC. To overcome this issue, Blair, Lefroy, and Lisle (1995) proposed the measurement of labile carbon (C_L), carbon lability index (CLI), carbon pool index (CPI) and carbon management index (CMI). SOC oxidized by potassium permanganate ($KMnO_4$) solution is considered as a useful index of C_L. Furthermore, it is more sensitive to changes in agricultural management practices compared to total SOC (Blair, Lefroy, and Lisle 1995; Blair et al. 2000; Verma et al. 2013). Wu et al. (2005) found the allocation of carbon (C) among fractions was altered with the addition of fertilizers and organic sources. Among the C fractions, C_L is the one of great importance as it represents biologically active C pool. To assess changes in the C stocks of soils with relatively low C reserves, CPI is a better indicator to provide information on whether there is a loss or sequestration of C. CMI, a product of CPI and CLI, serves as a yardstick in evaluating management practices for their impacts on SOC and soil quality (Blair, Lefroy, and Lisle 1995). Wendling et al. (2008) reported high values of CPI and lability and correlated with better soil quality. In the soybean–wheat system, Verma et al. (2013) reported high values of CMI with treatments having FYM as a soil amendment. Presently, knowledge about the effects of INM interventions on SOC quality is limited. In view of this, the present study was conducted to evaluate the effects of INM interventions involving PC and PM on seed cotton yield, nutrient uptake and soil fertility and quality based on CMI. The INM interventions were compared with the application of the recommended amount of fertilizers (100% NPK) and the prevalent farmers practice (FP)

Material and methods

Site

A field study was conducted for two seasons (2006 and 2007) in the experimental fields of the Indian Institute of Soil Science, Bhopal (23.037° N, 77.405° E). This region is characterized by a sub-humid climate with a mean annual rainfall of 1000 mm. The soil at the study site was Typic haplustert, with an alkaline reaction (pH 8.3). The soil was low in SOC (5.1 g/kg), available N (186 kg ha^{-1}), 0.5 M sodium bicarbonate extractable P (12.8 kg ha^{-1}) and high in 1 N ammonium acetate exchangeable K (535 kg ha^{-1}).

Treatments

An experiment with 10 treatments was conducted in a randomized block design with three replications. Treatments included control, FP, 100% NPK (80–17.2–16.6 kg NPK ha^{-1}), recommended INM (5 Mg FYM ha^{-1} + 100% NPK), 2.5 Mg FYM + 2.5 Mg PC + 75% N ha^{-1}, 5 Mg FYM + 2.5 Mg PC + 50% N ha^{-1}, 2.5 Mg PC + 100% N ha^{-1}, 2.5 Mg FYM + 2.5 Mg PM + 75% N ha^{-1}, 5 Mg FYM + 2.5 Mg PM + 50% N ha^{-1} and 2.5 Mg PM + 100% N ha^{-1}. In the FP treatment, 55 kg N and 10 kg P was supplied through diammonium phosphate (DAP) and urea. These rates were arrived based on the fertilization practice in the cotton-growing region of Madhya Pradesh, India. The organic sources were applied 15 days before sowing and incorporated into the soil. The average N, P and K content of FYM, PC and PM are given in Table 1. Fertilizer-N was applied in three splits, half at the time of sowing, and the remaining in two equal splits at square formation approximately 45 days after sowing and the other at boll formation (90–100 days after sowing).

Table 1. Average N, P and K concentration (g kg^{-1}) of the different organic sources.

Source	N	P	K
Farmyard manure	0.79 ± 0.03*	0.16 ± 0.02	0.69 ± 0.11
Phospho-compost	1.79 ± 0.12	2.20 ± 0.16	1.17 ± 0.12
Poultry manure	2.40 ± 0.16	1.01 ± 0.07	2.06 ± 0.11

*± standard error

Cotton hybrid (H-6) was sown after the onset of rains with a spacing of 0.90 m between rows and 0.6 m between plants. Seed cotton was handpicked twice in the season and pooled. Plant samples were collected at maturity, oven dried followed by powdering using a Wiley Mill. Samples were digested and N, P and K content was determined (Prasad 1996) and total N, P and K uptake was calculated.

