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Insights on soil biological properties and crop yields under natural farming in western Himalaya

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ABSTRACT

Sustainability of agricultural production systems is a major concern in context to present environmental conditions. Natural farming (NF) is being promoted as low-cost environment friendly option. A study was carried out to investigate the effects of NF *vis-a-vis* organic farming (OF) and conventional farming (CF) systems on soil microbial population, enzymatic activity, and microarthropod population under tomato crop in the mid-hill zone of Himachal Pradesh, India. The results showed that bacterial population under NF increased by 42.8% and 24% in comparison to CF and OF, respectively. Similarly, the population of soil fungi and actinomycetes under NF increased by 80.5 and 67.7% over CF, and by 47.9 and 39.6% over OF, respectively. The soil dehydrogenase activity under NF (22.5μg TPF/g soil/h) was 150.6% higher than CF and 85.2% higher than OF. Similar trend was found for phosphatase and urease activity. Soil micro arthropod population after two years of experiment was also highest under NF followed by OF and CF. The system yield was statistically at par to each other, among different farming systems. All the soil biological parameters were significantly correlated with each other ($P<0.001$, N=42). However, the correlation of these parameters was not significant for crop yield.

Keywords: Crop equivalent yield, Natural farming, Soil microbial population, Soil enzymatic activity, Soil microarthropods, Tomato yield

Soil and crop management practices affect the relationship between soil processes and agro-ecosystem function to a great extent, and thus affect the sustainability of agricultural production systems (White *et al.* 2012, Jernigan *et al.* 2020). Organic production systems have been reported to improve soil health, conserve soil biodiversity, increase net returns, reduce the risk of crop failure and reduce environmental impacts (Blanco-Canqui *et al.* 2017, Yanakittkul and Aungvaravong 2020). Soil biodiversity in healthy soil acts as a sort of natural insurance for climate change adaptation (Sidibe *et al.* 2018) as it supports numerous ecosystem functions and services essential for agricultural productivity and food security (Pascual *et al.* 2011, Tscharntke *et al.* 2012). The ever-increasing input costs even in organic production systems are a concern to the sustainability of the production systems. The subsequent focus on developing sustainable and equitable approaches to agriculture underpin the natural farming (NF) approach, which aims to address both environmental and socio-economic concerns within the agricultural sector. Zero budget natural farming has started during the recent past and is being widely accepted by farmers (Khadse and Rosset 2019, Fitzpatrick *et al.* 2022, Behl *et al.* 2023). The NF is based on farm-based low-cost inputs and influenced by agro-ecological principles, and has the potential to improve farm viability and food security (Duddigan *et al.* 2022, Laishram *et al.* 2022, Chandel *et al.* 2023).

Sustainability of a farming system is related to its effect on changes in soil quality with time. Changes in farming practices are foremost reflected in the changes in biological properties such as microbial populations and soil enzymatic activity. Soil enzymes have been suggested as one of the important indicators of soil quality, and for evaluating the degree of alteration and assessing the effect of different cropping systems on nutrient dynamics and soil quality (Bandick and Dick 1999). The soil microorganisms help in replenishing soil fertility, as they are involved in nutrient transformations and mineralization (Sreenivasa *et al.* 2009).

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Various researchers have studied effect of individual inputs on crop yields, but information is scarce on the effect of natural farming packages as a whole. Keeping this in view, an experiment was started to study the effect of NF on soil microbial populations, enzymatic activity, soil micro-arthropods and yield of tomato.

MATERIALS AND METHODS

The study was carried out at the Experimental Farms of Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (30º 51′ N and 77º 11′ E at an elevation of 1175 m amsl), Himachal Pradesh representing mid hill zone of Himachal Pradesh. The tomato crop (cv. Solan Lalima) was grown during rainy (*kharif*) 2018 and 2019 under three systems, viz. natural farming (NF), organic farming (OF) and conventional farming (CF). The tomato seedlings raised under different farming systems were transplanted on 24th April in 2018 and 9th April in 2019 at 90 cm × 30 cm spacing in plots of 4.2 m × 3 m. Sole tomoto crop was cultivated in OF and CF. While, in NF system, 4 rows of tomato (90 cm × 30 cm) were cultivated alongwith two rows of french beans and one row of brinjal between french beans (45 cm rows apart). Straw mulch was also applied under NF system. The initial soil *p*H was 6.3 and soil organic carbon was 7.50 g/kg. The available nitrogen, phosphorus and potassium were 329, 13.4 and 154.6 kg/ha, respectively.

