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Evaluation of Soil Health in Short Term Organic Vs Conventional Practices during Paddy Cultivation

Vandana Jaggi[1*], Samiksha Joshi[1], Hemant Dasila[1], B.S. Mahapatra[2] and Manvika Sahgal[1]

[1]Department of Microbiology, [2]Department of Agronomy, G. B. Pant University of Agriculture and Technology, Pantnagar-263 145, Uttarakhand, India

**Corresponding author*

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A B S T R A C T

Soil health indicators such as soil physico-chemical properties, total bacterial count, microbial enzyme activities were monitored at different crop growth stages (such as before ploughing, after transplantation (0 DAT), max tillering (45 DAT), flowering (60 DAT) and maturity (90 DAT) of rice variety Pusa Basmati 1. The treatment comprises green manure *Sesbania rostrata* and inorganic fertilizers for organic and conventional respectively. Moreover, field was cultivated with rice variety Pusa Basmati I. Total bacterial count; microbial enzyme activities (i.e Dehydrogenase, Fluorescein diacetate and Urease) and soil organic C and N significantly enhanced with crop growth and were maximum at maturity 90 DAT. Conversely, inorganic fertilizers did not affect soil C and N. However soil pH and alkaline phosphatase (AP) enhanced with crop growth. The calculated crop yields for organic and conventional treatments were 39.14 and 41.81 q/ha^{-1} respectively. Probable reason behind low yield in organic amendment could be short duration experiment study. Moreover, rice variety Pusa Basmati I is responsive for inorganic fertilizer. Result of this study suggest that green manure is a good source of organic nutrient to maintain soil health and crop yield but field require at least 3-5 years to under organic farming practices to give desirable results.

Introduction

Demand for organic farming is emerging owing to ill effects of agro-chemicals on environment as well as human health. It is a unique production management system, which enhances and propagates agro system health including biodiversity, biological cycles and soil biological activity. Conventional agricultural practices like excess use of chemical fertilizers and pesticides negatively affect the soil health. Soil health is defined as continued capacity of a specific soil type to sustain plant productivity and maintain favourable environment to sustain habitation and human health. Hence, soil health is key to achieving agricultural sustainability. Organic farming is an eco-friendly practice, it involves practicing crop rotation, using biofertilizers and pesticides (Kontopoulou *et al.,* 2015) to enhance the product quality and promote environmental safety. Currently organic mode of agriculture is practiced in 162 countries world over, accounting for 0.86% of total agricultural land. In India area under organic farming increased from 0.46 million ha^{-1} in 2009-10 to 0.72 million ha^{-1} in 2013–2014 (DAC & FW, 2016; Lernoud and Willer, 2016), which accounts for 0.4% of the total land under agriculture. Problems like soil erosion, decreased soil productivity due to frequent use of inorganic fertilizers divert the farmers towards organic farming practices. In India *Oryza sativa* is a staple crop next to wheat. Globally rice is cultivated on an area of about 155.62 million ha^{-1} with production of 461 million ton and productivity of 4.09 ton/ha^{-1}. India ranks first in world with respect of area under rice cultivation (44.50 million ha) and second in production 102.75 million tonne, only after China, but the productivity is very low only 2.20 ton ha^{-1} (Anonymous, 2012).

