Pak. J. Bot., 40(1): 275-282, 2008.

IMPROVEMENT OF SOIL PHYSICAL AND CHEMICAL PROPERTIES WITH COMPOST APPLICATION IN RICE-WHEAT CROPPING SYSTEM

G. SARWAR[1*], H. SCHMEISKY[2], N. HUSSAIN[3], S. MUHAMMAD[1], M. IBRAHIM[1] AND EHSAN SAFDAR[1]

[1]*Department of Soil & Environmental Sciences, University College of Agriculture, University of Sargodha, Sargodha, Pakistan.*
[2]*University of Kassel, Nordbahnnof Str1A, 37213, Witzenhausen, Germany.*
[3]*Soil Salinity Research Institute, Pindi Bhattian, Pakistan.*

Abstract

Crop productivity of soils of Pakistan has become stagnant in the last decade. One of the major constraints is organic matter status that has reached to bare minimum. This research work was conducted to evaluate the use of compost for the improvement of soil parameters of normal soil having no salinity (pH_s = 8.19, EC_e = 2.35 dS m^{-1} and SAR = 7.20). Compost (12 and 24 t ha^{-1}) was applied without and with chemical fertilizer (NPK for Rice: 100-70-70 and wheat: 140-110-70 kg.ha^{-1}) to investigate the probable effects of compost on crop yields and soil conditions. The soil pHs was lowered and SAR decreased due to acidic effect of compost, formation of acids, release of Ca and leaching of Na. There was a slight increase in EC_e of the soil. The available amount of all the major plant nutrients (N, P, K, Ca and Mg) and organic matter content increased in the soil. On the basis of experimental results, a recommendation for the farmers can be formulated that they should compost the crop residues and apply in their soils for the increased sustainable crop production. In this way, the soil fertility can be improved with a net improvement in land productivity.

Introduction

Land is the major non-renewable resource and faces the biggest threat of degradation. Land resources of the country are degrading at an alarming rate and causing environmental problems. Almost 70 % of the total area of the country falls under arid and semi-arid regions while in irrigated belt salinity is threatening about 6.6 M ha. Because of continued cultivation, the soils of Pakistan are becoming low and deficient in organic matter contents. According to Nizami & Khan (1989) Pakistani soils exhibit poor aggregate stability and are low in iron, aluminum and organic matter contents. Out of a total of 337714 samples analyzed in the Punjab, 96% of the samples were in the poor to medium range of organic matter and only 4% exhibited a moderate to adequate level. Micronutrient deficiency such as zinc is widespread in all rainfed areas (Rafique *et al*., 1990). Organic matter is regarded as a very important parameter of soil productivity. It has number of important roles to play in soils, both in their physical structure and as a medium for biological activity. Organic matter makes its greatest contribution to soil productivity. It provides nutrients to the soil, improves its water holding capacity, and helps the soil to maintain good tilth and thereby better aeration for germinating seeds and plant root development (Zia *et al*., 1993). Soil organic matter encourages granulation, increases cation exchange capacity (CEC) and is responsible for adsorbing power of the soils up to 90 %. Cations such as Ca^{2+}, Mg^{2+} and K^+ are produced during decomposition (Brady, 1990).

*Corresponding author's E-mail address: seerver@yahoo.com

Cultivation of high yielding crop varieties and multiple cropping is depleting the fertility of soils at a rapid pace. The soils, which were, once well supplied with available nutrients, are now gradually becoming deficient (Zia *et al*., 1994). Use of compost can be beneficial to improve organic matter status. Compost is rich source of nutrients with high organic matter content. Physical and chemical properties of soil can be improved by using compost, which may ultimately increase crop yields. So use of compost is the need of the time. Physical properties like bulk density, porosity, void ratio, water permeability and hydraulic conductivity were significantly improved when FYM (10 t ha^{-1}) was applied in combination with chemical amendments, resulting in enhanced rice and wheat yields in sodic soil (Hussain *et al*. 2001). Other organic materials like rice straw, wheat straw, rice husk and chopped salt grass also improved these physical properties of a saline sodic soil. The tillering, plant height, biomass and paddy yield were significantly increased (Hussain *et al*., 1998).

