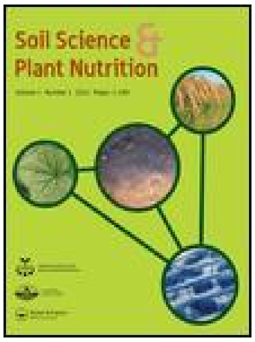

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ORIGINAL ARTICLE

Are horticulture-based land uses benign for fertility and health of soils in mid to high hills of the north-western Himalayan region?

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ABSTRACT

Soil fertility in many parts of the north–western Himalayan region (NWHR) has declined owing to accelerated nutrient mining under existing crop regime. Therefore, this study aimed to assess effect of the predominant horticulture–based land uses on soil fertility and health in mid and high hills of NWHR. Soil samples (0–20 cm) were collected, analyzed for different soil chemical attributes (pH, electrical conductivity, organic C, available primary-, secondary-, and micro-nutrients), and compared across five key land uses: perennial grass (PG), peach orchard (PO), apple orchard (AO), field vegetable farming (VF), and protected vegetable farming (PV). Soils of the investigated land uses were neutral to near neutral in soil reaction (6.3–6.8) except field vegetable and protected vegetable farming. Amount of soil organic C and labile organic C was significantly higher ($p \le 0.05$) in soils of apple orchards (18.6 g kg^{-1} and 687.3 mg kg^{-1}, respectively) and peach orchards (20.4 g kg^{-1} and 731.3 mg kg^{-1}, respectively) over others. An abrupt and significant increase in Olsen-P was recorded in soils of field vegetable farming (17.1 mg kg^{-1}) and protected vegetable farming (13.0 mg kg^{-1}), which shifted their nutrient index (NI) of P in to high category (≥ 2.33). The concentration of mineralizable-N in soil was statistically at par in soils under perennial grass and fruit orchards, while protected vegetable farming showed maximum soil mineralizable-N content (115.5 mg kg^{-1}) and NI of nitrogen (1.83). The NI was in high category (≥ 2.33) for copper, iron, and manganese in majority of the land uses. In view of the results, temperate fruit–tree based land uses are benign in up–keeping soil fertility and soil health, and needs promotion on large scale. Additionally, policies to create incentives for the build-up of soil organic matter and replenishment of the depleted soil macro and micro nutrients in vegetable-farmed lands are warranted.

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KEY WORDS
Micronutrients; soil quality; soil fertility depletion; temperate fruit crops; vegetable cultivation

1. Introduction

Horticulture is the mainstay of highland mountain economy in the north-western Himalayan region (NWHR), and greater part of the population in this region live in rural areas and depend primarily (~70%) on horticulture-based activities for their sustenance (Negi et al. 2013). At present, the area under temperate fruit crops is 200.0 thousand ha with a production of ~3.0 million metric tonnes; whereas the area under vegetables is 245.0 thousand ha with much higher production of ~4.5 million metric tonnes in the NWHR (DACFW 2018). The NWHR support cultivation of pome (apple and pear) and stone (peach, plum, cherry, and apricot) fruits and are most extensively grown by the orchardists under mid (1200 m) to high (up to 2500 m) hill conditions (Kishor et al. 2017). While, potato-based vegetable farming is perhaps the most profitable venture of all farming activities across the region. Moreover, use of protected vegetable farming (PV) has also increased dramatically in the last 10 years in this region, which has further increased farm income of the rural community. Protected structures (poly-house, shade net, poly-tunnel, etc.) are found to be quite useful in raising early vegetable nursery and for growing leafy and other vegetables during winter when ambient temperature is extremely low for a considerable period of time (Mishra et al. 2010; Negi et al. 2013).

The fragile land of this region has undergone a tremendous transformation due to changes from temperate woodland to agricultural/horticultural cropping system, urbanization, and industrialization in recent past (Vaidya et al. 2016; Annepu, Shirur, and Sharma 2017). Changes in land use and management regimes influence soil organic matter (SOM) content (Debnath et al. 2015a), which may alter physical, chemical, and biological soil properties, and ultimately affect soil fertility, productivity, and quality (Bargali, Padaliya, and Bargali 2019). Sidhu and Yadav (2016) has found in their extensive review that agricultural expansion in the Himalayan ecosystem without adoption of best management practices (BMPs) has led to environmental degradation through loss of soil fertility and soil organic C. For example, many researchers claimed that high cropping intensity and unscrupulous use of chemical fertilizers adopted by the farmers to attain higher productivity levels have ultimately rendered the soils of this region with depleted nutritional status (Parmar 2014; Annepu, Shirur, and Sharma 2017). Sustaining natural resources like soil for increasing food production today remains one of the most important challenges for humanity. Therefore, we assume that this ecosystem remains poorly conceptualized and characterized, and needs immediate attention in restoration of soil fertility and health.

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Effect of land use and land use changes on soil properties provides an opportunity to evaluate sustainability of agro-ecosystem and thus the basic processes of soil degradation in relation to crop husbandry. In a recent study by Vaidya et al. (2016) concluded that orchard and vegetable farming has deteriorated soil quality of the NWHR, and is not sustainable in upkeeping soil health. In contrast, good soil health occurred in tree planted (agroforestry and fruit orchards) soils than in open crop lands in this region, mainly attributed to better availability of SOM, litter diversity, and fine roots (Singh et al. 2018; Bargali, Padaliya, and Bargali 2019). Earlier, Parmar (2014) reported that continuous vegetable cultivation with sub-optimal doses of nutrients in an unbalanced proportion led to severe depletion of soil organic C and available nutrients in mid-hill zone of the NWHR. Thus, previous reports on the effect of dominant land uses on soil properties seem to be quite disjointed and often inconsistent in the Indian Himalayan region.