Soil organic matter (SOM) plays an important role in enhancing soil physical, chemical and biological functions and also a key indicator of soil quality (Murphy, 2015). SOM is both a source and sink of organic forms of carbon (C), nitrogen (N), phosphorus (P), and sulphur (S) (Kirkby *et al.*, 2011; Murphy, 2015). In the organic farming, decomposition of soil organic matter (SOM) through the activities of soil microorganism releases essential nutrients and make them available for plant growth. Hence, organic farming systems are known to improve both chemical and biological soil quality and subsequently increases the crop yield (Fließbach *et al.*, 2007). Soil biochemical activities of microorganisms play an essential role in nutrient mineralization and the decomposition of organic matter and are key drivers of nutrient supply to plants. Soil enzyme activities give information about soil microbial and physicochemical status, act as "sensors" of soil organic matter (SOM) decomposition (Aon and Colaneri, 2001; Baum *et al.*, 2003; Sinsabaugh *et al.*, 2008). Further, these have been used to elucidate influence of soil treatments on soil fertility (Chen *et al.*, 2003), and correlate well with nutrient availability (Asmar *et al.*, 1994; János *et al.*, 2011). Moreover, they respond quickly to physical and chemical changes in soil, including nutrient availability (Anderson *et al.*, 2002; Giacometti *et al.*, 2013). Conversely, loss of any microbial biochemical activity is an indicator of decreased soil quality (Chapman *et al.*, 2007; Chiurazzi, 2008; Zak *et al.*, 1994). Application of Organic amendment increases overall enzyme activity (Mäder *et al.*, 2002; García-Ruiz *et al.*, 2008; Moeskops *et al.*, 2010). However, activities of specific enzymes are influenced by several factors; composition of the amendments and its pH, texture and relative availability of nutrients (Acosta-Martínez *et al.*, 2007; Sinsabaugh *et al.*, 2008; Stursová and Baldrian, 2010). Higher enzyme activities were reported in the rhizosphere than in bulk soil. The probable reason is greater microbial activities on rhizosphere, sustained by root exudates and enzymes (George *et al.*, 2005; Villányi *et al.*, 2006. For long term agricultural sustainability microbial biomass acts as a reservoir of nutrients (Melero *et al.*, 2006).

Materials and Methods

Experimental site

To investigate the effect of organic amendments (*S. rostrata*)) over conventional fertilization (inorganic fertilizers) on microbial population, soil microbial enzyme activity and crop yield, a field experiment was conducted in a $402m^2$ plot at Norman-E-Borlaug crop Research Center (NBRC) of G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, located at altitude of 29º N, longitude 79º E and an elevation of 243.8m above sea level.

Field trial and agronomical parameters

For the analysis of effect of organic treatment on crop yield, field experiment was conducted in a 402 m^2 plot at Norman-E-Borlaug crop Research Center (NBRC) of G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. The soil of experimental plot was silt clay loam in texture and belongs to the order mollisol (USDA classification). The climatic conditions of experimental site vary from subtropical to temperate, with annual rainfall of 1000-2000 mm and temperature variation from 8 °C-46°C during winters and summer respectively. The experiment was set in randomized complete-block design. Experimental plots were cultivated with rice var Pusa Basmati I amended with green manure and inorganic fertilizers for organic and conventional treatments respectively. The agronomical parameters such as root length, root dry weight, plant height, and number of productive tillers were studied. Results were statistically analysed by two factorial analysis of variance (ANOVA2). Significance between treatments determined at p value <0.05.

Sampling and soil analysis

Soil was sampled from two depths of 0-15 and 15-30cm during various time intervals of growth (before ploughing, after transplantation (0 DAT), maximum tillering (45 DAT), flowering (60DAT) and maturity period (90 DAT). Moist field soil was sieved and divided into two subsamples. One was immediately stored at 4 ºC in sampling bags loosely tied to ensure sufficient aeration until assaying of microbiological and enzymatic activities. The other was air-dried for physico-chemical analysis.

Soil physico-chemical properties

All soil samples were analyzed for pH, oxidizable organic carbon, available phosphate, available potassium, ammonical nitrogen and nitrate nitrogen using soil testing kit from HiMedia laboratories.

Total bacterial count

The total aerobic bacterial count was enumerated through serial dilution spread plating on Nutrient agar media and incubated at 28±1ºC for 2-3 days in BOD. The bacterial colonies were enumerated and expressed as log cfu g^{-1} of soil.

