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REVIEW ARTICLE

Impact of cropping systems on pedogenic distribution and transformations of micronutrients, plant accumulation and microbial community composition in soils: a review

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Abstract

Different types of agricultural cropping systems involving wheat coupled with rice, maize and cotton are adapted by most of the farmers around the world. In order to increase the production of food grains with the adaptation of these cropping systems, intensive cultivation is required which eventually needs more quantity of macro as well as micronutrients. The availability of micronutrients to plants is majorly affected by cropping patterns and their profile distribution and the chemical pools. For instance, rice–wheat (R-W) cropping system depletes the available micronutrients status in soil. Many crops have a deep root system that allows them to fulfill their micronutrients requirement from deeper soil layers. In pedon, the surface layer of soil is richer in micronutrients than sub-surface soils. Thus, the knowledge of all the forms or fractions of micronutrient in soil and conditions that help in converting them to their available forms is essential. Excessive use of macronutrient fertilizers in soil with alkaline pH, results in an upsurge accumulation of micronutrients under R-W system. Consequently, it is essential to understand the relationship between accumulation of micronutrients by plants and different chemical pools of micronutrients and their distribution in the pedon. Also, the incorporation of different crops in various cropping systems has a marked influence on microbial communities in soil which play a crucial role in nutrient cycling, gaseous exchanges, aggregation and soil biochemical processes that ultimately influences crop productivity and soil health. Thus, imaging the extent of micronutrient availability to plants, various fractions of micronutrients and microbial community in soil under different cropping systems is necessary.

Keywords Cropping systems · Depthwise distribution · Micronutrients · Soil layers · Transformation

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Introduction

The rice–wheat (R-W) cropping system plays a vital role in global food security as it provides staple foods to the world's population (Lalik et al. 2014; Banjara et al. 2021a). In Asia, RW cropping system account for about 13.5 million hectares (mha), with 57% of it being in South Asia (Ahmad and Iram 2006; Ladha et al. 2009). Furthermore, more than 85% of the RW cropping system practiced in South Asia is distributed in the Indo-Gangetic Plains (Banjara et al. 2021b). In India, the pre-dominant rice–wheat system covers an area of 9.2 mha, thus playing a key role in the nation's food security (Jat et al. 2020). The RW cropping system is widely spread in the north-western parts of India, especially Punjab, Haryana, and Uttar Pradesh, and most of these regions depend on groundwater for irrigation (Ambast et al. 2006). With the advent of the Green Revolution, the country's food grain production increased many-fold due to technological intervention. However, current cultivation practices in the RW cropping system are degrading the soil and water resources and thus threatening the sustainability of this system and causing deficiency of macro as well as micronutrients in crops (Chauhan et al. 2012; Kumar et al. 2018). For instance, the Punjab soils presently are 12.1% deficient in zinc (Zn) and this deficiency had been decreased from 22% in 2010 (Dhaliwal et al. 2020). About 9.7% of Punjab soils are deficient in iron (Fe), whereas manganese (Mn) deficiency increased from 11% to 25.5% over the years (Dhaliwal et al. 2020). The escalation in the incidence of Mn deficiency, mainly in wheat and berseem, could be ascribed to the earlier cultivation of rice on coarse-textured soils, which causes the leaching of Mn to deeper soil layers during the period of rice season which resulted in Mn deficiency in wheat/berseem crop. The deficiency of copper (Cu) has also increased up to 4.5% over the years. Dhaliwal et al. (2013) during the analysis of soil samples observed that due to lack of effective nutrient management techniques, micronutrient deficiencies (Zn, Mn, Fe and B) appeared at a faster rate in the rice–wheat growing regions of Punjab. The intensity of these deficiencies depends on the type of crops sown as well as soil conditions.

Similarly, Cu, Zn, Fe and Mn deficiencies were observed in 1, 48, 14 and 2% of total soils of Punjab (Singh et al. 1999), out of which, the deficiency of Zn and Fe in Punjab soils has been decreased to 12.1 and 9.7%, respectively, while Cu and Mn deficiencies have been increased to 4.5 and 25.5%, respectively (Dhaliwal et al. 2020). Dhaliwal et al. (2022) observed the DTPA-extractable Zn, Cu, Fe and Mn content in different soil orders including Aridisol, Entisol and Inceptisol under different land use systems of Punjab. The micronutrient contents were negatively correlated with pH and electrical conductivity (EC) of soils, whereas organic carbon showed non-significant correlation. Also, the concentration of micronutrients was highly affected by pH as higher concentrations of available micronutrients were generally associated with a neutral to slightly acidic range of pH (Gondal et al. 2021). The heavy texture soils with higher organic matter and lower pH could usually provide a greater reserve of these elements than coarse textured soils such as, the sand having lesser reserves which tend to run out quickly (Yadav and Meena 2009).

Food grain production, no doubt, increased tremendously and made the country self-sufficient in food grains, yet it resulted in the faster depletion of the finite micronutrient reserves of soils. Adaptation of the rice–wheat system, mainly in the non-traditional areas of rice-cultivation, led to excessive exploitation of the natural resource base of soil and these trends further escalated due to imbalanced use of inputs. The increased usage of poor-quality irrigation water to meet the water requirement of the cropping systems had further intensified the micronutrient deficiencies problems. This section included the brief introduction of the R-W cropping system, different factors affecting the overall availability of micronutrients in soil along with the effect of R-W cropping system on the degrading soil parameters and nutrient levels. In this context, many researchers have discussed the dynamics and transformation of micronutrients in agricultural soils but less literature is available on the effect of different cropping patterns on the micronutrient status. Thus, the present review was compiled to discuss the effect of various cropping systems on the availability of micronutrients to plants and their transformations in soil along with microbial community composition in surface and subsurface soils which are discussed under the following heads.

Distribution of available micronutrients in surface and subsurface soils under different cropping systems

Impact of cropping systems on available micronutrients in surface soils

Cropping systems, including crop diversification, crop rotation, intercropping, and related agronomic practices used in agriculture show remarkable impact on the soil health and its quality from various spatial and temporal aspects (Vukicevich et al. 2016). Cropping systems were initially designed to maximize yield from agro-ecosystems, but modern agriculture has become increasingly concerned about the environmental sustainability of cropping systems (Fargione et al. 2018). The goal of soil health maintenance is to ensure long-term stable high productivity and environmental sustainability of cropping systems under five essential function evaluation standards, namely nutrient cycling, water relations, biodiversity and habitat, filtering, and buffering, along with physical stability and support (Hatfield et al. 2017). Bhaskar et al. (2017) reported pedogenic (profile) distribution of DTPA—extractable micronutrients in ten rice growing hydric soils of India. Trends of Cu, Zn, Fe and Mn availability fluctuate both in crop and soil with different fertilization practices and cropping systems as the inter-relation of micro- and macronutrients of soil affects the accumulation and availability of micronutrients in crops. Depletion of macro- and micronutrients is usually common under exhaustive rice–wheat cropping system. The levels of Zn, Cu, Fe and Mn were found to increase when leguminous crops were added to the soil under different cropping systems (Patel et al. 2009). Wei et al. (2006) also found that the rotation of legumes in a cropping system was effective in ameliorating the soil micronutrient deficiency. Nair et al. (2017) studied the DTPA extractable cationic micronutrients in two cropping systems and found that the mean nutrient content of available micronutrients was higher in rice based cropping system than chilies based cropping system. Irrespective of cropping systems, DTPA extractable cationic micronutrients were also found positively correlated with organic C (OC) content and negatively correlated with calcium carbonate content.