To manage our soil for maximum productivity and sustainability, soil characterization is the first and foremost step. A thorough study to elucidate soil properties vis-à-vis soil quality affected by the dominant land uses of the NWHR, therefore, remains crucial for adopting measures to improve soil health and to sustain crop productivity in future. In this light, we hypothesize that long-tem vegetable farming (open and protected condition) with suboptimal doses of nutrients would deteriorate soil fertility and health due to increased nutrient mining and loss of soil organic C. We also hypothesize that temperate fruit–orchard farming is a better practice to upkeep soil health due to long-term addition of carbon through organics and litter-fall in the NWHR. So, the present investigation aimed to (i) reveal the effect of long-tem fertilization strategy and crop regime on changes in soil chemical properties and (ii) develop nutrient and soil health index (SHI), under the prominent horticulture-based land uses in mid and high hills of the NWHR. It is very important to study the impact of land use on physicochemical properties, which can help policymakers and different stakeholders to have a proper land use planning aiming at sustaining soil fertility.

2. Materials and methods

2.1. Study area, climate and soil

The study area, located in the Nainital district, Uttarakhand (29° 0′ to 29°5′ N; 78°80′ to 80°14′ E), has a subhumid to semiarid temperate climate. The area encompasses towering mountains (altitudes of 700–2400 m msl) and is dominated by rugged terrain and steep slopes (25–34%). This division is subjected to three extreme climatic conditions, i.e., mild temperature in summers (18–25°C), very low in winter (2–14°C) and heavy rainfall during monsoon season (1400–1800 mm). Mollisols dominate the region (USDA Classification); while a small area of investigation comprises of entisols. Generally, the soil is sandy loam to loamy sand in texture, shallow, rich in mica, gravelly, and well drained with moderate permeability in the upper layer and rapid in the lower part.

2.2. Land use and crop husbandry

Four prevalent horticulture-based land uses namely apple orchard (AO), peach orchard (PO), field vegetable farming (VF), and PV were selected randomly from 14 locations distributed in the mid (1000–1600 m) and high hills (1600–2400 m) of the studied area (Table 1). These land uses are rainfed and are being followed in this region for over 50 years, except PV. The temperate fruit orchards, consisted of apple and peach of uniform age group (10–15 years), were low input–based and by default were an organic one. In other words, organic manures (20–25 and 10–15 kg FYM tree^{-1} year^{-1} in apple and peach, respectively) remained the sole source of supplying nutrients to these fruit crops.

Table 1. Geographical attributes of the studied sites and land uses.

				Horticulture-based land uses				
Location	Latitude	Longitude	Altitude	AO[†]	PO[#]	VF[§]	PV[¶]	PG[^]
Nathuakhan	29°28′ N	79°37′ E	1811 m		Y[Δ]	Y		Y
Chaubatia	29°37′ N	79°28′ E	1925 m	Y				
Chillianaula	29°40′ N	79°24′ E	1542 m	Y				
TallaRamgarh	29°27′ N	79°34′ E	1487 m		Y		Y	Y
Bhadgaon	29°35′ N	79°28′ E	1390 m		Y			
Sunkiya	29°25′ N	79°37′ E	1862 m	Y		Y	Y	
Naveen Sunkiya	29°25′ N	79°36′ E	1823 m	Y		Y	Y	Y
Mukteshwar	28°29′ N	79°39′ E	2275 m	Y	Y		Y	Y
Pokhrad	29°24′ N	79°38′ E	1704 m		Y		Y	
Darim	29°28′ N	79°38′ E	1995 m		Y		Y	Y
Pangrari	29°28′ N	79°42′ E	1877 m	Y		Y		
Gajar	29°26′ N	79°39′ E	1943 m	Y		Y		Y
Bana	29°47′ N	80°11′ E	1621 m			Y		
Chaukhuta	29°43′ N	80°06′ E	1152 m		Y	Y	Y	Y

[†] AO, apple orchard (*Malus domestica*)

[#] PO, peach orchard (*Prunus persica*)

[§] VF, field vegetable farming with *Solanum tuberosum* (potato), *Brassica oleracea* var. *botrytis* (cauliflower), *Brassica oleracea* var. *capitata* (cabbage), and *Solanum lycopersicum* (tomato)

[¶] PV, protected vegetable farming with *Solanum lycopersicum* (tomato), *Capsicum annuum* (bell pepper), *Pisum sativum* (pea), and leafy vegetables

[^] PG, perennial grass consisting *Lolium perrene* (ryegrass), *Imperata cylindrica* (thatch grass), and *Eragrostis curvula* (love grass)

[Δ] Y, presence of a land use

The VF system consisted of high input-based system wherein potato-centric vegetables are grown (potato-cauliflower/potato-cabbage/potato-tomato). Injudicious fertilization is mainly targeted for N and P (DAP at 350–400 kg ha^{-1}) with a very low quantity of organics addition (FYM at 2–3 t ha^{-1}) in potato only whereas, the following crop is raised on the residual nutrients. The PV is irrigated and is also high input-based with a cropping sequence of tomato/bell pepper-pea-leafy vegetable. Fertilizer is applied in tomato/capsicum (DAP at 50–75 kg ha^{-1}) and in pea (DAP at 50–150 kg ha^{-1}) only, and targeted for N and P with low amount of FYM (1.0–1.5 t ha^{-1}) addition. There is no fertilization in leafy vegetables.

In addition, a perennial grassland ecosystem (PG) was selected at different altitudes, which is considered as natural and undisturbed land (Table 1). However, hey is used to cut and removed once (September–October) in a year.