The NF system was implemented as per Palekar (2013). The seeds were treated with beejamrit @20 ml/20 g, one day before sowing, and kept overnight for drying. The nursery bed was applied with the ghanjeevamrit @100 g/m^2. The jeevamrit was sprinkled on the nursery bed @10%, one day before uprooting the seedlings. The roots of uprooted seedlings were dipped in jeevamrit for 2–3 min before transplanting. Ghanjeevamrit @5 q/ha was mixed in plots at the time of field preparation and jeevamrit was applied through foliar application at 15 days interval in the standing crop. For the management of insect-pests, darekaster @500 litre/ha, bramhaster @3% and agniaster @3% were used alternatively, at fortnightly interval starting from one week after transplanting till one week before harvest. The cow urine, dung and butter milk of indigenous cows (Sahiwal breed), maintained at the university dairy were used. Under OF, FYM @300 q/ha, vermicompost @50 q/ha and neem manure @20 q/ha were applied, and *Bacillus subtilis* @25 ml/plant and Neem kavach @2 ml/litre were used for plant protection whereas, under CF crop was grown following standard package of practices of the University (Anonymous 2014).

To study the short term effect of NF vs OF and CF, representative soil samples (0–15 cm depth) were collected from seven replications before and after the harvest of crop to determine the soil biological properties. Soil bacteria, fungi and actinomycetes were enumerated using a standard techniques (Subba 1999). The dehydrogenase activity was determined using colorimetric measurement of triphenylformazan (TPF) produced by the reduction of 2, 3, 5-triphenyltetrazolium chloride (TTC) (Thimmaiah 1999). The soil phosphatase activity was determined using p-nitrophenyl method (Tabatabai and Bremner 1969). Activity of soil urease enzyme was determined using method described by Thimmaiah (1999).

The soil microarthropods were determined after crop harvest in 2019 using the Berlese-Tullgren extraction method (Parisi *et al.* 2005). Soil samples were collected after harvest (with soil moisture around field capacity), in cylindrical cores (8.1 cm diameter and 11.2 cm height) from different farming systems i.e. NF, OF and CF, after removing the litter from soil surface. Soil samples were protected from thermal shock and transported to the laboratory immediately. A simple and cheap Berlese-Tullgren funnel was used for extraction. Samples were placed on coarse sieves fixed across the wide end of a funnel and heated by 60-watt light bulbs fitted into a wooden frame placed above the funnel. The heat of bulb dried and warmed up the soil sample creating a temperature gradient, which forced flightless soil micro arthropods move down from the soil sample to the collection vessels. The collection tubes filled with preservative liquid (2 parts 75% ethanol and 1-part glycerol) were kept beneath the funnel to prevent the micro arthropods from escaping. The system was kept free from vibrations and disturbances during the 7 days duration of extraction.

Crop yields were recorded at the end of the season from each plot. The crop (tomato) equivalent yield CEY) of the system was computed using the method of Verma and Modgel (1983) as:

$$\text{CEY}=Y_t+Y_b\times\frac{P_b}{P_t}+Y_f\times\frac{P_f}{P_t}$$

where Y_t, Yield of tomato; Y_b, Yield of brinjal; Y_f, Yield of beans; P_t, Price of tomato; P_b, Price of beans; P_f, Price of beans.

The data on various parameters generated during the study was statistically analysed for significance tests at 5% probability level (*P*= 0.05) using *R* software (R Core Team 2013).