Soil samples were collected at random from three locations in each plot, bulked, air dried and sieved to pass a 0.5 mm sieve. Samples were then analyzed for available N, P and exchangeable K following the procedures outlined in Prasad (1996). Wet acid digestion of the Walkley and Black method was adopted to determine the SOC and total organic carbon (TOC) (Nelson and Sommers 1996). Permanganate oxidizable soil C as a measure of the C_L fraction was determined by the method suggested by Weil et al. (2003). Non-labile C (C_{NL}) fraction was calculated as the difference between TOC and the C_L. CPI, CLI and CMI were determined following the procedures of Blair, Lefroy, and Lisle (1995).

$$\mathrm{CPI} = \frac{\mathrm{TOC(treatment\ plot)}}{\mathrm{TOC(reference\ plot)}}$$

$$\mathrm{CLI} = \frac{\mathrm{Lability\ of\ C\ in\ treatment\ plot}}{\mathrm{Lability\ of\ C\ in\ reference\ plot}}$$

$$\mathrm{Lability\ of\ C} = \frac{\mathrm{C\ fraction\ oxidized\ by\ KMnO_4}}{\mathrm{C\ fraction\ remaining\ unoxidized\ by\ KMnO_4}}$$

$$\mathrm{CMI} = \mathrm{CPI} \times \mathrm{CLI} \times 100$$

Data were statistically analyzed using MSTATC and the treatment differences were separated out using the least significant difference (LSD) at 5% probability. Data for seed cotton yield was pooled over years and statistically analyzed using Model No. 15 of MSTATC.

Results and discussion

Seed cotton yield and nutrient uptake

Averaged over treatments, mean seed cotton yield was 2316 and 2358 kg ha^{-1} in 2005 and 2006, respectively, and the differences were not significant. Seed cotton yields under different INM treatments for 2005, 2006 and pooled over years are given in Table 2. Seed cotton yield with 100% NPK and FP treatments were significantly higher than that of the control in both years. The yields obtained with 100% NPK treatment were similar to the FP in 2005 but were significantly greater in 2006. Averaged over seasons, the 100% NPK treatment had a significantly higher yield than the FP. This indicates that cotton responded significantly to fertilizer application. The recommended INM and INM treatments with PC and PM produced significantly higher seed cotton yields than the 100% NPK in both the years and averaged over seasons (Table 2). Differences in seed cotton between the INM intervention treatments, in general, were not significant. Use of 100% N along with 2.5 Mg ha^{-1} of either PC or PM gave seed cotton yields comparable to those obtained with 5 Mg FYM + 100% NPK. INM interventions involving 2.5 Mg PC ha^{-1} were effective as the recommended INM treatment with respect to cotton yields and similar to the 2.5 Mg PM and FYM ha^{-1} + 75% N treatments. However, the recommended INM treatment was significantly better than the 2.5 Mg FYM and PM ha^{-1} + 75% N and 2.5 Mg PM ha^{-1} + 100% N treatments. These results suggest the possibility of formulating flexible INM modules for cotton

Table 2. Seed-cotton yield (kg ha^{-1}) as affected by INM interventions over years and pooled over years.

Treatments	2005	2006	Mean
Control	1466	1170	1318
FP	1936	1836	1886
100% NPK	2109	2152	2130
INM (5 Mg FYM + 100% NPK)	2619	2728	2673
2.5 Mg FYM + 2.5 Mg PC + 75% N	2506	2652	2579
5 Mg FYM + 2.5 Mg PC + 50% N	2635	2833	2734
2.5 Mg PC + 100% N	2403	2600	2501
2.5 Mg FYM + 2.5 Mg PM + 75% N	2440	2512	2476
5 Mg FYM + 2.5 Mg PM + 50% N	2567	2666	2617
2.5 Mg PM + 100% N	2483	2432	2457
LSD (P = 0.05)	242	209	183

depending on the availability of different organic manures. Furthermore, INM interventions that include PC or PM would reduce dependency on not only FYM but also P and K fertilizers. Nyakatawa, Reddy, and Mays (2000) and Reddy, Nyakatawa, and Reeves (2004) reported cotton yield in the poultry litter plots was similar to the ammonium nitrate-fertilized plots on the Decatur silt loam soils of Alabama, USA. Ghosh et al. (2004) reported 25% saving of fertilizer-NPK following application of PM or FYM or PC to wheat.