2.3. *Soil sampling and analysis*

Composite soil samples (0–20 cm) were collected in triplicates from each study site by scrapping away surface litter from winter to summer season (February–June) of 2016. Since the winter and summer season is dominated by drought in this region, precipitation influence on the soil properties are limited. Furthermore, since there is no significant variance in the climatology, soil type, long-term crop husbandry, and crops/cropping system across experimental sites, the effect of altitude on soil properties is presumably minimal. Collected samples were air dried, ground, and passed through 2.0 mm sieve, and stored for further laboratory analysis. For C-related analysis, samples were passed through a 0.5 mm sieve since the soils contain high amount of sand particles. Soil pH and electrical conductivity (EC) was determined in soil-water suspension (1:2 w/v) by using pH and conductivity meter (Jackson 1973). Soil organic carbon (SOC) was determined by wet combustion method (Walkley and Black 1934) and labile organic C (LOC) by $KMnO_4$-oxidation method (Blair, Lefroy, and Lisle 1995). Mineralizable N was estimated by alkaline permanganate oxidation method (Subbiah and Asija 1956) using micro-kjeldahl distillation unit (Kelplus Classic DX, Pelican Equipments, Chennai). Olsen-P was extracted using 0.5 M $NaHCO_3$ and determined colorimetrically (Olsen et al. 1954) using a spectrophotometer (Nanodrop 2000 C, Thermo Scientific, Massachusetts). Potassium (K), exchangeable Ca, and Mg were estimated by neutral 1 N ammonium acetate method (Schollenberger and Simon 1945) using flame photometer (FP 128, Systronics India Pvt. Ltd., New Delhi) and atomic absorption spectrophotometer (240 FS AA, Agilent Technologies, Santa Clara), respectively. DTPA-extractable micronutrients (Zn, Cu, Fe, and Mn) were extracted following the method outlined by Lindsay and Norvell (1978) and measured through atomic absorption spectrophotometer.

2.4. *Nutrient indexing*

A nutrient index (NI) was computed for primary- and micronutrients (Parker et al. 1951), which is an estimate of the distribution of soil samples (%) across three categories: low, medium, and high classes of nutrient status as per the soil test interpretation guide by Muhr et al. (1965) in Indian context. The NI was computed using Eq.:

$$\mathrm{NI} = \frac{(\mathrm{N_l} \times 1) + (\mathrm{N_m} \times 2) + (\mathrm{N_h} \times 3)}{\mathrm{N_t}}$$

Where N_l, N_m, and N_h indicated the number of samples falling in the low, medium, and high classes of nutrient status and N_t is the total number of samples. Levels of the NI are then calculated as per the following guide: low (<1.67); medium (1.67–-2.33), and high (>2.33).

2.5. *Computation of soil health index*

A simple SHI was calculated to determine the effect of land uses. For this purpose, principal component analysis (PCA) was performed to identify the minimum dataset among the soil parameters. The number of soil parameters having higher correlation with principal components in PCA was considered as minimum dataset. Then, these parameters were first assigned unit less score from 0 to 1 by linear scoring function. To do so, all the parameters in the minimum dataset were grouped into a mathematical algorithm function known 'more is better' (Andrews, Karlen, and Mitchell 2002). Therefore, in each selected parameters, individual observation was divided by the highest observed value of the whole dataset to provide a score of 1 to the highest observed value. After scoring the parameters, a soil health equation was developed by weighted additive approach.

$$\text{Soil Health Index(SHI)} = \sum\nolimits_{i=0}^{n}(\mathrm{WiSi})$$

Where, Wi is the weight factor determined form the ratio of variance of each factor to total cumulative variance coefficients of the principal component considered and Si is the score of the ith parameter in minimum dataset.

Since treatments were absent, subsites within a land use were considered as replicates ($n = 6$) during statistical analysis. The significance of differences ($p \leq 0.05$) between means was evaluated by Duncan's multiple range test using SPSS 16.0 Windows version package. Soil chemical health index was also worked out using the same statistical package.

3. Results and discussion

3.1. *Physico-chemical properties*

Soil pH showed variations under the different horticulture-based land uses (Figure 1(a)). Soil pH under VF (5.9) system was found to be significantly ($p \leq 0.05$) lower as compared to other land uses. Soil pH under PG (6.3), AO (6.8), PO (6.6), and PV (6.0) was found to be statistically identical ($p \leq 0.05$). On the other side, lands of VF (0.28 dS m^{-1}) and PV (0.46 dS m^{-1}) exhibited significantly ($p \leq 0.05$) higher electrical conductivity (EC) over other land uses (Figure 1(b)).

A range of pH 6.0–7.8 has previously been reported by many researchers in soils under different land uses ranging from grassland, vegetable farming, orchard, agri-horticulture to woodland in the NWHR (Vaidya et al. 2016; Annepu, Shirur, and Sharma 2017; Debnath et al. 2017; Singh et al. 2018; Bargali, Padaliya, and Bargali 2019). Similarly, our studied land uses were also neutral to near neutral in soil reaction except vegetable farming systems