The rice and wheat crop residues are mainly burnt after grain harvesting with Combine Harvesters. Similarly, vegetables and fruits residues from vegetable and fruit markets in big cities are wasted that can be collected, segregated and composted by contracting firms. Composting of these materials and their application may minimize this huge wastage of organic matter. There is therefore need that the use of organic matter be promoted.

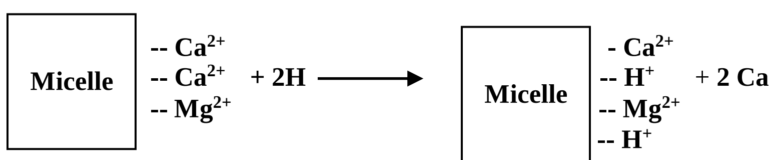
The objectives of present study were (1) To assess the effects of compost on soil properties and soil fertility improvement (2) To recommend an economical and practically adaptable technology for dissemination among farmers.

Materials and Methods

Compost was prepared at the campus of the Soil Salinity Research Institute, Pindi Bhattian through hot method using different organic materials like rice and wheat residues, flowers, leaves and soft parts of different trees, vegetable and fruit wastes and was subsequently applied to the normal field (pH_s = 8.19, EC_e = 2.35 dS m^{-1}, SAR = 7.20 and organic matter = 0.35 %). Randomized Complete Block Design (RCBD) with four replications with six treatments viz., (1) Control, (2) Recommended fertilizer (Rice (N-P-K) = 100-70-70 Kg ha^{-1} (Wheat (N-P-K) = 140-110-70 Kg ha^{-1}, (3) Compost 12 t ha^{-1}, (4) Compost 24 t ha^{-1}, (5) Compost 12 t ha^{-1} + recommended fertilizer, (6) Compost 24 t.ha^{-1} + recommended fertilizer. The experiment was started from rice crop and followed by wheat. Compost was incorporated one month before transplanting rice seedlings in the field. Rice crop was harvested at maturity. Seedbed was prepared for subsequent wheat crop through plowing and wheat seeds were sown at field capacity moisture. Wheat crop was also harvested at maturity after recording necessary crop data. After rice as well as wheat harvesting, soil samples were collected from all the treatment plots, brought to the laboratory, prepared and analyzed accordingly.

Results and Discussion

The yield of rice is reported to be 2.0 t ha^{-1} while that of wheat is 2.4 t ha^{-1} (Anon., 2003). The above yields are very low as compared to many other parts of the world. Continuous cultivation of rice-wheat crops without replenishing any organic material into the soils is the root cause of such low yields. The organic matter status of the soil has reached the bare minimum. This study was planned to investigate the possibilities of composting rice and wheat residues, which are burnt otherwise. The composted material was assessed for enhancing the fertility status of soils. Soil pH is the single soil characteristic, which elucidates an overall picture of the medium for plant growth including nutrient supply trend, fate of added nutrients, salinity/sodicity status and soil aeration, soil mineralogy and ultimate weather conditions of the region. The numerical values are always within range of 8.0 to 8.4 in normal soil while pH of sodic soils may approach 10.00 in Pakistan. Hence, a decrease in soil pH due to any land management strategy is always appreciable and results in ultimate conversion of soil medium towards favorable one and net translation into increased yields. Application of compost alone and in combination with chemical fertilizer reduced the soil pH significantly as compared to control as well as chemical fertilizer after harvesting rice and wheat (Table 1). Effects on pH were similar with compost alone or its combination with fertilizer at same level of application. Numerical values were a bit lower after wheat in the same treatments indicating consistent positive impact of compost on this soil parameter. Smiciklas *et al*., (2002), Pattanayak *et al*., (2001) and Yaduvanshi (2001) also observed a decrease in soil pH after the use of organic materials. The production of organic acids (amino acid, glycine, cystein and humic acid) during mineralization (amminization and ammonification) of organic materials by heterotrophs and nitrification by autotrophs would have caused this decrease in soil pH. The pH of an acidic soil is controlled by H, Fe and Al ions while that of alkaline soils (as in this study) is driven by Ca and Mg (Brady, 2005) while Na is in controlling position when the soil is sodic as well. The possible reactions which contributed towards a net decrease in pH of the experimental soils can be visualized as under:



[1]

(Normal alkaline soil)

Electrical conductivity showed an increasing trend with the application of fertilizer and compost to the soil. After rice, the lowest EC_e (2.40 $dS.m^{-1}$) was in control treatment (without compost) increased to 3.23 dS m^{-1} in treatment that received compost 24 t ha^{-1} followed by treatment 6 (compost along with fertilizer) (Table 1). Differences among treatments were significant in terms of statistics. However, increasing effect of chemical fertilizer was less than compost that remained at par with control. The increase in EC_e was more pronounced after wheat as compared to rice because control value of 2.38 dS m^{-1} increased to 3.61 dS m^{-1} in treatment with compost (24 t ha^{-1}) and fertilizer followed by T4, T5 and T6 with values 3.48 and 3.11 dS m^{-1} respectively. All treatments were statistically significant with each other except chemical fertilizer (T2) that remained at par with control. Electrical conductivity is a soil parameter that indicates indirectly the total concentration of soluble salts and is a direct measurement of salinity. A trend of general increase in EC of normal soil was observed after rice and wheat crops by application of sole compost or in combination with chemical fertilizer. Although EC of the soil increased in different treatments but the actual values did not cross the critical limit of 4.0 dS m^{-1}. Such similar results have been reported in the literature (Sarwar *et al*., 2003; Niklasch & Joergensen, 2001; Selvakumari *et al*., 2000), which indicated that EC increased in acidic as well as alkaline soils when organic materials of different nature were applied to the soil. The decomposition of organic materials released acids or acid forming compounds that reacted with the sparingly soluble salts already present in the soil and either converted them into soluble salts or at least increased their solubility. Hence, the EC of soil was increased e.g., $CaCO_3$ (ever present in the soils of arid and semi-arid regions) may be converted to $CaHCO_3$ or even to Na_2CO_3 which are more soluble forms. However, the quantum of increase will depend how much quantity of the acids or acid forming substances was produced which will in turn relay upon the amount of the organic materials applied.

Application of chemical fertilizer and compost at both levels lowered sodium adsorption ratio (SAR) of soil after rice and wheat crops significantly over control (Table 1). The highest value [6.5 (mmol $L^{-1})^{1/2}$] of SAR was recorded in control after rice harvesting which decreased to minimum of 3.0 (mmol $L^{-1})^{1/2}$ in treatment 4 where sole compost was added at the rate of 24 t ha-1. The treatment 6 followed control showing SAR value of 4.8 (m mol $L^{-1})^{1/2}$ and remained non-significant with control. Treatments 2, 3, 4, 5 and 6 were also at par among each other but differed significantly from control. Similarly, SAR was reduced after wheat crop from 6.7 (T1) to 3.1 (mmol $L^{-1})^{1/2}$ and differences between treatments to control were found significant in terms of statistics. Application of chemical fertilizer followed control having 4.5 (mmol $L^{-1})^{1/2}$ SAR. Chemical fertilizer proved inferior to compost in reducing the soil SAR. Sodium adsorption ratio (SAR) is yardstick used to measure the sodicity of a soil. Sodicity is the accumulation of sodium ion in excessive quantities, which hinder plant growth directly or through the impairment of physical soil conditions. A clear decrease in SAR of the normal soil was recorded after wheat as well as rice crops. The effect of compost was favorable over control or chemical fertilizer. Studies of Zaka *et al*., (2003) also indicated the same trend of decrease in soil SAR with the use of FYM, rice straw and *Sesbania* green manure. They attributed the reduction in SAR of the soil with organic materials due to the release of organic acids causing mobilization of native calcium present as $CaCO_3$ in the soil. The values of SAR become lesser either due to an increase in divalent cations (Ca + Mg) or decrease in mono-valent cation (Na). Values of Na could decrease during leaching while Ca + Mg increase due to reactions of organic acids wit $CaCO_3$ after the application of compost. The chemical reactions proposed under soil pH section above further elaborates how a net increase in Ca + Mg and decrease in Na in the soil solution occurred. The acid or acid forming substances expelled Na or Ca + Mg from the clay micelle, the hydrogen ion taking their place. Sodium salts being readily water soluble left the soil system and went into the lower depths of soil profile. The divalent cations (Ca + Mg) increased the net concentration of the soil solution. However, a part of these would have also precipitated with carbonates (CO_3) and bicarbonates (HCO_3) present in the soil. The released Ca (equation 1) increased the Ca concentration of the soil solution resulting in decrease of soil SAR (Table 1).