Determination of soil enzyme activities

Organic amendment leads to changes in the functioning of the system, as evaluated by soil enzyme activities. The soil health was monitored by estimating activities of four soil enzymes, dehydrogenase, fluorescein diacetate, alkaline phosphatase and urease in soil samples at different crop growth stages from soil depth (0-15cm). The hydrolysed product of each enzyme was analysed spectrophotometrically and compared with a standard curve. All assays were conducted in triplicates. Urease activity was determined as given by Kandeler and Gerber (1988). Five grams of field moist soil was placed in 50-ml Erlenmeyer flasks drenched with 2.5 ml 0.08 M urea solution and incubated at 37 °C. After 2 h incubation 50 ml of 1N KC1 was added and shaken for 30 min. The resulting suspensions were filtered. One ml of filtrate was diluted to 10 ml with DW followed by addition of 5ml Sodium salicylate and 2ml 0.1% sodium dichlorisocyanurate. The samples were incubated at 28±1ºC for 30 min and absorbance read at 690nm.

Alkaline phosphomonoesterases activity was analysed according to a method of Tabatabai and Bremner (1969). 1 gm of moist soil was placed in a 50-ml Erlenmeyer flask, 4 ml of Modified Universal Buffer (MUB), 0.25 ml of toluene; 1 ml of p-nitrophenyl phosphate (PNPP) solution was added and swirled for a few seconds to mix the contents and flasks incubated at 37º C. After 1 h, 1 ml of 0.5M calcium chloride and 4 ml of 0.5M sodium hydroxide was added. Thoroughly mixed soil suspension was filtered and analyzed spectrophotometrically at 400 nm.

Fluorescein diacetate hydrolyses was determined according to the method of Inbar *et al.*, (1991). 1 gm of field moist soil taken in Erlenmeyer flask was drenched with 1 ml of FDA solution and 15 ml of buffer. The flasks were shaken for 20 min on a rotary shaker at 25 ºC, after which 10 ml of acetone was added for extraction. The samples were filtered and absorbance measured at 490 nm. Dehydrogenase enzyme activity was estimated according to the method of Thalmann (1968). 5 gm field moist soil was placed in Erlenmeyer flask and 5 ml TTC-TRIS buffer was added followed by 24 h incubation at 30ºC in the dark. Thereafter, the sample was extracted with 25 ml acetone. The resulting solution was shaken for 2h in the dark and filtered. The absorbance of the triphenyl-formazen formed was measured immediately at 546 nm on PE Lambda 35 spectrophotometer.

Results and Discussion

Soil physico - chemical properties

The soil was sampled from organic and conventional plots after the harvesting of previous crop as well as after the transplantation of rice variety Pusa basmati I and assayed for its physico-chemical properties (pH, organic carbon, ammonical nitrogen, nitrate nitrogen, available form of phosphate (AP) and potassium (AK). The initial pH of soil was calculated as 8.0-8.5. The pH gradually decreased upto 7.5 in organic treatment whereas increases for conventional treatment and is measured as 8.5 at crop maturity (Table 1). Alkaline pH of the soil before the application of organic amendment might be explained by the fact that the residues of previous crop and chemical fertilizers tend to make the soil alkaline (Massey *et al.*, 2009). However, the decrease in pH reaching near neutral with organic treatment may be due to the green manure itself or by the high microbial count (as cfu $g^{-1)}$ and their metabolic activities as represented by soil enzyme activities. Dumbrell *et al.*, (2010) reported that bacterial diversity varies with Soil pH and was highest in neutral soil. Total organic carbon status is an indicator of soil fertility. In soil its status changes quickly due to application of either chemical, biological or pesticides. In present study total organic carbon increased from initial concentration (kgha^{-1}) 0.300 to 0.750 at crop maturity (90DAT) in organic treatment and 0.100 – 0.500 kgha^{-1} in conventional fertilized soil. Other parameters like available phosphate, available potassium, and ammonical nitrogen were not significantly affected with organic or inorganic treatments (Table 1). There was no significant increase or decrease in their concentration with respect to the growth period of the plants as shown in Table 2. Whereas, nitrate nitrogen concentration increased in organic treatment. It increased from 4 kgha^{-1} before ploughing to 10 kgha^{-1} at maturity stage (90DAT).

Total bacterial count

In field amended with green manure bacterial population increased from 6.62 to 6.80 log cfu g^{-1} during different growth stages of crop whereas, from 6.57 to 6.72 log cfu g^{-1} in field applied with inorganic fertilizer (Fig. 2). Similar observations were reported in previous studies. Organic amendment improves soil microflora and structure (Crecchio *et al.*, 2001). Birkhofer *et al.*, (2008) observed a similar increase in microbial biomass and activity in organically treated compared with conventional.