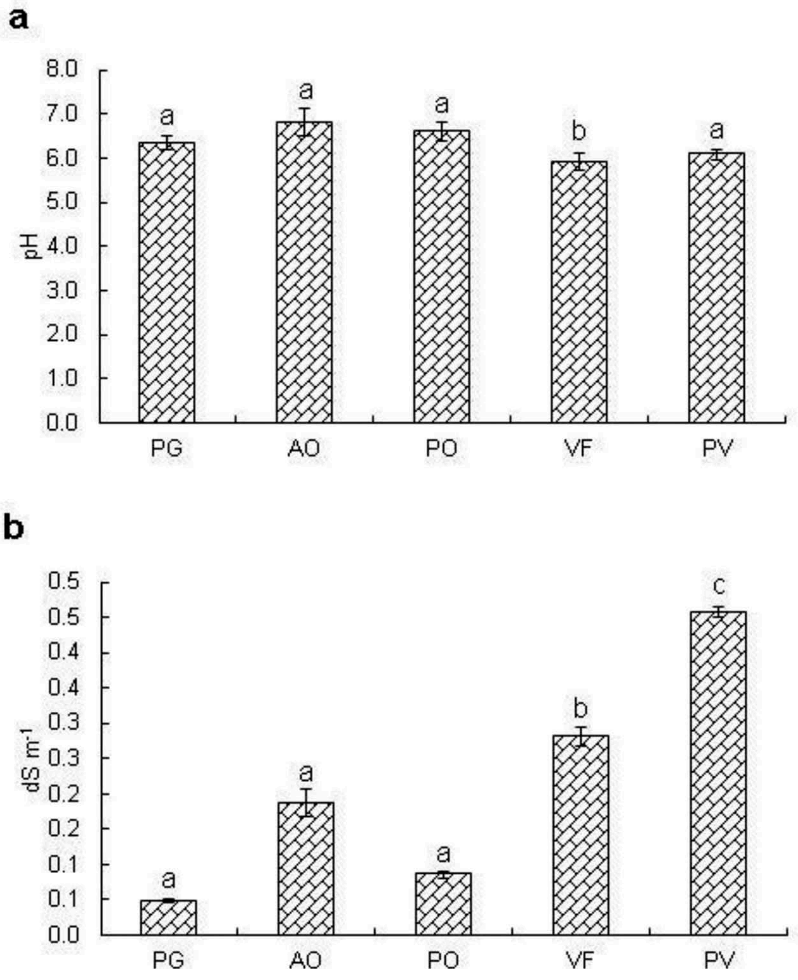

Figure 1. Soil physico-chemical attributes *viz.* (a) pH and (b) electrical conductivity as influenced by the dominant horticulture-based land uses. Vertical columns followed by different letters are significantly different according to Duncan's multiple range test at $p \le 0.05$. Bars on the column indicate standard error ($n = 6$). PG: perennial grass; AO: apple orchard; PO: peach orchard; VF: field vegetable farming; PV: protected vegetable farming.

(VF and PV), which were slightly acidic in nature. The slight increase in soil pH at the fruit orchards (PO and AO) over PG could be due to continuous addition of organics, which supply relative high amount basic plant nutrients to soils (Almaz et al. 2017). On the other side, more reliance on acid forming inorganic fertilizer (DAP) with low organic inputs has shifted soil reaction from neutral under natural vegetation (PG) to acidic under the vegetable farming systems. Soil acidification under olericulture owing to continuous reliance on chemical fertilizers in the NWHR was earlier reported by many authors (Parmar 2014; Vaidya et al. 2016). The EC values within normal range (<1.0 dS m^{-1}) may be ascribed to excessive leaching of salts to lower horizons of soil due its light texture. EC within the normal range (<0.5 dS m^{-1}) have also been reported by Loria, Bhardwaj, and Ndungu (2016) in vegetable and orchard soils of NWHR. A slight accretion of salts in soil of vegetable farming systems could be originated from long-term annual application of inorganic fertilizer.

3.2. *Soil organic C (SOC) and labile organic C (LOC)*

The SOC and LOC concentrations were significantly higher ($p \le 0.05$) under AOs (18.6 g kg^{-1} and 687.3 mg kg^{-1}, respectively) and POs (20.4 g kg^{-1} and 731.3 mg kg^{-1}, respectively) over other land uses (Figure 2(a,b)). Lands under PG showed an intermediate amount of SOC (15.7 g kg^{-1}) and LOC (600.7 mg kg^{-1}). While, intensive vegetable farming–based land uses (VF and PV) exhibited relatively low quantity of these organic C fractions.

A transitional magnitude of organic C fractions in the grasslands (PG) is interesting to observe. It is perhaps due to annual removal of hey that eliminates its incorporation in to soil during fall and thus reduces C input. On the other side, accumulation of these C fractions in the temperate fruit plantation is mainly due to long-term addition of C through organic manures and leaf-litter, and from dead roots of the trees. Additionally, soils of these plantations were rarely disturbed by tillage operations that endorse little decomposition of SOM owing to temperate climate (Brady and Weil 2010). Experiments by Debnath et al. (2015a) and Debnath et al. (2017) in temperate fruit orchards of NWHR showed relative higher SOC content (10.7–14.5 g kg^{-1}) as compared to uncultivated land. Bargali, Padaliya, and Bargali (2019) also observed significantly higher soil organic C (>20 g kg^{-1}) in tree based systems than cropland in Indian central Himalaya. Another study provided grassland (4.8 g kg^{-1}) ecosystem had significantly lower values of organic carbon than various tree-based (6.0–7.5 g kg^{-1}) land-use systems (Singh et al. 2018). Our results are thus in agreement with these previous findings.