Organic matter status of soil was improved with application of compost and chemical fertilizer. Addition of compost alone and in combination with fertilizer enhanced organic matter status of soil significantly after rice crop (Table 2). Use of chemical fertilizer alone was inferior to compost, which remained at par with control. The lowest content of organic matter 0.56 % analyzed for control raised to 0.98% in treatments 6 where compost and fertilizer were added followed by T5, T4 and T3 indicating organic matter percentage of 0.93, 0.89 and 0.85 respectively. Almost similar trend of organic matter enhancement was noticed after wheat crop with further improvement of organic matter status of soil. The treatment (T5) receiving compost 24 $t.ha^{-1}$ alone indicated the maximum level by recording 1.23% organic matters. Organic matter is regarded as the ultimate source of nutrients and microbial activity in the soil. It is the deciding factor in soil structure, water holding capacity, infiltration rate, aeration and porosity of the soil. Thus, if only one soil parameter of productivity is to be considered that may be organic matter. It was observed that both rates of compost resulted in an increase of soil organic matter status. A combination of compost and chemical fertilizer proved further helpful in increasing the organic matter level of the soil. Similar results were also obtained by earlier workers (Pattanayak *et al*., 2001; Singh *et al*., 2001; Selvakumari *et al*., 2000; Smiciklas *et al*., 2002; Sarwar *et al*., 2003). The reason for the increase in organic matter status is very clear. Application of compost resulted in overall increase of the soil organic matter level. The status of organic matter in the soil had a relationship with the quantity applied. Comparatively more biomass production in different treatments also contributed towards the improvement of organic matter status of the soil. Phosphorus status of soil was improved significantly when chemical fertilizer and compost were added to the soil after rice as well as wheat crops (Table 2).

Amount of available P determined in control after rice harvest was 5.72 mg kg^{-1} that reached to the highest value of 27.55 in T6 (compost 24 t ha^{-1} with fertilizer) followed by T5 and T4 having 18.34 and 16.18 mg.Kg^{-1} available phosphorus respectively. Application of chemical fertilizer proved superior to control but equal to sole compost 12 t ha^{-1} (T3). This trend of increase in available P was not only maintained after wheat but was further enhanced. Maximum available P was determined in T6 (31.39 mg Kg^{-1}) followed by T4 and T5 with values of 23.58 and 22.65 mg kg^{-1} respectively. Phosphorus is second major element for plant growth. It is an integral part of adenosine diphosphate (ADP) and adenosine triphosphate (ATP); the two compounds involved in almost all energy transformations in plants. It is also essential part of DNA, which is the seat of genetic inheritance in plants. Perhaps the availability of this nutrient is the most dynamic in the soil. Beside other factors, its availability is controlled by soil pH, clay content, calcareousness and organic matter percentage of the soil. The ideal pH for maximum availability of phosphorus ranges from 6.5 to 7.5. Brady (1990) represented variable soil pH effects on availability of phosphorus by the following equation:

$$H_2PO_4^- \underset{H^+}{\rightleftharpoons} H_2O + HPO_4^{2-} \underset{H^+}{\rightleftharpoons} H_2O + PO_4^{3-} \quad [2]$$

(Very acid solutions) **(Very alkaline solutions)**

The overall conclusions drawn from these data lead to say that compost contributed more than chemical fertilize in building up the phosphorus status of the soil. When compost at the higher level alone or combined with chemical fertilizer was applied, the available phosphorus concentration became very high. But the availability of phosphorus is also affected by the presence of $CaCO_3$ in the calcareous soils. Thus, the available phosphorus starts becoming unavailable. When an organic source of nutrition is applied, the bond of phosphorus compounds with $CaCO_3$ is broken. Resultantly, phosphorus is kept at higher amounts of available form. Earlier scientists also determined availability of phosphorus in the soil by using various organic materials and their findings supported the above results (Pattanayak *et al*., 2001; Parmer & Sharma, 2002; Verma *et al*., 2002; Singh *et al*., 2002).