Additionally, Rekha et al. (2016) studied the availability of micronutrients among different cropping systems in a typical black soil of northern Karnataka. The DTPA extractable micronutrients varied significantly among 3 major cropping systems in the order: sugarcane > maize/groundnut-onion > cereal-pulse systems. Greater availability of micronutrients in sugarcane cropping system as compared to others might be ascribed to the deviations in soil properties as influenced by irrigation practices, high dose fertilizers applications and high biomass turnovers. El-Fouly et al. (2015) studied the effect of long-term intensive cropping under incessant tillage and uneven use of fertilizers on soil nutrient status of soil. A variation of 7.8 to 22.1 mg kg soil^{-1} in case of Fe content was observed among sites in the year 1981 which was about 4.3 to 16.9 mg kg^{-1} at depth of 0 to 30 cm in 2008. Thus, Fe content decreased with continuous cultivation. This decline might be due to the removal of Fe from the native soil reserve by the successive crops. Similar decrease was observed in Mn (from 12.2–44.4 mg kg^{-1} in 1981 to 1.92–7.8 mg kg^{-1} in 2008) and Cu (from 2.73–6.34 mg kg^{-1} in 1981 to 0.3–2.0 mg kg^{-1} in 2008) contents also.

Zhang et al. (2015) studied the dispersal of micronutrients under four nutrient-management systems viz. no fertilizer or manure (control), combined applications of inorganic NPK fertilizers, wheat/maize straw plus NPK (SNPK), and dairy manure plus NPK (MNPK). It was found that DTPA extractable Zn and Fe contents were affected more intensely by fertilization than contents of DTPA-extractable Cu and Mn. The MNPK treatment has evidenced the improvement in DTPA extractable Fe status with preservation of sufficient Fe levels through all the soil profiles. However, in comparison to NPK and SNPK, MNPK treatment preserved only the adequate concentrations of DTPA extractable Mn and Zn in the top layer of soil. Similarly, Singh (2010) reported that there was a considerable improvement in the status of available Fe in puddled as compared to un-puddled soil after the harvest of rice. Among the water management treatments, continuous submergence and irrigation, one day after drainage were equally effective in maintaining available Fe status in soil, but were less effective than irrigation after 3 days of drainage. Available Mn was depleted due to continuous submergence particularly under un-puddled conditions.

Nyoki and Ndakidemi (2018) carried out a field experiment in order to study the effect of intercropping systems, fertilization with P and K and *Rhizobium* inoculation on chemical properties of soybean rhizosphere areas in soil. A significant increase in Fe (10.6%), Cu (31.4%), Mn (41.7%), and Zn (25%) contents was observed in *Rhizobium* inoculated soybean as compared to un-inoculated soybean. Influence of nutrient management on soil properties and micronutrient availability in six-year pearl millet-wheat cropping system was assessed where the results revealed that the higher content of available Zn and Fe i.e. 1.54 and 5.68 mg kg^{-1} respectively were sustained under FYM + NPK treatments. Whereas, the greater content of Mn and Cu i.e. 6.16 and 1.07 mg kg^{-1} respectively were found in plots treated with only FYM, which was prominent in upper soil layer than sub-surface soils (Moharana et al. 2016). The study depicted the crucial role of FYM application to improve soil properties along with available micronutrient contents in soils for producing crops in a sustainable manner. Yerima et al. (2013) studied the dispersal of micronutrients in vertisols of Ethiopia and concluded that pH of soil and concentration of $CaCO_3$ exert a major influence on the extractable Fe, Mn and Zn. Parameters such as pH, EC, OC along with the mutual interrelationships among these metals are important for the development of predictive models for available indices of micronutrients and can be determined at minimal cost, they could be used for the prediction of the available micronutrients with a fair degree of accuracy at little cost as compared to heavy metals.

Effect of different land use systems in submontaneous tract of Punjab was also studied (Dhaliwal et al. 2009a). Notably, a greater degree of Cu, Zn, Fe and Mn availabilities were reported in forest land use system and cultivated lands in comparison to pastures and undisturbed lands. Greater degrees of Cu, Zn, Fe and Mn availabilities in crop land use system were due to the addition of fertilizers and FYM whereas; higher levels of micronutrients in forest land use system were due to the consistent addition of organic matter in the form of leaf litter. On similar basis, Patel et al. (2007) found that the application of groundnut manures along with FYM (10 t ha^{-1}), $FeSO_4$ and $ZnSO_4$ @ 25 kg was the most suitable combination in alkaline soil with low Fe and Zn contents for wheat crop under groundnut-wheat system. Nadeem and Farooq (2019) compiled a review on deficiency of available Zn in soil under RW cropping system. Randhawa et al. (2021) concluded that the organic manures significantly improved DTPA-extractable micronutrient content over uncultivated soil. The levels of Zn, Cu and Fe availability were more under FYM application over poultry manure, press mud and rice straw compost. Agbenin (2003) found an association between Fe distribution and clay dispersal in soils but no association was observed between Mn distribution and dispersal of clay. Verma et al. (2005) reported greater micronutrient status in soils with fine textures especially in case of old flood plains while lesser content was noted in sandy soils, however in both cases, DTPA extractable Zn, Cu and Fe declined with the increase in depth. Dhaliwal et al. (2022) observed greater micronutrients availability in surface layer (0–10 cm) that reduced with depth, which might be due to changes in OC levels in different layers. Sangwan and Singh (1993) found negative correlations in Mn and Fe status in soils with soil pH and $CaCO_3$ content while clay contents and CEC were recognized as effective influencers regarding Cu availability.

Perennial and annual cropping systems were evaluated for available nutrient concentration by Ayele et al. (2014). It was found that the nutrient concentrations in most of the soils under perennial cropping system were higher than annual cropping system in irrigated agriculture and less than rainfed agriculture systems. Patel et al. (2009) stated that leguminous crops like cowpea inclusion in pearl millet-mustard cropping system improved micronutrients levels in the soil as a result of increased SOM. Similarly, Li et al. (2007) reported that the levels of DTPA extractable micronutrients were not significantly different after 16 years of maize-wheat cropping system, though the Zn in soil was slightly higher in the treatments as compared to control. Walia et al. (2008) reported that green manure treatment increased Zn content, organic manure increased Cu content and FYM resulted in maximum DTPA extractable Fe content in soil. Kumar and Yadav (2005) found a decrease in DTPA-extractable Zn, Mn and Cu contents whereas rise in available Fe was noted over the 23 years under various cropping systems where the plot received P fertilizer. Maqueda et al. (2014) reported a higher availability of studied micronutrients after composted olive + mill wastewater sludge treatment (A) than with a concentrated and de-potassified sugar beetvinasse (V) which was due to the higher amount of organic matter (OM) supplied with A than with V to attain the same amount of total N. The dispersal of micronutrients in the soils of Tehran due to different types of lands has been studied (Mahmoudabadi et al. 2015) where the maximum concentrations of Mn and Cu were observed in the rangeland, while Zn content was higher in broadleaf and needle leaf forests. Bradl (2004) reported that organic chelate agents had a tremendous effect on Zn bioavailability. Thus, higher concentrations of available Zn could be ascribed to higher amount of organic matter in broadleaf and needle leaf forests. Therefore, land use types determine Zn concentrations around the region by affecting the organic matter value.