RESULTS AND DISCUSSION

Soil microbial population: Farming systems had a significant effect on the soil microbial count, which was highest under NF followed by OF and least under CF (Fig. 1). The soil bacterial count increased from 140.0 × 10^7 cfu/g soil to 142.9 × 10^7 cfu/g soil, 117.1 × 10^7 cfu/g soil to 123.6 × 10^7 cfu/g soil in NF and OF systems while, in CF system, it increased over its initial population from 98.6 × 10^{7}cfu/g soil to final 105.6 × 10^{7}cfu/g soil during 2018 (Fig. 1). During 2019, bacterial count increased over its initial value 141.4 × 10^{7}cfu/g soil to 147.9 × 10^7 cfu/g soil in NF system. Bacterial population increased from 115.9 × 10^{7}cfu/g soil to 118.4 × 10^{7}cfu/g soil in OF system while, in CF system, increased from 99.3 × 10^{7}cfu/g soil to 103.6 × 10^{7}cfu/g soil. After two cropping seasons, the bacterial count under NF (147.9 × 10^{7}cfu/g soil) was significantly higher than that under CF (103.6 × 10^{7}cfu/g soil), and OF (118.4 × 10^{7}cfu/g soil).

The fungal count was also significantly influenced by different farming systems during both the seasons (Fig. 1). The fungal count under NF was statistically higher than OF and CF. After two years of study, the fungal count under NF (15.2 × 10^4cfu/g soil) was significantly higher than that under CF (8.4×10^4cfu/g soil) and OF (10.3× 10^4cfu/g soil). The population of actinomycetes in the soil after harvest of crop was significantly different under different systems (Fig. 1). The increase in actinomycetes population followed the similar trend as that of fungi population. During 2018, actinomycetes population increased from 39.2 × 10^3 cfu/g soil to 43.9 × 10^3 cfu/g soil in NF system, and from 28.9 × 10^3 cfu/g soil to 34.1 × 10^3 cfu/g soil under CF. In the year 2019, actinomycetes population increased from 44.0 × 10^3 cfu/g soil to 48.6 × 10^3 cfu/g soil, 32.6 × 10^3 cfu/g soil to 34.8 × 10^3 cfu/g soil and 27.8 × 10^3 cfu/g soil to 29.0 × 10^3 cfu/g soil in NF, OF and CF, respectively. The actinomycetes population under NF was significantly higher than that under OF and CF, and that under OF was significantly higher than CF. After two years of study, the bacterial population under NF (147.9 × 10^7cfu/g soil) increased by 42.8% and 24.9% in comparison to CF and OF, respectively. Similarly, the population of soil fungi (15.2 × 10^4 cfu/g soil) and actinomycetes (48.6 × 10^3 cfu/g soil) under NF increased by 80.5 and 67.7% over CF, and by 47.9 and 39.6% over OF, respectively. The microbial populations were also higher under OF in comparison to CF. These results are in line with Liao *et al.* (2019) who reported increase in microbes under natural farming.

Soil enzymatic activity: Farming systems significantly affected the soil enzymatic activity. During 2018, dehydrogenase activity increased from 14.0 µg TPF/g soil/h (at the time of sowing) to 17.0 µg TPF/g soil/h (at harvest) under NF system (Fig. 2). In OF system, dehydrogenase activity increased from 9.7 µg TPF/g soil/h to 12.0 µg TPF/g soil/h while, in CF system, it increased from 8.3 µg TPF/g soil/h to 9.7 µg TPF/g soil/h. During 2019, the activity of dehydrogenase increased from 18.3 µg TPF/g soil/h to 22.5 µg TPF/g soil/h, 9.8 µg TPF/g soil/h to 12.2 µg TPF/g soil/h and 8.1 µg TPF/g soil/h to 9.0 µg TPF/g soil/h under NF, OF and CF, respectively. The activity of dehydrogenase enzyme under NF and OF was significantly higher than CF, and that under NF over OF.

The phosphatase activity increased from 104.4 µg PNP/g soil/h to 106.8 µg PNP/g soil/h in NF, from 68.5 µg PNP/g soil/h to 71.5 µg PNP/g soil/h under OF and from 62.3 to 63.5 µg PNP/g soil/h under CF during 2018. The corresponding increases during 2019 were from 110.5 to 115.8 µg PNP/g soil/h, 70.3 to 74.3 µg PNP/g soil/h and 61.9 to 62.8 µg PNP/g soil/h under NF, OF and CF, respectively. The phosphatase activity under NF (115.8 µg PNP/g soil/h) and OF (74.3 µg PNP/g soil/h) was significantly higher than CF (62.8 µg PNP/g soil/h), and that under NF over OF.