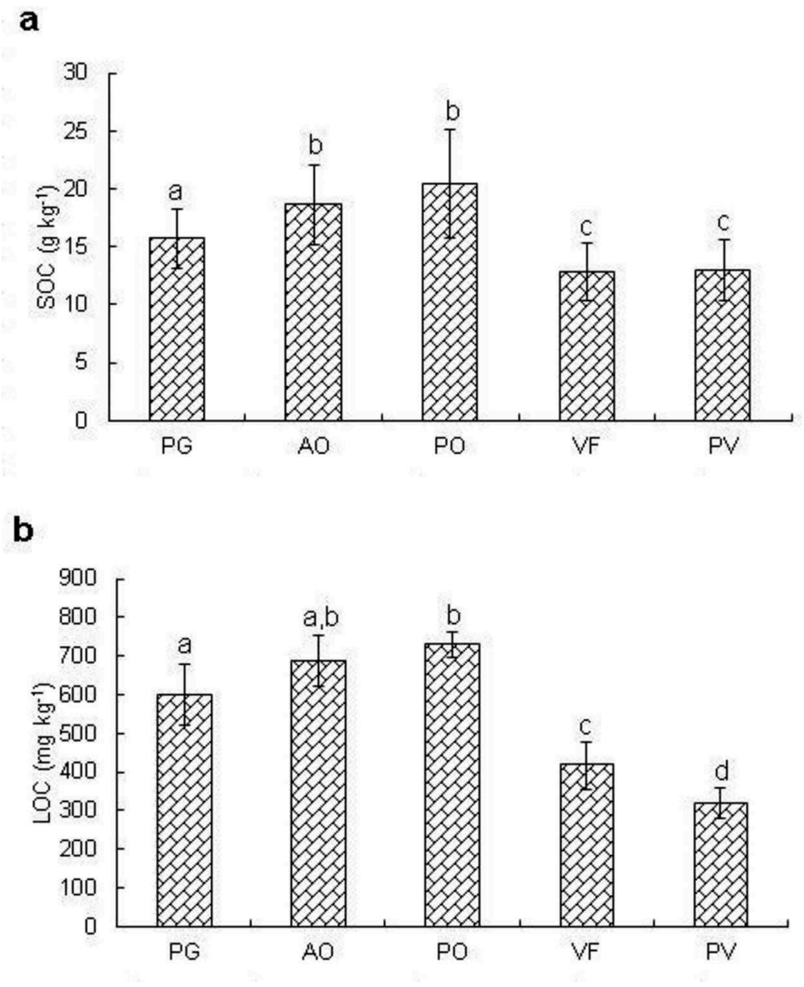

Figure 2. Soil organic C (a) and labile organic C (b) content in soils of the dominant horticulture-based land uses. Vertical columns followed by different letters are significantly different according to Duncan's multiple range test at $p \leq 0.05$. Bars on the column indicate standard error ($n = 6$). PG: perennial grass; AO: apple orchard; PO: peach orchard; VF: field vegetable farming; PV: protected vegetable farming.

The lower SOC and LOC density under vegetable farming systems (VF and PV) may be due to reduced amount of organic material being returned to the soil and high rate of oxidation of SOM owing to continuous cultivation and tillage and removal of green materials (Yimer, Ledin, and Abdelkadir 2007; Singh et al. 2018). Loria, Bhardwaj, and Ndungu (2016) also observed that

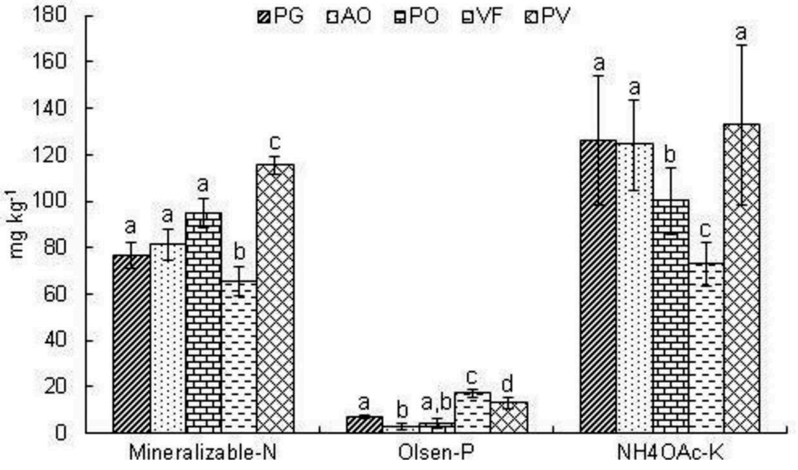

Figure 3. Soil availability of mineralizable-N, Olsen-P, and NH_4OAc-K as affected by the dominant horticulture-based land uses. Vertical columns followed by different letters are significantly different according to Duncan's multiple range test at $p \leq 0.05$. Bars on the column indicate standard error ($n = 6$). PG: perennial grass; AO: apple orchard; PO: peach orchard; VF: field vegetable farming; PV: protected vegetable farming.

vegetable farmed lands (7.3 g kg^{-1}) registered relatively low SOC over fruit-based cropping system (9.7 g kg^{-1}) in the Shiwalik hills of NWHR, and this trend was attributed to intensive cultivation that might have increased decomposition of SOM. Change in LOC concentration corresponding to SOC content among land uses suggested that the production and concentration of LOC was primarily determined by the amount of SOM in these soils.

3.3. *Availability of primary nutrients*

Mineralizable-N, Olsen-P, and NH_4OAc-K content of the soils varied significantly ($p \leq 0.05$) in different land uses and ranged from 65.6 to 115.5 mg kg^{-1}, 2.7 to 17.1 mg kg^{-1}, and 72.8 to 133.0 mg kg^{-1}, respectively (Figure 3). Their concentrations, however, remained statistically at par between perennial grasslands and both fruit orchards. The order of mineralizable-N recorded in the land uses was PV (115.5 mg kg^{-1})> PO (94.8 mg kg^{-1})> AO (81.4 mg kg^{-1})> PG (76.5 mg kg^{-1})> VF (65.6 mg kg^{-1}). Vegetable cultivation in field (VF) and protected condition (PV) registered significantly higher Olsen-P content (17.1 and 13.0 mg kg^{-1}, respectively) over other land uses (Figure 3). NH_4OAc-K followed the order: PV (133.0 mg kg^{-1})> PG (126.3 mg kg^{-1})> AO (124.4 mg kg^{-1})> PO (100.2 mg kg^{-1})> VF (72.8 mg kg^{-1}).

Since SOC content is an indicator of N availability, soils of the experimental sites should have been sufficient in available N. It seems that high SOC content does not necessarily associate with better N availability, which could perhaps be ascribed to stronger leaching phenomenon operating in these soils due to its coarseness and increased N mineralization (Haag and Kaupenjohann 2001). Cultivating the lands without adopting BMPs could further hasten loss of N from soils (Sidhu and Yadav 2016). This is exactly what has happened in VF, which exhibited the lowest N concentration in soil among the land uses. Contrarily, Vaidya et al. (2016) found that soils under vegetable land use had significantly higher available N (170.2 mg kg^{-1}) over orchards (152.1 mg kg^{-1}). Therefore, more detailed study is required to confirm such observation. On the other side, continuous N fertilization and limited soil erosion and leaching of N probably caused significant accretion of N (115.5 mg kg^{-1}) under protected condition. Relative higher amount of N at the fruit orchards over the grasslands indicates better return of N in to the orchard soils through organic materials (manures and litter).

Results showed that low soil P availability could be a limiting factor of fruit production in orchards. The unprecedented buildup of P in soils of vegetable-based land uses (VF and PV) over grasslands (PG) could be explained by very high P fertilization regime adopted by the farmers over the past decades. Increase in the available fraction of soil P in vegetable cultivated soils due to long-term P fertilization has been reported earlier by Vaidya et al. (2016) and Loria, Bhardwaj, and Ndungu (2016) in mountain soils of north-western Himalayas. However, such accrual of P could contribute to nutritional imbalance in soils.