The different soil parameters affecting the nutrient availability in soils are shown in Fig. 1. Various studies have reported that the organically managed soils showed greater OC levels and microbial activity as compared to soils fertilized with mineral fertilizers (Su et al. 2021). The NPK application in recommended dose coupled with FYM/poultry manure/press mud has evidenced the significant improvement in micronutrients status (Randhawa et al. 2021). Similarly, Singh et al. (2014) observed the influence of climate and soil texture on the distribution of micronutrients under continuous rice–wheat system in four agro-climatic zones i.e. undulating sub-region (Zone 1), piedmont alluvial plains (Zone 2), central alluvial plains (Zone 3) and south-western alluvial plains (Zone 4). It was observed that the Zn contents in zone 1, 2 and 3 were significantly higher than zone 4 exhibiting lower level of OC. Cu level was observed to be maximum in zone 1 followed by zone 3, 2 and 4. They perceived that available Cu content improved with the escalation of clay and OC levels, specifically in soils that were primarily low in OC. Significantly higher amounts of Mn and Fe were found in zone 1 compared to others. Also, higher Fe, Zn, Mn, and Cu contents were detected in silty clay loam in comparison to other coarse textured soils. It was

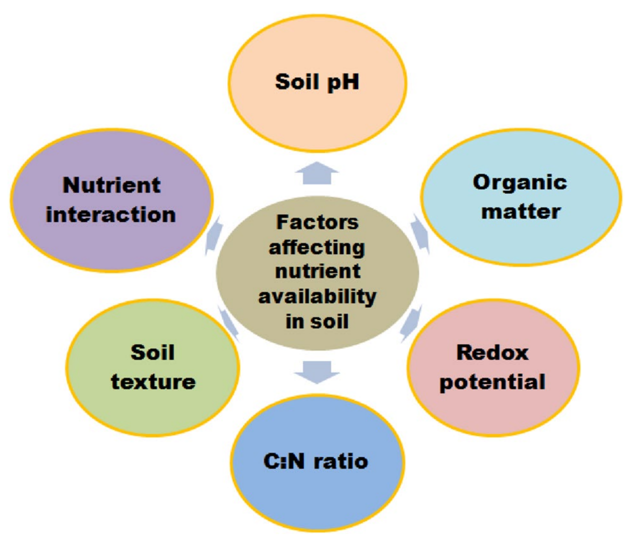


Fig. 1 Factors affecting nutrient availability in soil

concluded that the availability of micronutrients improved with the escalation in SOC and clay content.

Dhaliwal et al. (2011) carried out a field experiment to study the long term effect of different cropping systems on physico-chemical properties of soil and distribution of DTPA and total Cu, Zn, Fe and Mn after 8 years of continuous cropping. They observed highest content of DTPA-Zn (5.86 mg kg^{-1}), Fe (13.96 mg kg^{-1}) and Mn (5.08 mg kg^{-1}) in R-W system followed by maize-wheat, maize-wheat-summer mungbean, maize-potato-summer mungbean and maize-potato-onion cropping systems. They observed that sarson based cropping systems viz. cotton-African sarson, cotton-gobhi sarson transplanted and summer groundnut-toria + gobhi sarson reported the highest content of DTPA-Zn, Fe and Mn followed by groundnut-potato-pearl millet system. It was also observed that sarson and groundnut-based cropping systems reported the greater content of total Cu, Zn, Fe and Mn indicating that the total fractions of micronutrients can be transferred to their corresponding readily available forms. It was concluded that the inclusion of cotton, gobhi sarson, African sarson, toria and groundnut in the cropping systems could help in the mobilization of DTPA Zn, Cu, Fe and Mn and build their concentrations in the soil to sustain the agricultural systems (Table 1). Dhaliwal et al. (2010) reported the introduction of organic nutrition in maize, potato and onion improved the micronutrient status of soil. Thus, this section summarized the effect of different soil parameters such as soil texture, pH, organic carbon along with various cropping systems on the nutrient availability in soil. Crop diversification nowadays is considered as a shift from traditionally grown less remunerative crops to more remunerative crops. This acts as a powerful tool in minimizing the risks in farming. Among different cropping systems discussed, pulse-based cropping systems are environmentally sustainable as it requires lower amount of fertilizers, pesticides and irrigation due to their mutualism which enhances the overall productivity by increasing the yield of subsequent crops. So, there is a need to choose such cropping systems which would help in improving the fertility status and nutrient levels in soil.

Table 1 Distribution of DTPA-extractable micronutrients in different cropping systems (Dhaliwal et al. 2011)

Cropping systems	DTPA extractable nutrients (mg kg^{-1})			
	Zn	Cu	Mn	Fe
Rice–wheat	6.86	0.36	13.96	7.08
Maize-wheat	4.65	0.38	9.62	4.62
Maize-wheat-mungbean	5.38	0.34	11.36	5.42
Maize-potato-mungbean	5.42	0.47	11.56	5.60
Maize-potato-onion	4.02	0.43	5.64	4.62
Cotton-wheat	4.20	0.46	6.78	4.34
Cotton-African sarson	5.98	0.40	7.74	5.98
Cotton-gobhi sarson	5.76	0.48	7.40	5.76
Groundnut-toria + gobhi sarson	3.98	0.35	5.24	4.46
Groundnut-potato-bajra	4.35	0.36	5.18	4.50
Average	5.06	0.40	8.45	5.24
CD (0.5)	0.19	0.07	0.12	0.08

Impact of cropping systems on available micronutrients in subsurface soils

The downward movement of micronutrients in soils, as well as the intrinsic capacity of soil to supply the micronutrients to plants, could be found from the information regarding the upright dispersal of micronutrients in soil. In many cases, roots of several plants go deep down profile and meet their partial requirements for micronutrients from the sub-surface soils though a greater degree of available micronutrients is observed in the surface layer of soil than sub-surface layer (Wei et al. 2006). Most soils are inherently heterogeneous, and consequently, nutrient availability is variable both in time and space (Giehl and Wirén 2014). The constant interaction of processes, such as weathering, atmospheric deposition, nutrient leaching, and biological cycling, results in the formation of vertical and horizontal nutrient gradients within the soil. Many processes are involved in the formation of vertical gradients in soils, such as nutrient uptake, nutrient leaching, biological cycling, and movement of water. An increased nutrient uptake from the superficial soil strata decreases nutrient concentrations in this soil layer. In addition, concentrations of mobile nutrients may decrease as they move downward and become prone to leaching. Biological nutrient cycling acts in an opposite way to leaching, because it recovers nutrients from deeper soil profiles and brings them back to the surface in the form of litter deposits. In addition, the increased topsoil deposition of OM increases the availability of P and organic nitrogen (org. N) in this soil layer. Some nutrients, such as calcium (Ca) and magnesium (Mg), do not generally show strong vertical gradients in most soils.