The urease activity increased from 11.6 to 14.7 µg urea/g soil/h, 8.2 to 10.5 µg urea/g soil/h and 7.8 µg to 10.5 µg urea/g soil/h in NF, OF and CF during 2018, respectively. In 2019, urease activity increased from 16.8 to 19.9 µg urea/g soil/h, 9.9 to 10.9 µg urea/g soil/h and 8.4 to 9.2 µg urea/g soil/h under NF, OF and CF, respectively. Similar to the soil microbial population, the enzymatic activity also followed the trend NF>OF>CF. After two years, the soil dehydrogenase activity under NF (22.5 µg TPF/g soil/h) was 150.6% higher than CF and 85.2% higher than OF (Fig. 2). The soil phosphatase and urease enzyme activity under NF was 115.8 µg PNP/g soil/h and 19.9 µg urea/g soil/h after harvest during the second season (2019), which was 84.4 and 115.6% higher than CF, respectively. The soil phosphatase and urease enzyme activity under NF was also 55.9 and 83.2% higher than OF. Increase in enzymatic activity under NF also indicates higher microbial activity. Similar results have been reported by Verma *et al.* (2018) and Rana *et al*. (2021) under OF/NF systems as compared with conventionally managed soils. The formulations applied in NF had higher bacterial populations followed by N-fixers, P-solubilizers, fungi and actinomycetes, which help in

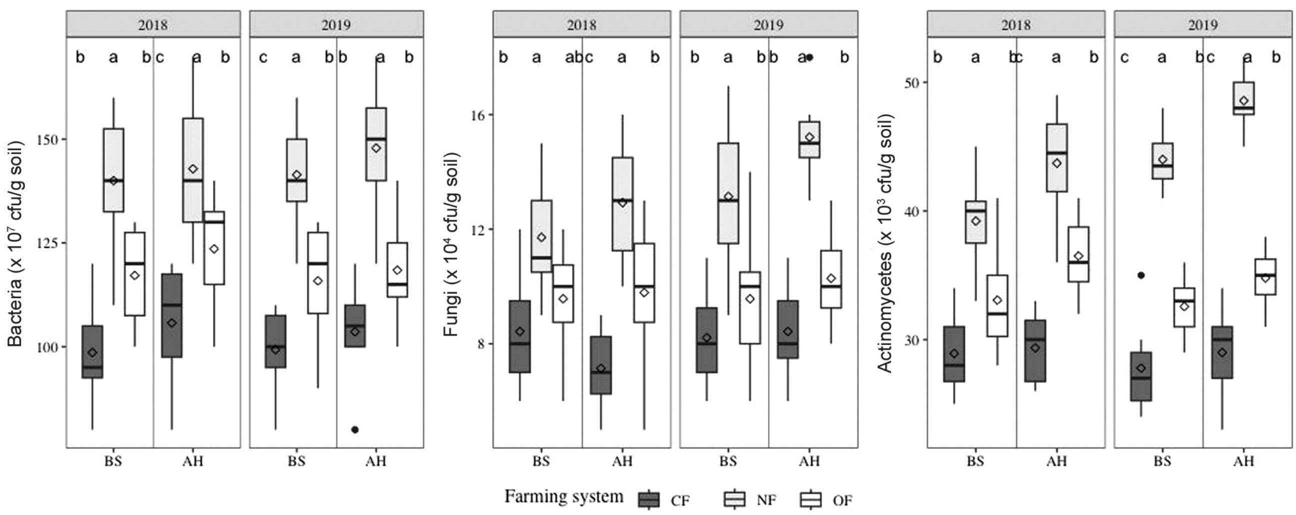

Fig. 1 Soil microbial count under different farming systems during 2018 and 2019.