Higher level of K across the lands was expected. It may be attributed to the prevalence of K-bearing clay minerals like mica, vermiculite, and smectite in these soils as reported by Debnath et al. (2015b); Debnath et al. (2017). Potassium level declined sharply in VF over the natural vegetation (PG), which suggests excessive mining of K under intensive olericulture. This result does not corroborate with the finding of Loria, Bhardwaj, and Ndungu (2016) who noted highest available K in vegetable lands receiving K fertilization. Vegetable farming in absence of K fertilization in this study may have intensified this scenario. It may also be due to accelerated soil erosion and intense leaching owing to poor organic matter content and tillage operations (Sidhu and Yadav 2016; Debnath et al. 2017). However, such depletion in K availability was absent in PV. It is perhaps due to limited soil erosion and leaching under the protected structures.

3.4. *Availability of secondary nutrients*

Exchangeable Ca content in soils followed the order of PG (2830.0 mg kg^{-1})> AO (2509.1 mg kg^{-1})> PO (2348.8 mg kg^{-1})

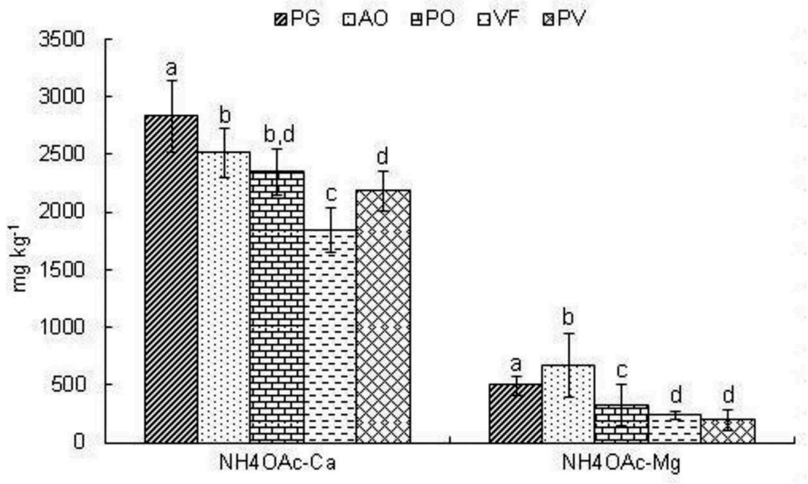

Figure 4. Status of NH_4OAc-Ca and NH_4OAc-Mg in soils as affected by the dominant horticulture-based land uses. Vertical columns followed by different letters are significantly different according to Duncan's multiple range test at $p \leq 0.05$. Bars on the column indicate standard error ($n = 6$). PG: perennial grass; AO: apple orchard; PO: peach orchard; VF: field vegetable farming; PV: protected vegetable farming.

> PV (2182.6 mg kg^{-1})> VF (1843.6 mg kg^{-1}) (Figure 4). On the other side, maximum (665.6 mg kg^{-1}) exchangeable Mg content was observed in AO and minimum (199.1 mg kg^{-1}) in PV (Figure 4). PG also registered significantly high exchangeable Mg (495.3 mg kg^{-1}) in soils over the vegetable–based land uses.

The soils under study were seem to be low in exchangeable Ca when compared to earlier studies by Dar et al. (2014) in pear plantation (4767.0 mg kg^{-1}) and by Singh et al. (2018) in citrus plantation (5893.3 mg kg^{-1}) in the NWHR. In contrast, these soils were quite high in exchangeable Mg content. Earlier Dar et al. (2014) and Debnath et al. (2015b) reported in their studies that soils in NWHR were derived from limestone parent material with substantial quantity of dolomite and shale of Triassic age along with illite, smectite, and chlorite minerals, and thus soils are typically well supplied with base cations like Ca and Mg.

This study has clearly indicated that transformation of lands from natural grassland to either temperate fruit plantation or olericulture had caused loss of exchangeable bases from soils. Substantial depletion of exchangeable bases in soils of vegetable–based land uses (VF and PV) is attributed to the artificial land management practices such as fertilizer (devoid of secondary nutrients) application (Singh et al. 2018) and tillage intensities (Sidhu and Yadav 2016), and nutrient mining.

3.5. *Availability of micronutrients*

The experimental land uses have also exerted significant ($p \leq 0.05$) influence on the availability of micronutrients like Cu and Zn except Fe and Mn (Figure 5(a,b)). There was no consistent trend in their availability among the land uses. Soils of PO and PG registered the highest amount of DTPA-Zn (2.2 mg kg^{-1}) and DTPA-Cu (3.7 mg kg^{-1}), respectively among the land uses (Figure 5(a)). Field vegetable cultivation (VF) exhibited the least concentration of DTPA-Zn (0.9 mg kg^{-1}) and DTPA-Cu (1.4 mg kg^{-1}) in soils. In contrast, the same land use showed maximum concentration of DTPA-Fe (46.0 mg kg^{-1}) and DTPA-Mn (23.0 mg kg^{-1}) in soils (Figure 5(b)).

Muhr et al. (1965) suggested the critical limits of DTPA-extractable Zn, Cu, Fe, and Mn as 0.6, 0.2, 4.5, and 2.0 mg kg^{-1}, respectively in Indian soils. Considering these limits, soils of the investigated area contain micronutrients well above their critical limit. Previous studies also confirm sufficient level of