Pedogenic influence on profile distribution of DTPA—extractable micronutrients in ten rice growing hydric soils of India were studied by Bhaskar et al. (2017). They reported that the DTPA-extractable Fe varied from 4 to 2500 mg kg^{-1} with a mean of 182.64 ± 423.01 mg kg^{-1}. The vertical distribution of DTPA-extractable Fe was irregular in terms of its amelioration in A_p horizons (mean of 530.8 ± 839.2 mg kg^{-1}) subsequently C horizons and B horizons with mean values of 141 ± 217.7 and 64.7 ± 109.5 mg kg^{-1}, respectively. Available Mn varied from 0.7 mg kg^{-1} in the C_z horizon to 30.8 mg kg^{-1} in A_p horizons with a mean of 8.86 ± 8.1 mg kg^{-1} and constituting 16.6% of total Mn. The DTPA extractable Cu varied from

0.04 mg kg^{-1} to 11.5 mg kg^{-1} in the B_w horizon with a mean of 2.67 ± 2.55 mg kg^{-1}. The DTPA extractable Zn constituted less than 0.5% of total Zn which decreased with depth except in one profile where irregular trends were observed. The DTPA extractable Zn showed enrichment in surface horizons (mean of A_p horizon = 0.57 ± 0.27 mg kg^{-1}) but subsequent decrease in AC horizon (0.38 ± 0.13 mg kg^{-1}), B_w horizon (0.24 ± 0.15 mg kg^{-1}) and C horizons (mean = 0.21 ± 0.19 mg kg^{-1}) was observed.

The distribution profile of DTPA extractable micronutrients viz. Fe, Zn, Mn and Cu in eighteen profiles of citrus orchard in Manipur has been examined (Athokpam et al. 2016). They found that the DTPA extractable Fe, Zn, Mn and Cu contents were higher in surface layers of soil and decreased with depth in maximum number of profiles. They further stated that Mn distribution was positively influenced with EC in the first and second layer i.e. 0–20 and 20–40 cm, Cu distribution was affected inversely by OC and positively by EC, Zn was affected positively with cation exchange capacity (CEC) and Fe was impacted by clay content of the soils. Khalil (2014) studied the depth-wise distribution of soils of Egypt. It was reported that Fe had an irregular distribution pattern with depth. The lowest value was recorded in the deepest layer which possessed fine texture, whereas the highest value was detected in the light textured surface layer. Similarly, the lowest value of Zn was found in the deepest layer representing the sandy soil exhibiting coarse texture, while the highest value was detected in the subsurface layer representing the soil which exhibited clayey texture. Depth-wise distribution of Zn content was also noted where the values of available Zn decreased with increased depth. The lowest values of Mn in soil profiles were associated with both high pH (8.4 and 9.4) and calcium carbonate percent (9 and 9.2%), respectively. The lowest values of Cu were mostly found in the surface layers of soil samples which had coarse texture for both Entisols and Aridisols, whereas the highest values were detected in coarse and fine textured classes of soil families of Aridisols and Entisols, respectively.

A greater degree of micronutrients mobilization in deeper layers in case of deep rooted systems resulted in enhancement of micronutrient content in the sub-surface layer of soil (Pierret et al. 2016). Jiang et al. (2009) carried out an experiment on the profile deviation and DTPA extractable Fe, Mn, Cu and Zn storage at 0–150 cm depth of an aquic brown soil. It was revealed that the effect of land use, their interactions on micronutrients and soil depth were significantly different. Micronutrients levels were found to be lessened with soil depth. Micronutrients were positively related to SOC, but showed negative relation with soil pH. Plant cycling and soil pH might be recognized as crucial controlling factors for improving soil micronutrient status in fallow land and woodlands but in case of rice fields, poorer OC content and greater soil pH might have prevented the availability of micronutrients to a notable extent. This report indicated that the dispersal of micronutrients throughout the soil profile was largely controlled by anthropogenic disturbance, biological cycling, leaching and land uses. Similarly, Sankar and Dadhwal (2009) stated that the dispersal pattern of micronutrients is governed by various factors like particle size fractions organic matter, $CaCO_3$, pH, cation exchange capacity, EC, exchangeable cations, etc. They observed that Fe content increased with deepness in one pedon whereas in other pedons asymmetrical trend with increasing depth was noted. Similarly, Zn, Mn and Cu also showed irregular patterns with increasing depth in all the pedons. Kumar et al. (2017) also stated higher contents of DTPA extractable Zn and Fe on the upper layers as compared to subsurface layers which were related to higher content of OC in soils as a result of regular addition of plant residues. Meena et al. (2012) studied the distribution of available micronutrients with respect to soil characteristic in southern Rajasthan. They stated that the available Zn, Fe, Mn and Cu contents were higher in surface soil and declined with depth in most of the pedons. Similarly, Chander et al. (2012) reported that amongst mechanical separates, finer the soil fractions higher the availability of Cu and Mn that decreased with coarse soils and reverse relation was observed in DTPA extractable Zn from upper surface (0 to 0.15 m) soil samples collected from vegetable growing fields in mid-hills, sub-humid and high hills wet temperate, sub-agroclimatic zones of Himachal Pradesh. Panwar et al. (2010) conducted a study to assess micronutrient status in a soil profile managed with organic (OMP), chemical (CMP), and integrated (IMP) management practices for 3 years under a soybean-durum wheat cropping sequence. It was reported that micronutrient content declined with depth as there is a significant positive correlation between organic matter and micronutrient cation availability. Consequently, a greater level of available micronutrients would be expected where the organic-matter content was greater (topsoil). A decline in SOC content with depth causes less complexation of micronutrients and thus maintains a lower amount of exchangeable forms of micronutrients. Similarly, Yerima et al. (2013) also reported that the distribution of the extractable micronutrients decreased in concentration with depth except for Fe and Cu, which did not show a definite trend. It was concluded that the decrease in micronutrient content with depth was associated with decrease in OC content whereas the increase in pH resulted in reduced metal solubility. Thus, this section summarized the effect of cropping system on the micronutrient status in soil depth where the different factors governing the micronutrient content in soil included organic matter, $CaCO_3$, pH, cation exchange capacity, EC, exchangeable cations, etc.

Transformations of micronutrients in the surface and subsurface soils under different cropping systems

Impact of cropping systems in transformations of micronutrients in the surface soils

Knowledge of different micronutrient fractions in soil and the condition under which they convert to available forms help in understanding their availability to plants. It is also essential to understand the association amongst micronutrient fractions in soils and their accumulation by crops. This requires the estimations of micronutrients supply into the soil and their distribution amongst the distinguished fractions under various cropping systems. Liu et al. (2018) has studied the transport mechanism of nutrient elements in biochar-soil–plant system. Figure 2 clearly shows the migration of nutrient elements during biochar pyrolysis and the transport mechanisms of nutrient elements into the plant. In the process of preparing biochar, nutrient element movement in the straw is very obvious under suitable preparation conditions (such as 400 °C under a CO_2 atmosphere): ① 20.77% of N in crop straw (CS-N) is released as biogas, in which P and K do not appear; ② 14.29% of the N migrates from the straw to the pyrolysis liquid (bio-oil), which contains neither K nor P; ③ biochar retains 64.94% of N in the straw while retaining 100% P and 88% K. Therefore, biochar prepared under these conditions is rich in nutrients.

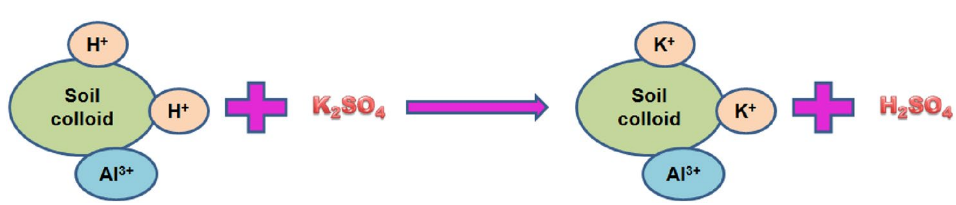
Also, micronutrients are reported to exist in connotation with soil solution and solid phases viz. organic and inorganic soil phases under continuous cropping system and this connotation is also known as speciation (Behera et al. 2009b). Information regarding the changes in micronutrient fractions in soils where the same cropping system is being practiced with different fertilizer rates can assist in planning better strategies for their management. Micronutrients exist in different fractions under soil environment and they transform from one fraction to other under various cropping systems (Dhaliwal et al 2019). Organic amendments like green manures, press mud and FYM increase.