Water soluble potassium improved in the soil significantly after rice and wheat with incorporation of compost in the soil at two different levels (24 and 12 t ha^{-1}) alone or in combination with chemical fertilizer (Table 2). The lowest value (0.57 $mmol_c\ L^{-1}$) of water soluble K after rice harvest was determined in control against the highest value of 2.29 $mmol_c\ L^{-1}$ in T6 followed by T4 and T5 having 1.89 and 1.67 $mmol_cL^{-1}$ K values respectively. Chemical fertilizer proved superior to control. This trend was further improved after wheat. Maximum level (2.34 $mmol_cL^{-1}$) was observed in T6 that was followed by T4 and T5 with values of 2.04 and 1.77 $mmol_c\ L^{-1}$ respectively. Potash is found in different forms; readily available/water soluble, exchangeable and fixed as part of clay micelle. All the forms are in a balance with each other. A shift in one form triggers similar changes in other forms automatically. When the acid or acids forming compounds are added in the form of compost to the soil, these affect potassium availability. The effect is positive resulting in more availability of K to the plants. The hydrogen ions released from organic materials are exchanged with K on exchange site or set free from the fixed site of the clay micelle. Thus, the overall status of soil regarding availability of potassium content is improved. The probable equation proposed for K will be as under:

$$\boxed{\textbf{Micelle}}\begin{matrix}\text{--}\,K^{+}\\ \text{--}\,Ca^{2+}\\ \text{--}\,Mg^{2+}\\ \text{--}\,K^{+}\end{matrix} + 2H \longrightarrow \boxed{\textbf{Micelle}}\begin{matrix}\text{-}\,Ca^{2+}\\ \text{--}\,H^{+}\\ \text{--}\,Mg^{2+}\\ \text{--}\,H^{+}\end{matrix} + 2K \qquad [3]$$

Research conducted by other scientists proved the above hypothesis. Selvakumari *et al*., (2000), Swarup & Yaduvanshi (2000), Singh *et al*., (2001), Khoshgoftarmanesh & Kalbasi (2002), Verma *et al*., (2002) and Singh *et al*., (2002) also reported that continuous use of chemical fertilizers, FYM, compost and green manure enhanced the potassium status in the soil.

Conclusions

Farmers practicing rice-wheat system in Pakistan particularly and elsewhere in the world generally having similar climatic and soil conditions are recommended to compost the rice and wheat straw coupled with animal dung and other crop residues instead of burning or wasting otherwise. The composts prepared will not only supplement the chemical fertilizers but also reduce the environmental pollution. In this strategy, the cost of production is also reduced. Hence, higher yield with resultantly more income is expected for the farming community in this farming system. The fertility and productivity of the soil can be improved on sustainable basis.

References

Anonymous. 2003. *Agricultural Statistics of Pakistan*. Government of Pakistan, Ministry of Food, Agriculture & Livestock (Economic Wing), Islamabad.

Brady, N.C. 2005. *The nature and properties of soil* (13^{th} Ed.). Macmillan Publishing Co. New York.

Hussain, N., G. Hassan, A. Ghafoor and G. Sarwar. 1998. Bio-amelioration of sandy clay loam saline sodic soil. *Proc. 6th Intl. Micro-Irrigation Congress*, March 8-10, 1998, Florida, p. 293-300, 6 vef (En).

Hussain, N., G. Hassan, M. Arshadullah and F. Mujeeb. 2001. Evaluation of amendments for the improvement of physical properties of sodic soil. *Intl. J. Agric. Bio*., 3:319-322.