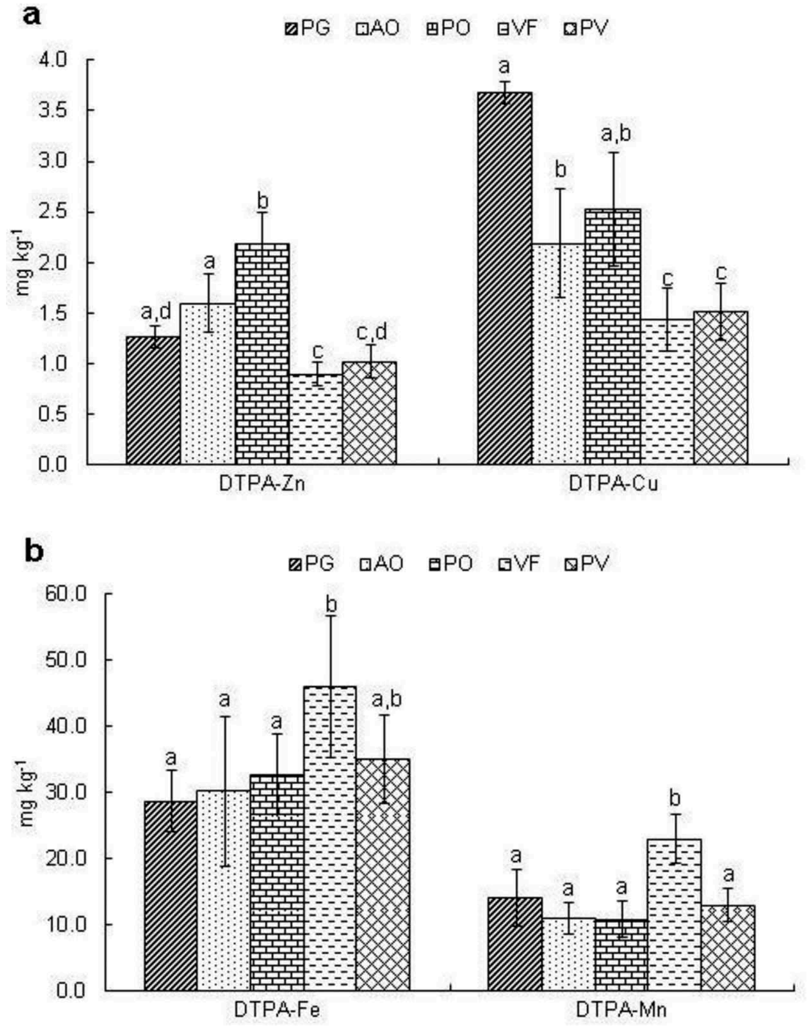

Figure 5. Concentration of (a) DTPA-Zn and DTPA-Cu, and (b) DTPA-Fe and DTPA-Mn in soils as influenced by the dominant horticulture-based land uses. Vertical columns followed by different letters are significantly different according to Duncan's multiple range test at $p \leq 0.05$. Bars on the column indicate standard error ($n = 6$). PG: perennial grass; AO: apple orchard; PO: peach orchard; VF: field vegetable farming; PV: protected vegetable farming.

available Zn (0.6–11.7 mg kg^{-1}), Cu (0.2–5.9 mg kg^{-1}), Fe (2.7–51.6 mg kg^{-1}), and Mn (0.5–40.2 mg kg^{-1}) in various temperate stone fruit orchards, vegetable and uncultivated lands (Debnath et al. 2015a; Vaidya et al. 2016; Annepu, Shirur, and Sharma 2017).

The critical observation of data indicated that soils rich in SOC are less prone to Fe and Mn deficiency. This result corroborates with the research findings of Vaidya et al. (2016) and Annepu, Shirur, and Sharma (2017) conducted in the similar region. This observation was further substantiated by generation of electrons during decomposition of organic matter which, in turn, reduce the oxides of Fe and Mn (Brady and Weil 2010), and transform them to more soluble forms that are easily available to plants. Results explained that conversion of lands from natural grasslands to temperate fruit plantations did not alter Fe and Mn availability in soils, which perhaps implying better nutrient cycling in orchards.

Better availability of Zn and Cu in soils under fruit plantations over olericulture could be explained by organic practice and nutrient recycling from litter and root residue. Further, extension of roots into deep soil layers facilitates enhanced nutrient accession from subsoil in fruit trees (Debnath et al. 2017) that causes less exhaustion of nutrients from topsoil. There was a severe depletion of Zn and Cu availability in soils under vegetable cultivated lands (VF and PV) over the PG. The possible reasons could be intensive cropping, lack of micronutrient fertilization, and unscrupulous N-P fertilizer application strategies practiced by the farmers. Improper fertilization and mismanagement of land resources have been accelerating deficiencies of micronutrients worldwide (Brady and Weil 2010) and are likely to become more severe problems in the intensively cropped area in the long run (Debnath, Pachauri, and Srivastava 2015).

3.6. *Nutrient and soil health index*

Soils under PV showed highest NI of N (1.83), falling under medium category while, other land uses fall under low (<1.67) category (Figure 6(a)). NI of P followed the order VF (3.00)> PV (2.33)> PO (1.33)> AO (1.16)> PG (1.00) (Figure 6(a)). The trend in NI of K was: PV (2.50)> AO (2.33)> PO (2.16)> PG (1.33)> VF (1.00) (Figure 6(a)). The NI was in high category (≥ 2.33) for Cu, Fe, and Mn in majority of the land uses (Figure 6(b)). However, NI of Zn was high in PG (2.66), medium in PO (2.16), and low in VF (1.00), PV (1.33) and AO (1.66).

Five principal components (PC) were identified in PCA analysis, which explained cumulatively 78% of the total variances present in the original dataset, comprised of measured parameters across all five land uses (Table 2). In total five soil parameters were chosen from first four principal components having factor loading more than 0.70 to calculate the SHI. To calculate the SHI based on PCA method, the following equation was developed and used:

$$SHI = 0.40\,LC + 0.40\,P + 0.19\,Mg + 0.16\,K + 0.13\,Fe$$

The PCA based SHI was 0.75, 0.72, 0.71, 0.62, and 0.57 for PG, AO, PO, VF, and PV, respectively (Figure 6(c)). It was revealed that fruit orchards and grassland exhibited significantly ($p \leq 0.05$) higher SHI than vegetable cultivated lands.