Fe and Mn concentrations in fractions that are considered as plant available forms of micronutrients viz. water soluble, exchangeable and organically bounded fractions. Also, the flooding method in rice results in a reduced environment in soil which assists the conversion methods of crystalline oxides of Fe and Mn to amorphous or easily reducible Fe and Mn. The alternate flooding in rice and upland conditions in wheat affects the change of Zn, Mn, Fe and Cu from one fraction to another (Manchanda et al. 2003).

Similarly, Ramzan and Bhat (2017) studied the chronological extraction of micronutrients in soils collected from the five agricultural land uses (cereals, apple orchards, vegetables, saffron, pastures and forests) of temperate Himalayas and found the residual fraction as the main binding sites for Zn, Cu and Fe which indicates the association of a large proportion of metals with silicate minerals in the form of a matrix. In the five land use soils studied, the distribution, availability and mobility of different metals varied depending upon various soil properties and agricultural practices. The mean potential mobility of Fe, Zn and Mn estimated under all land uses was highest in forest and pasture soils whereas Cu mobility was found highest in cereal soils. Joshi et al. (2015) studied the chemical speciation and appropriateness of soil extractants for evaluating Cu availability to maize (*Zea mays* L.) in acidic soils and found that in acid soils, residual Cu was the most dominant fraction followed by Mn oxide; amorphous Fe-oxide bound; organically bound; crystalline Fe-oxide bound; acid soluble; exchangeable; Pb displaceable- and water soluble-Cu fractions. From plant availability point of view, water soluble and organically bound Cu fractions were very significant in the acidic soils. Preetha and Stalin (2014) conducted a study on the spread of diverse forms of soil Zn and response of maize to inherent soil Zn content. A greater release of water soluble plus exchangeable Zn, organically bound Zn and crystal bound Zn were observed at 15 days after incubation which slowly declined at the end of the experiment up to 30 days after incubation whereas other forms such as manganese oxide bound zinc, amorphous sesquioxide bound zinc, residual zinc and total Zn showed a prolonged release up to 30 days after incubation. More than 95% of the total Zn content occurred in the relatively inactive and mineral-bound residual form, whereas only a small fraction occurred in water soluble form and other fractions.

Al Jaloud et al. (2013) investigated the fractioning of micronutrients and revealed that the order of the metals content in the CO_3 bounded fraction was Mn > Fe > Cu > Zn; the

Fig. 2 Transport mechanism of nutrient elements (N, P, K) in biochar-soil–plant system



oxide- bound fraction followed the order Fe > Mn > Zn > Cu; the organic bound fraction led to the sequence Fe > Mn > Cu > Zn; and the sequence for residual fraction was Fe > Mn > Zn > Cu. The fractionation study displayed that the residual content of fractions was in this order: oxide bound > CO_3 bound > organic bound > exchangeable. Similarly, Aikpokpodion et al. (2012) also reported that the organic fraction was the most abundant pool for Cu and Zn. Rostami and Ahangar (2013) conducted a study to observe the influence of cow manure on availability and distribution of different fractions of Zn, Fe and Mn in soil. The study revealed strong sorption of Zn, Fe and Mn onto inorganic soil colloids (as Fe and Al oxides) and significant reduction in carbonates and residual fractions of Zn, Fe and Mn during cow manure application.

An experiment was conducted by Isoda and Shinohara (2013) in order to examine the change in chemical forms of Cu, Fe, and Zn in compost produced from horse dung and that produced from swine manure. It was found that Cu and Fe were mainly found in an organic complex fraction and residual fraction of horse dung and swine manure. Zinc was primarily found in an iron and manganese oxide fraction and an organic-complex fraction. They reported that the quantity of Cu and Fe in the organic complex fraction declined significantly and that of Zn in the iron and manganese oxide and organic complex fractions also decreased significantly. Hellel (2007) reported an increment in water soluble + exchangeable (WSEX) and acid soluble Fe in soil in case of application of composts which might be due to augmented availability of Fe in calcareous soils because of greater acidulation effects of compost. Chemical fractionation of Cu, Fe, Mn, and Zn in 28 surface soil samples (0–20 cm) selected from paddy soils of Iran were studied by Jalali and Hemati (2013). They observed that Fe, Mn, and Zn existed in paddy soils mainly in Fe–Mn oxides (53.6, 65.2, 53.3% respectively), whereas Cu occurred essentially as residual mineral phase (41.4%). They also found that silt and clay were more important in regulating total concentrations of Cu, Mn, and Zn in these paddy soils. These findings suggested that Fe, and Cu, were held in a more stable fraction in which the movement of these metals in the soil profile would be negligible.

Singh et al. (2012) reported significantly greater soil Cu and Zn contents under cotton-wheat system than other cropping systems. The least level of water soluble + exchangeable (WSEX) Zn was noted in RW system in comparison to maize-wheat and cotton-wheat systems. Significantly greater levels of Zn and Cu in water soluble + exchangeable, specifically adsorbed (SpAd), Mn-Oxide bound fraction (MnOX), Amorphous Fe-oxide bound (AFeOX) and OM fractions were reported under maize-potato-mungbean cropping system. Among cotton-based systems, significantly higher concentrations of Cu in water soluble + exchangeable, specifically adsorbed, Mn-Oxide bound fraction, amorphous Fe-oxides bound and OM fractions were observed under cotton-gobhi/sarson cropping system. Copper in water soluble + exchangeable, specifically adsorbed, Mn-Oxide bound fraction and OM fractions were found significantly more under groundnut-potato-bajra (fodder) system. On the other hand, Sekhon et al. (2006) found that RW cropping for 7 years without any fertilizer did not alter the original micronutrient levels in their different fractions of soil whereas use of FYM increased the levels of micronutrients as well as their conversion from non-available forms to readily available and potentially available forms in soil.

Behera et al. (2009b) assessed the change in levels of Cu, Fe and Mn in various fractions in soil under continuous maize-wheat cropping system for more than 30 years and found fluctuations in levels of total and various other forms of Fe in top soil over years but fluctuation did not follow a particular trend. The level of sorbed fraction and water-soluble fraction of Mn ranged from 1.79–4.48 to 0.19–1.06 mg kg^{-1} respectively over years. The major portion of Cu was in residual form while the presence of water-soluble Cu was prominent in surface layers. Sudhir et al. (1997) found an overall reduction in soil Mn and Cu status due to the continuous practice of finger millet-hybrid maize-cowpea system. Zinc level also declined except for FYM treatment that showed a significant increase in Zn levels. FYM treatment also showed a positive impact on Cu and Fe content but was not effective enough to maintain the initial levels of Cu.