Nutrient uptake by cotton among different treatments followed the pattern similar to that observed for seed cotton yield (Table 3). The N, P and K uptake by cotton varied significantly between treatments in both the years. Total nutrient uptake was lower in the control and FP treatment, whereas uptake was higher with the INM treatment. Nutrient uptake especially of N and P is mostly dependent on yield level since cotton seed is the major sink for N and P. In case of K, carpel is the major sink, followed by the stem (Blaise, Singh, and Bonde 2009). The INM intervention plots had higher productivity (Table 2), which was due to higher boll retention and thus contributed to greater NPK uptake compared to the control, FP and 100% NPK. In an on-farm trial on the Vertisols, lower nutrient uptake was reported for the FP compared to the best agronomic management practices wherein sufficient amount of nutrients was supplied (Blaise, Bonde, and Choudhary 2005).

SOC and available nutrient status

Data on SOC and available nutrient status are presented in Table 4. SOC and nutrient availability showed significant variation as a result of different nutrient management practices. Significantly lower values of SOC were observed in the control, FP and 100% NPK treatments as compared to the INM treatments that received 5 Mg or more organic matter. Treatments with organic matter addition at rates of 2.5 Mg ha^{-1} of either PC or PM did not bring about any significant improvement in SOC than the 100% NPK treatment. Availability of N, P and K in soil was generally lower in the

Table 3. Effect of INM interventions on total N, P and K (kg ha^{-1}) uptake by cotton during 2005 and 2006.

	2005			2006		
Treatments	N	P	K	N	P	K
Control	62.5	4.1	65.5	54.0	3.4	56.5
FP	89.1	6.2	84.9	78.6	5.7	78.4
100% NPK	95.4	7.2	92.3	93.4	7.3	91.3
INM (5 Mg FYM + 100% NPK)	116.8	10.0	116.7	115.4	10.3	116.4
2.5 Mg FYM + 2.5 Mg PC + 75% N	112.8	9.5	108.6	115.1	9.9	110.5
5 Mg FYM + 2.5 Mg PC + 50% N	117.8	10.3	111.6	120.2	10.8	118.9
2.5 Mg PC + 100% N	109.7	9.4	103.9	110.9	10.0	104.2
2.5 Mg FYM + 2.5 Mg PM + 75% N	110.1	8.8	107.1	107.0	8.9	102.7
5 Mg FYM + 2.5 Mg PM + 50% N	115.1	9.8	110.7	115.1	10.0	114.2
2.5 Mg PM + 100% N	110.5	8.6	105.7	102.9	8.2	96.9
LSD (P = 0.05)	10.3	1.3	10.9	9.9	1.2	10.1

Table 4. Soil organic carbon (g kg^{-1}) and N, P, and K availability (kg ha^{-1}) as affected by different INM interventions.

Treatment	SOC	N	P	K
Control	4.7	163	8.9	503
FP	5.0	174	12.0	489
100% NPK	5.1	188	15.2	519
INM (5 Mg FYM + 100% NPK)	5.7	212	21.0	602
2.5 Mg FYM + 2.5 Mg PC + 75% N	6.0	200	18.7	582
5 Mg FYM + 2.5 Mg PC + 50% N	6.3	237	23.5	614
2.5 Mg PC + 100% N	5.6	202	17.8	563
2.5 Mg FYM + 2.5 Mg PM + 75% N	5.7	197	19.8	554
5 Mg FYM + 2.5 Mg PM + 50% N	6.0	210	21.7	602
2.5 Mg PM + 100% N	5.4	203	16.5	553
LSD (P = 0.05)	0.6	15	2.1	52

control and 100% NPK treatments than the INM treatments. In earlier studies on cotton, significant improvement in SOC and available nutrient status was reported with FYM application (Blaise, Rupa, and Bonde 2004; Das et al. 2004). Adeli et al. (2010) reported an increase in available nutrients such as extractable P and K with the application of poultry litter. Similarly, Reddy et al. (2009) observed a buildup in soil available P levels with the long-term application of poultry litter on an equivalent rate of N application.