Farming systems having same letter above within same sampling time are statistically at par. BS, Before sowing; AH, After harvest.

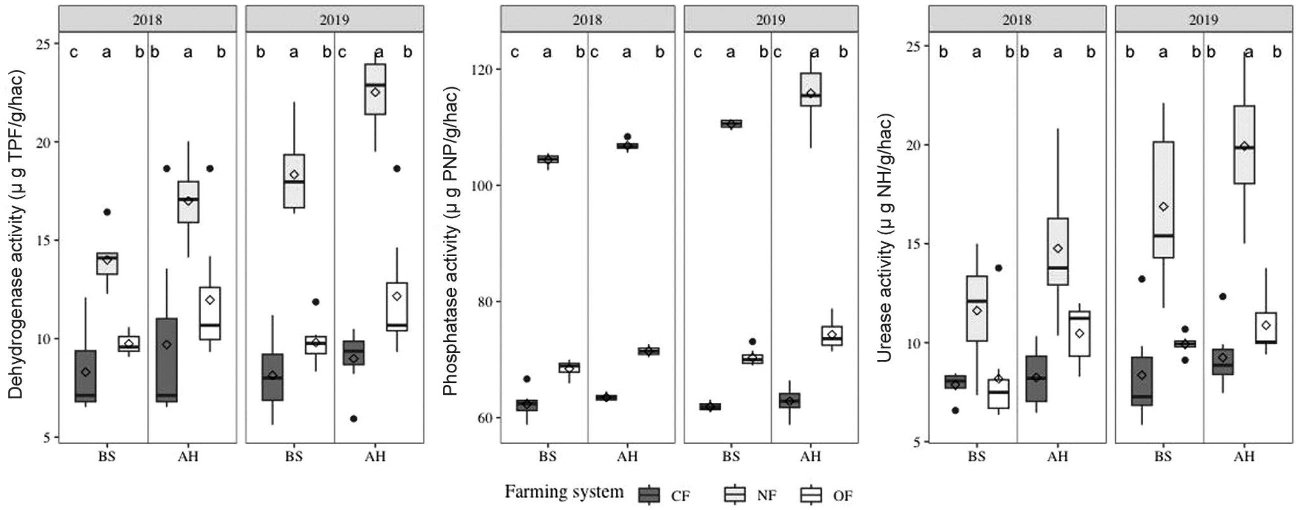

Fig. 2 Soil enzyme activity under different farming systems during 2018 and 2019.
Farming systems having same letter above within same sampling time are statistically at par. BS, Before sowing; AH, After harvest.

mobilization of plant nutrients and provide plant growth promoting substances (Devakumar *et al.* 2014).

Soil microarthropods population: Soil microarthropods population (per unit volume of soil; number/m^3) determined after the crop harvest in 2019 is given in Table 1. Highest population of soil microarthropods was found in NF (7054/m^3 soil), which was significantly higher than CF (2015/m^3 soil). Soil microarthropods population was double in OF (4031/m^3 soil) in comparison to CF, but was statistically at par due to variability among replications. The soil microarthropods from orders namely Coleoptera, Diptera, Hymenoptera, Chilopoda, Hemiptera, Collembolan and Acarina were found under all the farming systems. However, apart from these orders, microarthropods from Dermaptera, Diplura and Isoptera were also present under NF, and were not found under OF and CF. Soil microarthropods have been found to be sensitive to changes in land management practices (Parisi *et al*. 2005) and are thus being used as indicators of soil quality. Thus, apart from higher microarthropod population, additional diversity was there under NF. The abundance of soil microarthropods has been observed to be positively correlated with soil C and N, and negatively with soil *p*H (Wang *et al.* 2015). The *p*H of cow urine is in alkaline range, which might have increased the soil *p*H under NF system, where cow urine-based formulations were applied repeatedly. Higher microbial populations and higher *p*H under NF system might be the reason for significantly higher soil micro-arthropod population. Soil microarthropods have been reported to improve soil health through their roles in decomposition and nutrient cycling and direct and indirect suppression of plant pests (Neher and Barbercheck 2019).