Singh et al. (2012) investigated the chemical fractions of Zn and Cu under different cropping systems in alluvial soils of India and found that among chemical fractions, higher levels of Zn and Cu were observed in case of maize-potato-mungbean and cotton-gobhi sarson systems respectively. They also reported that among different fractions, especially adsorption held on organic sites, oxide bound and amorphous fractions of Zn and Cu contributed towards plant available (water soluble and exchangeable) fractions. Dhaliwal et al. (2012) investigated the long-term effect of chemical fertilizers (NPK) alone and in combination with manures on different fractions of Fe and Mn and their interactions with each other. The results revealed that the FYM, green manure and wheat cut straw applied before transplantation of rice increased the concentrations of water soluble + exchangeable, amorphous iron oxide, crystalline iron oxide and organic matter bound fractions of Fe and Mn. Whereas, their fractions specially adsorbed on inorganic sites and manganese surfaces decreased with the inclusion of FYM, green manure and wheat cut straw. The results further suggested that after 27 years of RW cropping system, the application of FYM, green manure and wheat cut straw resulted in considerably greater content of the water soluble plus exchangeable Fe and Mn in the soil with green manure followed by FYM and wheat cut straw which may be attributed to the greater supply of Fe and Mn through the disintegration of organic manures. Dhaliwal et al. (2013) studied the transformations of Fe and Zn under 10 different types of manures application and found significant augmentation in total as well as available Zn and Fe in soils in case of FYM, green manure, poultry manure and biogas slurry application prior to transplantation of rice. This might be attributed to the greater release of micronutrients as a result of the decomposition of added organic manures. Thus, this section summarized the effect of different types of inorganic fertilizers and organic manures in transforming various micronutrients into their readily available forms so that they could be easily taken up by the crop. It is essential to analyze the impact of manures and their use in increasing the micronutrient level in soil which could be transferred to the crop for enhancing its nutritional value.

Impact of cropping systems in transformations of micronutrients in the subsurface soils

Understanding the distribution of micronutrients in various fractions facilitates in acquiring knowledge regarding retention of micronutrients in soil system as well as their release and availability to plants. Alteration in soil properties acts as a crucial factor that controls the distribution of micronutrients in different chemical pools. Knowledge of micronutrient distribution in soil profile notably helps in the assessment of micronutrient supplying ability of soil as well as contributing soil layers towards crop nutrition during the growth period. It depends largely on management practices, cropping systems, soil-forming processes and to a notable extent on the composition of the parent materials.

The fractionation and dispersal of Zn under an integrated nutrient management system on LTFE's (Long Term Fertilizer Experiments) maize-wheat cropping system was studied (Priyanka and Meena 2017). The Zn fractions declined with depth in all integrated nutrient management (INM) treatments. Water soluble Zn content of the soil after harvest of maize-wheat crop varied from 0.16 to 0.42 mg kg^{-1}at 0–15 cm and 0.14 to 0.40 mg kg^{-1} at 15–30 cm depth. DTPA soluble Zn content of the soil at 0–15 cm and 15–30 cm depth after harvest of wheat crop varied from 2.02 to 3.71 mg kg^{-1} and 1.95 to 3.64 mg kg^{-1}, respectively. The highest values of the reducible form of Zn (6.74 mg kg^{-1} and 6.53 mg kg^{-1}) at 0–15 cm and 15–30 cm depth were recorded. This form of Zn also decreased with depth irrespective of different INM treatments applied. The residual Zn which contributed the major fraction in soil and apparently associated with soil minerals, showed a higher pooled value in 0–15 cm than in 15–30 cm depth i.e. 263.60 and 261.93 mg kg^{-1}, respectively. Thus, this section summarized the studies showing the variation of readily available forms of micronutrients in deep soil layers.

Impact of cropping systems on micronutrients accumulation in plants

Several researchers around the world have studied the influence of various degrees of nitrogen (N), phosphorus (P) and potassium (K) on soil micronutrient availability and their accumulation in various crops (Sharma and Dhaliwal 2020; Randhawa et al. 2022). Behavioral variations of Cu, Zn, Fe, and Mn in case of different soils and crops also vary with changes in fertilizer applications and cropping systems. The interrelation of micro- and macro-nutrients of soil also influenced availability of micronutrients and their accumulation in crops. N, P and K fertilization could enhance the available Cu, Zn, Fe, and Mn in soil as well as their concentration in various crops (Randhawa et al. 2022). Glowacka (2013) assessed the influence of cropping methods and weed control methods on Cu, Zn, Fe and Mn contents in maize and two cropping methods were studied i.e. sole cropping and strip cropping along with two weed control methods viz. mechanical and chemical. Strip cropping decreased the Mn level in maize and did not affect Zn content significantly, whereas it resulted in increased accumulation of Cu and Fe. Xue et al. (2014) observed that maize shoots contained more Mn, Fe and Cu at maturity with escalations in yield and biomass production but the pre-silking proportions of shoot Cu and Fe decreased significantly. These results showed that with higher yield, more Fe and Cu would be needed, not only during the vegetative stage, but also during reproductive stages for maximum yields.

Additionally, Shahid et al. (2015) studied the accumulation of micronutrients under different management treatments and observed the highest accumulation of Fe under NP + FYM application which was significantly higher than

Table 2 Micronutrient accumulation (g ha^{-1}) of rice in the year 2010–2011 under different fertilization (Shahid et al. 2015)

Treatments	Fe	Zn	Mn	Cu
Control	765	198	1082	18.3
N	929	303	1555	26.8
NP	1125	281	1764	25.8
NK	985	314	1601	25.7
NPK	1058	283	1620	30.9
FYM	1038	288	1316	28.5
N + FYM	1174	296	1746	33.8
NP + FYM	1200	290	1822	32.5
NK + FYM	1111	330	1695	30.3
NPK + FYM	1109	304	1782	34.7
LSD ($p < 0.05$)	208	38	171	2.7

Fe accumulation in the control, N and NK treatments but was statistically similar to NPK + FYM, NK + FYM, N + FYM, FYM, NPK and NP treatments (Table 2). Enhanced accumulation of Mn as a result of application of super phosphate with FYM might be due to the addition of Mn by their use. By examining the influences of management practices and weeding under maize cultivation, Glowacka (2014) found around 26% and 62% greater accumulation of Zn, 5.4% and 27% higher Fe accumulation and 61% and 46% higher Mn accumulations in the aboveground portions of crops grown under the strip cropping over sole cropping, in case of mechanical and chemical weeding, respectively. Kumari et al. (2017) stated that the crop residue inclusion and application of Zn improved its accumulation by 60 and 57%, respectively while incorporation of crop residues increased Fe accumulation in rice and wheat by 19 and 39%, respectively after 18-year rice–wheat rotation.