Khoshgoftarmanesh, A.H. and M. Kalbasi. 2002. Effect of municipal waste leachate on soil properties and growth and yield of rice. *Commun. Soil Sci. Plant Analysis*. 33(13&14): 2011-2020

Niazmi, M.I. and N.A. Khan. 1989. The effect of soil crust on yield of maize crop on three soil families under rainfed condition. *Pak. J. Soil Sci*., 4(1-2): 25-29.

Niklasch, H. and R.G. Joergensen. 2001. Decomposition of peat, biogenic municipal waste compost, and shrub/grass compost added in different rates to a silt loam. *J. Plant Nutr. Soil Sci*., 164: 365-369.

Parmer, D.K. and V. Sharma. 2002. Studies on long-term application of fertilizers and manure on yield of maize-wheat rotation and soil properties under rain-fed conditions in Western-Himalayas. *J. Indian Soc. Soil Sci*., 50(3): 311-312.

Pattanayak, S.K., K.N. Mishra, M.K. Jena and R.K. Nayak. 2001. Evaluation of green manure crops fertilized with various phosphorus sources and their effect on subsequent rice crop. *J. Indian Soc. Soil Sci*., 49(2): 285-291.

Rafique, E., A. Rashid and M. Yasin. 1990. Extent and severity of micronutrient status in soils of Jhelum district. (unpublished) National Agriculture Research Centre (NARC), Islamabad, Pakistan.

Sarwar, G., N. Hussain, F. Mujeeb, H. Schmeisky and G. Hassan. 2003. Biocompost application for the improvement of soil characteristics and dry matter yield of *Lolium perenne* (Grass). *Asian J. Plant Sci*., 2(2): 237-241.

Selvakumari, G., M. Baskar, D. Jayanthi and K.K. Mathan. 2000. Effect of integration of Flyash with fertilizers and organic manures on nutrient availability, yield and nutrient uptake of rice in alfisols. *J. Indian Soc. Soil Sci*., 48(2): 268-278.

Singh, M., V.P. Singh and K.S. Reddy. 2001. Effect of Integrated use of fertilizer nitrogen and Farmyard manure or Green manure on transformation of N, K and S and productivity of rice-wheat system on a vertisol. *J. Indian Soc. Soil Sci*, 49(3): 430-435.

Singh, S., R.N. Singh, J. Prasad and B. Kumar. 2002. Effect of green manuring, FYM and bio-fertilizer in relation to fertilizer nitrogen on yield and major nutrient uptake by upland rice. *J. Indian Soc. Soil Sci*., 50(3): 313-314.

Smiciklas, K.D., P.M. Walker and T.R. Kelley. 2002. Utilization of Compost (Food, Paper, Landscape and Manure) in Row Crop Production. Department of Agriculture and Health Sciences, Illinois State University, USA.

Swarup, A. and N.P.S. Yaduvanshi. 2000. Effect of Integrated nutrient management on soil properties and yield of rice in Alkali soils. *J. Indian Soc. Soil Sci*., 48(2): 279-282.

Verma, T.S., V.K. Suri and J. Paul. 2002. Prescription-based fertilizer recommendations for rice, maize and wheat in different Agro-climatic zones of Himachal Pradesh. *J. Indian Soc. Soil Sci*, 50(3): 272-277.

Yaduvanshi, N.P.S. 2001. Effect of five years of rice-wheat cropping and NPK fertilizer use with and without organic and green manures on soil properties and crop yields in a reclaimed sodic soil. *J. Indian Soc. Soil Sci*., 49(4): 714-719.

Zaka, M.A., F. Mujeeb, G. Sarwar, N.M. Hassan and G. Hassan. 2003. Agromelioration of Saline Sodic Soils. *Online J. Biol. Sci*., 3(3): 329-334.

Zia, M.S. 1993. *Soil Fertility Evaluation and Management for Flooded lowland rice soils of Pakistan*. Ph. D. Dissertation, Kyoto University, Japan.

Zia, M.S., M.I. Nizami and M. Salim. 1994. Problems of soil degradation in Pakistan. In the collection of land degradation data. Report of the expert consultation on the Asian network on problem soils. RAPA Publication: 1994/3. Regional office for Asia and the Pacific. Food and Agriculture Organization of the United Nations. Bangkok. Thailand. pp. 179-202.

(Received for publication 20 November 2007)