Table.1 Total bacterial count and soil physicochemical properties in organic and conventional treatments at different crop growth stages

Treatment	Sampling time	Log cfu/g⁻¹ soil	Soil pH	Organic Carbon (Kg/ha⁻¹)	Available phosphorous (Kg/ha⁻¹)	Available potassium (Kg/ha⁻¹)	Ammonical nitrogen (Kg/ha⁻¹)	Nitrate nitrogen (Kg/ha⁻¹)
control	Before ploughing	6.62	8.0-8.5	ML(0.300-0.500)	L(<22)	M(112-280)	L (15)	VL(4)
Organic	After transplantation	6.65	8.5-9.0	ML(0.300-0.500)	M(22-56)	M(112-280)	L(15)	VL(4)
Conventional		6.57	8.5	ML(0.300-0.500)	M(22-56)	L(<112)	M(73)	VL(4)
Organic	45 days	6.67	8.5	ML(0.300-0.500)	L(<22)	M(112-280)	L(15)	M(20)
Conventional		6.65	9.0	ML(0.300-0.500)	L(<22)	H(280-392)	M(73)	VL(4)
Organic	60 days	6.72	7.5-8.5	M(0.500-0.750)	L(<22)	M(112-280)	L(15)	VL(4)
Conventional		6.67	9.0-9.5	ML(0.300-0.500)	MH(56-73)	M(112-280)	M(73)	VL(4)
Organic	90 days	6.80	7.0-7.5	M(0.500-0.750)	L(<22)	M(112-280)	L(15)	L(10)
Conventional		6.72	8.5-9.0	ML(0.300-0.500)	H(>73)	M(112-280)	L(15)	L(10)

M=Medium, ML= Medium Low, L= Low, H=High

Table.2 Soil enzyme activities in organic and conventional treatments days after transplantation

Treatments	Dehydrogenase activity (µgTPFg⁻¹soil/24h⁻¹)			FDA (µg hydrolyzed FDA/g⁻¹ soil)			Alkaline phosphatase (µgPNPg⁻¹soil/h⁻¹)			Urease (µgNH_4^+g⁻¹soil/h⁻¹)		
	45DAT	60DAT	90DAT	45DAT	60DAT	90DAT	45DAT	60DAT	90DAT	45DAT	60DAT	90DAT
O	62.22±1.4	67.77±1.4	93.33±1.9	102.11±0.09	103.09±0.19	113.75±1.5	31.96±0.19	36.79±0.76	35.91±0.16	14.16±0.34	27.08±1.04	30.58±0.55
C	60.00±0.9	61.66±1.6	80.55±1.1	90.41±0.15	91.25±0.31	96.38±0.5	31.71±0.11	38.69±0.32	39.75±0.29	11.96±0.10	23.28±0.21	27.30±0.14

O=Organic, C=Conventional

Soil enzyme activities

Several previous studies reported that organic management increases overall enzyme activity (Mäder *et al.,* 2002; García-Ruiz *et al.,* 2008; Moeskops *et al.,* 2010). At the beginning of experiment different soil microbial enzyme activities were calculated as 61.66 and 60.00 µg (TPF g^{-1}/ 24 h^{-1}) for dehydrogenase, 99.61.04 and 89.47 µg (FDA g^{-1}/ h^{-1}) fluorescein diacetate, 31.37 and 31.18 (PNP g^{-1}/ h^{-1}) alkaline phosphatase, and 6.61 and 6.25 µg ($NH_4^+g^{-1}$/ h^{-1}) for urease in organic and conventional treatments respectively (Table 2). However at crop maturity (90 DAT), the increase in enzyme activity by 93.33 and 80.55 µg (TPF g^{-1}/ 24 h^{-1}), 113.75 and 96.38 µg (FDA g^{-1}/ h^{-1}) (Fig. 1), 35.91 and 39.75 (PNP g^{-1}/ h^{-1}) and 30.58 and 27.30 µg ($NH_4^+g^{-1}$/ h^{-1}) for organic and conventional treatments respectively (Fig. 1). Results were statistically analysed and found significant at $p<0.05$. It was observed that treatment with green manure (*S. rostrata*) enhanced the enzyme activity more than inorganic fertilizer application. Initially the increase was gradual but after 60 DAT drastic increase was observed for dehydrogenase, urease and fluorescein diacetate. However, alkaline phosphatase activity decreased in green manure amended field. The probable reason could be decrease in pH during various crop growth stages. Soil pH influences its microbial activity. This indicates that active microbial population in soil plays important role in all enzyme activities (Tabatabai, 1994; Burns *et al.,* 2013). They depolymerize the structurally diverse polymeric macromolecules, which is the rate-limiting step in decomposition and nutrient mineralization potential of soil (Schimel and Bennett, 2004). However at crop maturity the activities of all soil enzymes showed an increasing trend. The organic amendment with *S. rostrata* positively contributed to the increase in overall bacterial population and hence increased soil microbial enzyme activities.