A study conducted by Massawe et al. (2017) suggested that the use of the Rhizobium inoculants in common bean or lablab intercropped with maize increased micronutrients concentration and their accumulation in shoot, root and whole plant. Lablab had a more positive effect on interspecific competition through micronutrients accumulation and partitioning than common bean with the intercropped maize. This confirmed the advantage of intercropping maize-common bean or lablab over sole cropping system on micronutrients accumulation. The provision of rhizobium inoculants to *P. vulgaris* and *L. purpureus* appeared to promote greater nutrient accumulation (Cu, Zn, Fe and Mn) in the whole plant and accumulation in their plant tissues. Taghizadeh et al. (2014) reported that the concentration of micronutrients (Cu, Fe, Zn and Mn) in both the crop and weeds increased under conservation tillage systems compared to the conventional tillage. On the other hand, excess tillage can have an undesirable effect on soils and soil organisms. Of course tillage is an important tool for fertility management. Perennial sods are mechanically killed, cover crops are plowed in, and manures are incorporated. The Fig. 3 shows how tillage has been argued to alter the soil food web. The increased soil stratification and size along with activity of soil organism populations under conservation tillage compared to conventional tillage lead to increased nutrient retention. Heavy reliance on tillage inorganic farming systems can only be maintained without harm in systems that include adequate plant cover and where tillage is timed to avoid compaction and erosion. Soil texture, slope, and climate all influence the degree to which tillage can or can-not be safely tolerated. This is why organic strategies for fertility management focus as much or more on crop rotation and tillage practices than they do on nutrient dense soil amendments. Nitrogen had a significant and positive effect on micronutrient accumulation by the crop and weeds under all tillage systems. The results of this study suggested that conservation tillage systems (minimum and no tillage) facilitate micronutrient accumulation for both the crop and weeds. A field study was conducted at Palampur by Rana et al. (2017) with different levels of N, Zn and boron (B) where the increase in

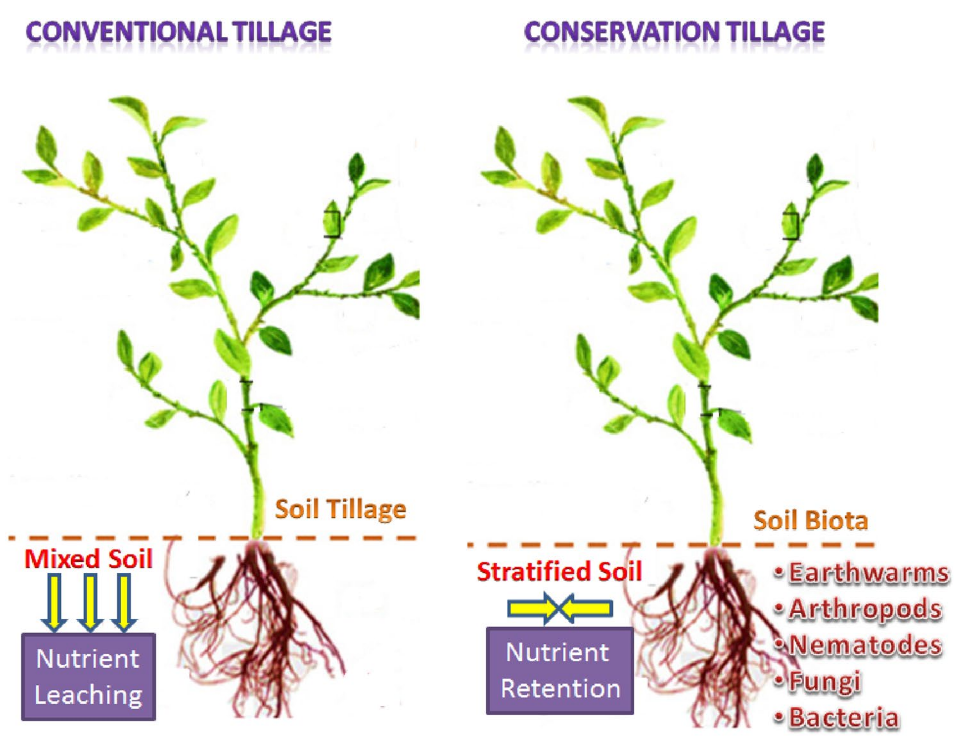


Fig. 3 Difference between conventional and conservation tillage system

concentrations of N, P, K, Mn, Fe, Cu, Zn and B in plants at maximum tillering of wheat was observed. Zn and Fe concentration increased upto 50% recommended dose of nitrogen while application of Zn resulted in increased N, K, Zn and B concentrations and decreased Fe, Mn and Cu concentrations, whereas B application significantly increased N, P, K, Zn and B concentrations at maximum tillering of wheat.

The Cu, Zn, Fe and Mn contents varied differently under various cropping systems and the concentrations were low under rice–wheat-cowpea (Singh and Ram 2007) than maize-wheat system (Behera and Singh 2009a). This could be due to the reason that maize straw contains greater levels of micronutrients than wheat straw (Li et al. 2007) and their residues also increase the soil micronutrient levels. Walia et al. (2008) noted that the maximum accumulation of micronutrients by rice under RW cropping system was observed at 75% recommended N + 25% N through green manure. Mishra et al. (2009) observed less accumulation of Zn in crops under continuous cultivation with or without fertilizer applications over crops grown under Zn treatments. Improved Zn accumulation in grain and straw of wheat crops as a result of inclusion of FYM in applied treatments might be accredited to higher levels of organically bound Zn in soil. Kulandaivel et al. (2004) recognized the application of $ZnSO_4$ (30 kg ha^{-1}) + 5 kg $FeSO_4$ (5 kg ha^{-1}) chelating with FYM as the best combination to increase the micronutrients accumulation by rice in RW cropping system under sandy clay loam soil having low levels of Fe and Zn.

Similarly, Dhaliwal et al. (2014) observed that the accumulation of Zn, Cu, Fe and Mn (123.1, 23.6, 189.4 and 112.1 g ha^{-1}, respectively) in wheat grains and (158.4, 17.3, 184.2 and 306.1 g ha^{-1}, respectively) in rice grains were found higher where organic manure was added along with chemical fertilizers and biogas slurry. Kharia et al. (2017) conducted a field experiment to study the impact of the conservation practices in RW cropping system on the accumulation of micronutrients. They observe significantly higher micronutrients (Zn, Fe, Mn and Cu) accumulation under ZTW + R (zero tillage wheat with rice straw retained as surface mulch using Happy Seeder) compared with zero tillage and conventional tillage without rice straw. Prasad et al. (2010) observed that incorporation of rice and wheat straw significantly increased the Zn, Fe, Mn and Cu accumulations as compared to straw removal in RW system. The use of organic manures increased the accumulation of micronutrients which may be attributed to an increase in DTPA-extractable micronutrients in soil. This section summarized the various studies including the use of inorganic fertilizers and organic manures in order to check the nutrient level in different crops where the mixed use of organic manures along with fertilizers proved most efficient for increasing the micronutrient content in crops. Additionally, crop rotation and conservation tillage practices further append to the enhanced nutrient concentrations in crop.

Impact of cropping systems on soil microbial community composition

According to several researchers, microbial parameters could be considered as potentially credible indicators for maintaining soil ecological processes (Dhaliwal et al. 2009b; Roberson et al. 1995) as greater microbial activity is usually considered as a positive indicator of soil fertility. Microbial soil respiration indicates biotic activities in soils that include activities of microbes (fungi, bacteria, actinomycetes, protozoa etc.), invertebrates (earth worms, nematode etc.) and even plant roots. Parkin et al. (1996) and Dhaliwal et al. (2008a) used the metabolic quotient (qCO_2) approach to describe the process of soil respiration. Metabolic quotient (qCO_2) is mainly a ratio of total respiration to the total biomass that reduces with time and succession in an ecosystem and is an effective indicator that specifies the influence of environment on microbial activity and population (Dhaliwal et al. 2009c). Lower qCO_2 values indicate a mature and stable soil system (Anderson and Domsch 1985). Similarly, Anderson and Domsch (1990) also noted the sensitivity of qCO_2 towards changes in temperature regimes and cropping systems. Sparling et al. (1992) and Dhaliwal et al. (2008b) conducted an experiment with two land use systems on surface soils (0–10 cm) and profiles (10–20 cm) to study its effect on soil respiration. The pasture system had greater soil respiration (7.16 µl g^{-1} h^{-1}) in comparison to the agricultural systems (4.62 µl g^{-1} h^{-1}). However, when pasture systems were restored for agricultural system, soil respiration decreased during the initial years and then increased. Also, soil respiration decreased with depth in pasture and in cultivated systems.