Table 1 Effect of farming systems on soil microarthropod population

Farming system#	Soil microarthropods population (No./m^3)#
NF	7054^{a}
OF	4031^{ab}
CF	2015^{b}

#Farming systems followed by same letter are statistically at par.
NF, National farming; OF, Organic farming; CF, Conventional farming.

System yield: The data on the effect of various systems on CEY is given in Table 2. The system yield was statistically at par to each other. The results are in conformity to the findings of Moccia *et al*. (2006) and Murmu *et al.* (2012), who have also found higher tomato yields with organic nutrient management. Yadav *et al.* (2019) and Gore and Sreenivasa (2011) reported significant increase in various yield attributes with the application of jeevamrit*,* a bio-formulation rich in beneficial microbes. The increased yield of tomato fruits in NF system may also be due to increase in soil microbial populations and higher enzymatic activity, which consequently facilitates the mineralization of organic matter. Chadha *et al.* (2012) reported that jeevamrit as foliar spray was quite effective in enhancing productivity of different crops and efficacy against various plant pathogens. Beejamrit and jeevamrit are rich sources of beneficial micro-flora which support and stimulate plant growth as well as help in getting better vegetative growth together with good quality yield (Devakumar *et al.* 2014). The synergistic and complementary effect of jeevamrit and panchgavya after fermentation might stimulate the root growth as well better absorption of water and nutrients and thus enhance the crop yield. In addition, mulching, which

Table 2 Effect of farming systems on crop equivalent yield under various farming systems

Farming system#	2018	2019
NF	438.72^{a}	379.08^{a}
OF	390.65^{a}	376.46^{a}
CF	399.42^{a}	386.49^{a}

#Farming systems followed by same letter are statistically at par.
NF, National farming; OF, Organic farming; CF, Conventional farming.

Table 3 Correlation among various soil biological parameters and system yields

Parameter	Actino-mycetes	Fungal count	Bacterial count	Dehydrogenase activity	Phosphatase activity	Urease activity
Fungal count	0.838**	--				
Bacterial count	0.708**	0.700**	--			
Dehydrogenase activity	0.710**	0.660**	0.680**	--		
Phosphatase activity	0.894**	0.805**	0.742**	0.836**	--	
Urease activity	0.831**	0.674**	0.582**	0.738**	0.849**	--
CEY	0.161	0.168	0.201	-0.024	0.170	0.019

**Correlation is significant at the 0.01 level (N=42). CEY, Crop equivalent yield.

is another important factor in NF, enhances growth and yield. Moreover, organic manures are also responsible for increased availability of nutrients to the plants throughout the growing period that further contribute in the increased yield with improved quality.

Correlation among various parameters: Correlation among the various soil biological properties and CEY is presented in Table 3. The data shows that the soil biological properties, viz. actinomycetes population, fungal count, bacterial count, soil dehydrogenase activity, phosphatase activity and urease activity were significantly correlated (P<0.001, N=42) with each other.

However, no significant correlation was observed between CEY and the soil biological properties. All the soil biological parameters were significantly correlated with each other (P<0.001, N=42). The correlation of these parameters was not significant with the crop yield. This could be due to variability in the crop yield over the 2-year study period, which resulted in non-significant difference among the three farming systems.

Conclusion and policy implications

The natural farming practices significantly increased the soil microbial (bacteria, fungi and actinomycetes) population and enzymatic (dehydrogenase, phosphatase and urease) activity over organic and conventional farming systems. A significant increase in population of soil microarthropods was recorded under natural farming in comparison to conventional farming, but was at par with organic farming. The system yield was statistically similar under all three farming systems. The increased microbial and enzymatic activity in natural farming system seems to have compensated the replacement of 'source' and 'amount' of plant nutrients in organic farming and conventional farming systems, and led to equivalent yield of system. The improvement in soil microbial properties and positive results in crop yield under natural farming in comparison to organic and conventional farming are encouraging. However, further studies on soil physical and biological properties through urine and dung based decoctions from various animals need to be undertaken.

Such insights suggest to learn further incrementally on how natural farming practices can be undertaken as an approach of enhancing agricultural sustainability.

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