Agronomical parameters and crop yield

Agronomical parameters (plant height, root length, dry weight and number of tillers) were studied for the rice plant grown under organic and conventional treatments and the results were compared. All the studied agronomic parameters positively correlated with organic treatment but crop yield was lower in organically amended field. The yield in organic amended and conventionally fertilized soil was 39.14 and 41.81 q/ha^{-1} respectively (Fig. 3).

Present study investigated the effects of green manure (organic amendment) on soil quality as determined by soil physico- chemical properties by microbial population in soil. There was not much difference in soil physicochemical properties of organically and conventionally amended field. Therefore, soil physicochemical properties alone were not sensitive enough to track relatively subtle soil quality improvements in short term organic treatments over conventional one. Similar conclusions were drawn by (Mijangos *et al.,* 2006 and Parr and Papendick (1997) who reported that physical and chemical properties of soil usually change very slowly and at a temporal scale which is not supposed to be suitable for short-term management practices (Roberto Garcı´a-Ruiz *et al.,* 2008). Our study demonstrated that experimental site supplemented with green manure exhibited greater biological activity (i.e. soil enzymes activities) than the conventional amendment and similar observations have been preiously reported by (Mader *et al.,* (2002), van Diepeningen *et al.,* (2006), Melero *et al.,* (2006) and Benitez *et al.,* (2006). Dehydrogenase, as an indicator of oxidoreductase activity of soil micro- biota (Alef and Nannipieri, 1995), was found higher in organically managed soil. Similar results were obtained with FDA and urease which participate in esterase activity and nitrogen cycle respectively. These results are supported by Gupta and Germida (1988), Bandick and Dick (1999), Riffaldi *et al.*, (2002), and Sena *et al.*, (2002) under organic practices. The soil enzyme activities were due to biochemical activities of microorganism present in soil. Thus, soil microbial population is directly correlated with soil enzyme activities. Several studies have reported that microbial populations in soil are pH sensitive higher populations are reported at neutral pH (pH 6-7). In present study highest bacterial population was reported in organic amendment at pH 7.6, slightly higher than neutral limit. However, yield was significantly higher in conventional 41.81 q/ha^{-1} as compared to organic amended 39.14 q/ha^{-1}. It has been reported that organic manuring takes at least 3-5 years to become fully effective. Although initial yield is comparatively less in organic treatment but will increase gradually over the years. From present study we found that bacterial populations and their biochemical activities (enzyme analysis) in soil are major determinant of soil fertility in short term organic practices. Thus, organic farming is an eco-friendly approach that protects soil from detrimental effect of inorganic fertilizers and maintain soil fertility as a result crop yield increases.

Use of organic amendment significantly increased soil microbial biomass and enzyme activities during complete crop cycle from transplantation to crop maturity. It is obvious that application of organic manure increases the nutrient availability as a result microbial population and soil enzyme activities increases simultaneously. However, they may be very sensitive early indicators of soil quality. It can be concluded that use of organic manure for fertilization management can be recommended as a means for promoting soil fertility and productivity.

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