Generally, crop and land management practices have both positive and negative effect on soil quality parameters (Andrews, Karlen, and Mitchell 2002). Results indicate that soils of the studied land uses were inherently low in available N and P, and high in available micronutrient cations, except Zn. It was also noted that lands under olericulture was associated with improvement in soil quality parameter such as P. Such improvement in P availability can be ascribed to fertility management practices involving addition of DAP fertilizer rich in

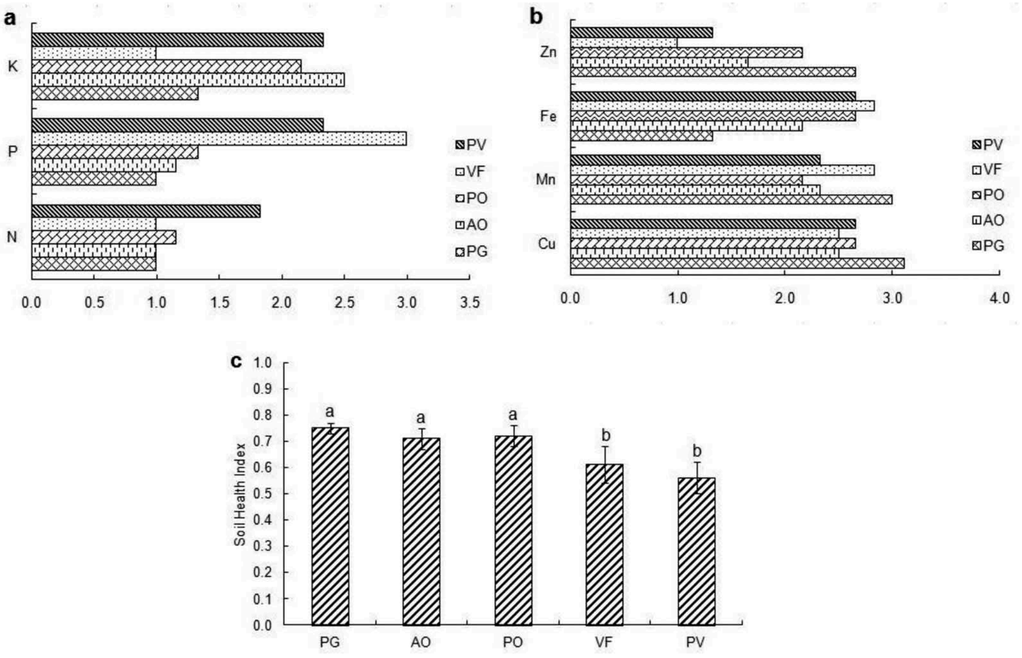

Figure 6. Nutrient indices of (a) primary nutrients and (b) micronutrients, and (c) soil health indices of the dominant horticulture-based land uses. Vertical columns followed by different letters are significantly different according to Duncan's multiple range test at $p \leq 0.05$. Bars on the column indicate standard error ($n = 6$). PG: perennial grass; AO: apple orchard; PO: peach orchard; VF: field vegetable farming; PV: protected vegetable farming.

Table 2. Factor loading of soil chemical properties of the studied land uses identified by principal component analysis.

Principal components	PC1	PC2	PC3	PC4	PC5
Eigen value	3.75	1.82	1.51	1.27	1.00
Explained variance (%)	31.23	15.21	12.63	10.65	8.40
Accumulated explained variance (%)	31.23	46.44	59.07	69.72	78.12
Eigen vectors[§]					
pH	0.66	−0.25	0.22	0.22	−0.46
Soil organic C	0.62	0.14	−0.23	−0.07	0.66
Labile organic C	**0.83**	0.34	−0.08	0.01	0.30
Mineralizable-N	−0.45	−0.19	0.53	−0.47	0.17
Olsen-P	**−0.83**	0.20	−0.23	−0.06	0.02
NH_4OAc-K	0.01	0.44	**0.76**	−0.12	0.11
NH_4OAc-Mg	0.17	**0.71**	0.39	−0.19	−0.17
NH_4OAc-Ca	0.55	−0.28	0.43	0.47	0.18
DTPA-Cu	0.34	0.44	−0.13	−0.19	−0.30
DTPA-Mn	−0.60	0.61	−0.14	0.31	0.11
DTPA-Fe	−0.44	0.26	0.19	**0.77**	0.03
DTPA-Zn	0.57	0.42	−0.28	−0.02	−0.26

[§] Factor loading >0.70 (bold-face) was considered to calculate soil health index.

phosphorus (46%). Results reveal reduced micronutrient availability (except Fe) in the horticulture-based lands over perennial grassland owing to nutrient exhaustion of the cultivated lands.

Intense farming and unscrupulous use of fertilizers in the vegetable cultivated parcels has deteriorated soil health, which supports the hypothesis of this investigation. The greater factor loading of the parameters in PCs indicated that changes in soil health was mainly driven by alteration in labile organic carbon, Olsen-P, NH_4OAc-K, NH_4OAc-Mg, and DTPA-Fe. In other words, these factors could aid as better indicator of soil health alteration. Among these indicators, labile organic carbon and Olsen-P came out to be the strongest indicator of soil health with highest factor loading (0.83). The results are in agreement with the findings of Singh et al. (2014) and Vaidya et al. (2016) who have also observed SOC and available P as the indicators contributing toward soil quality index in soils of Indian Himalayas.

Results indicate that soils of the studied land uses were poor in available N and P, especially in lands receiving no chemical fertilization. It was apparent that soils of these land uses encompass sufficient quantity of exchangeable bases and available micronutrients. Parameters such as SOC and Olsen-P appeared as the key indicators of soil health in these lands. Lands under olericulture (VF and PV) have influenced the soil health adversely over grassland and orchards. Therefore, it is concluded that the existing temperate fruit-tree planted agroecosystems are better in sustaining soil health and are encouraged over potato-based vegetable farming, and could act as hotspots of C accumulation to offset atmospheric C in NWHR. However, low P availability at the orchards could limit fruit production, and thus P fertilization is recommended for sustainability of quality apple and peach production. Future research to examine the suitability of conservation tillage and targeted organic and inorganic fertilizer application that matches nutrient use efficiency and production sustainability in vegetable farming may be warranted.

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Disclosure statement

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