SOC fractions and CMI

TOC content values were the least in the control plots, followed by the FP and 100% NPK treatments (Table 5). However, these differences were not significant. The TOC content was significantly higher with the INM interventions compared to that with fertilizer-alone treatments (FP and 100% NPK). At identical rates of application, PC maintained relatively higher TOC than PM. These results are similar to those of Adeli et al. (2010). The TOC content in plots receiving variable quantities of organic manures followed the order: 5 Mg FYM + 2.5 Mg PC > 5 Mg FYM + 2.5 Mg PM = 2.5 Mg FYM + 2.5 Mg PC > 5 Mg FYM = 2.5 Mg FYM + 2.5 Mg PM = 2.5 Mg PC > 2.5 Mg PM. From the data, it is evident that the TOC content was higher in the plots amended with a higher rate of organic manure. Zhang et al. (2015) reported increases in TOC content with application of manure over time.

The C_L in the soil differed widely and significantly between treatments (Table 5). Among the treatments, C_L was significantly higher in the INM treatments than in the control and FP. The PC-based INM treatments maintained significantly greater levels of C_L than the PM-based INM interventions. The least values were observed in the control plot, followed by the FP and the 100% NPK treatments. However, the C_L values of the FP and 100% NPK treatment did not differ significantly. The C_{NL} under different treatments followed the trend similar to that observed for the TOC. The results are similar to those of Kalambukattu et al. (2013). All the INM interventions led to an increase in CPI and CLI. Values >1 for the

Table 5. TOC, labile (C_L) and non-labile C (C_{NL}) in soil (mg kg^{-1}) and CMI for different INM interventions used for cotton.

Treatment	TOC	C_L	C_{NL}	Lability	CPI	CLI	CMI
Control	6251	257	5994	0.043	1.00	1.00	1.00
FP	6694	288	6406	0.045	1.07	1.05	1.13
100% NPK	6827	312	6515	0.048	1.09	1.12	1.22
INM (5 Mg FYM + 100% NPK)	7537	393	7144	0.055	1.21	1.28	1.55
2.5 Mg FYM + 2.5 Mg PC + 75% N	8024	429	7596	0.056	1.28	1.32	1.69
5 Mg FYM + 2.5 Mg PC + 50% N	8379	452	7927	0.057	1.34	1.33	1.78
2.5 Mg PC + 100% N	7448	402	7046	0.057	1.19	1.33	1.59
2.5 Mg FYM + 2.5 Mg PM + 75% N	7537	348	7188	0.048	1.21	1.13	1.36
5 Mg FYM + 2.5 Mg PM + 50% N	7936	389	7547	0.051	1.27	1.20	1.53
2.5 Mg PM + 100% N	7226	333	6893	0.048	1.16	1.13	1.30
LSD (P = 0.05)	683	63	626	–	–	–	–

CPI suggest an improvement in the soil organic matter. In this study, higher CPI values were observed with interventions involving PC as a component of INM (Table 5).

CMI is a product of CPI and CLI and was designed to give an indication of the C dynamics of the system and reflect how different management strategies are being influenced (Blair, Lefroy, and Lisle 1995). CMI was markedly greater for all the INM treatments than those of the inorganic fertilizer treatments, namely the FP and 100% NPK. The INM interventions with PC resulted in relatively higher CMI values compared to those with PM. High CMI values were reported for treatments incorporating organic matter (Kalambukattu et al. 2013; Sodhi, Beri, and Benbi 2009; Verma et al. 2013). High CMI values observed with an integration of organic sources indicate an improvement in the SOC quality and thus an increase in sustainability of the management practice.

Conclusions

Our results indicate the possibility of using organic resources such as PC and PM as components of INM practice for cotton grown on Vertisols. Thus the dependency on FYM as an organic component of current INM practice is reduced. Furthermore, with PC or PM, the need to supply fertilizer-N is lower; in addition, there is no need to apply fertilizer-P or K. The INM interventions involving PC or PM also proved effective in improving soil quality, as is evident from the increased values for labile organic carbon and CMI.

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