Microorganisms are key components of soil as soil microbial communities play a crucial role in the nutrient transformation and soil bio-chemical processes that ultimately influences the crop productivity and soil health (Ashworth et al. 2017; Song et al. 2018). Agricultural management practices influence physical, chemical and biological processes in soils that eventually lead to a significant alteration in soil microbial community structure (Zhang et al. 2016). Continuous monoculture reduces the diversity of soil microbes and makes the crops prone to diseases by altering the balanced proportion of beneficial and pathogenic microbes (Mo et al. 2016; Xiong et al. 2016). As soil microbial community could be affected not only by soil physical and chemical properties (Xun et al. 2015; Cai et al. 2017) but also by species and even genotype of host plants (Ofek et al. 2014), cropping systems play pivotal roles in maintaining the balance of soil microbial activities which in turn optimize crop productivity by improving soil health, nutrient availability and reducing detrimental impacts of soil borne pathogens (Gurr et al. 2016; Benitez et al. 2017; Fargione et al. 2018; Barbieri et al. 2019).

Different crops and cropping systems impart marked influence on soil microbial communities (Mayer et al. 2019) and this is of utmost importance for the selection of most effective cropping system for a particular area. Yang et al. (2013) found a rotation of various chickpea cultivars which significantly modifies soil microbial activities and productivity of both the cultivated pulses and following wheat crop. Benitez et al. (2017) observed significant alteration in soil microbial community in case of corn-soybean rotation where the effect was prominent in case of fungi over bacteria. Among different cropping systems, potato-green gram-rice recorded the highest microbial diversity as compared to wheat-rice, lentil-rice, mustard-rice and wheat-green gram-pearl millet. Thus, inclusion of legumes in RW cropping systems significantly increased the microbial activities (Singh et al. 2020). The addition of various types of residues and root exudates produced by different crops in a cropping system enhances the diversity and activities of soil microorganisms that augment soil microbial biomass as well as C and N cycling (Gurr et al. 2016; Li et al. 2019). For example, the addition of high protein-containing biomass from soybeans and other leguminous cover crops enhance microbial activities and proliferation because of greater labile character as compared to the residues of cereals having high C:N ratio (Sarrantonio and Gallandt 2003). Optimized crop rotation in a cropping system could also limit pest infestation in crops by breaking down the life cycle of pathogens by altering the presence of the host (Yang et al. 2020). But according to Bainard et al. (2017), it is not necessary that crop diversity would always be able to check soil-borne disease as they found a rise in pulse-specific pathogens as a result of inclusion of more pulse crops in rotations. Alterations in rotation length and frequency of growing a crop in a rotation over a period also influence soil microbial community (Lupwayi et al. 2018; Yang et al. 2021).

Greater soil microbial biomass was observed in wheat phase of a 5 years rotation as compared to the wheat phase of 3 years rotation due to improvement in soil health as a result of soil C build-up through the addition of crop residue and compost into the soil that improved the productivity (Lupwayi et al. 2018). Hamel et al. (2018), in western Canada observed significant changes in bacterial activities in the rhizosphere in case of three phase legume system in a 4 years rotation as compared to continuous wheat growth. Despite of above-mentioned benefits, crop rotations possess some drawbacks also. Figure 4 depicts the effect of continuous cropping on soil biotic and abiotic properties, while advocating that it may alter soil health followed by its impact on soil physicochemical properties. For example, the inclusion of non-mycorrhizal plants in crop rotation could cut down the population of arbuscular mycorrhizal fungi and mycorrhizal growth in the following crops (Njeru et al. 2014). The establishment of symbiosis with rhizobacteria could not be achieved when some non-mycorrhizal plants, such as canola and mustard are introduced in a rotation (Ellouze et al. 2014). As a result, the application of greater amount of mineral fertilizers to meet the nutrient demand in such cases could alter the physico-chemical properties of soil in the long-term (Ellouze et al. 2014).

Chang et al. (2014) reported that soil organic C, soil total N, soil microbial carbon (SMC) and soil microbial nitrogen (SMN) contents were found to be significantly correlated with respiration rate and soil enzyme activities, except proteinase, urease and alkaline phosphatase. The close relationship between enzymatic activities with soil organic carbon (SOC) content might be due to the promoting effects of SOC on MBC, MBN and enzyme activities. The enzyme activities closely correlated with MBC content revealed that the microbes were the main source of enzyme production in

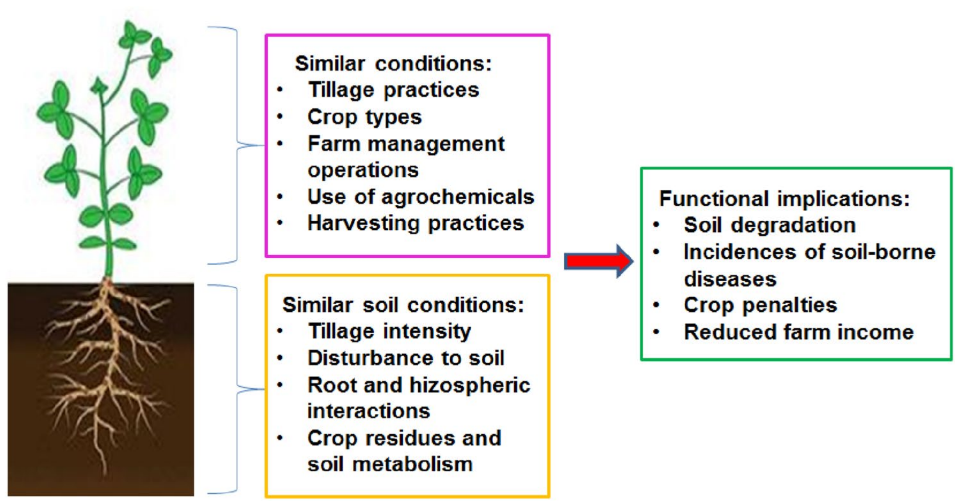


Fig. 4 Predicted hypothetical impact of continuous cropping on soil health

soils. Comparing different agricultural management practices, Hou et al. (2021) recorded maximum soil respiration in case of irrigated treatment as compared to non-irrigated treatment. Moreover, green cover, deep tillage, and shallow tillage practices increased the soil respiration rate by 57%, 36% and 14%, respectively over the no tillage treatment. Yazdanpanah et al. (2016) observed that a consistent supply of nutrients and energy in case of cultivations with organic amendments stimulated the activities of soil microbes. Comparison of different organic amendments revealed greater degrees of soil respiration in plots amended with municipal solid wastes (MSW) over alfalfa residue (AR) treatments in both studied textural classes. However, such values of soil respiration under different organic amendments usually vary based on the rate of application, the composition of amendments and the soil type (Mahmoodabadi and Heydarpour 2014). Thus, this section inferred that organic amendments positively influenced the soil microbial properties. But, there is a growing need to carefully select the cropping systems which would lead to the increased microbial population in soil needed for improved quality of crop.

Conclusions

The incorporation of organic matter into the soil through cropping system played a key role in build-up of soil microbial communities, micronutrients content and transformations in the soil. The distribution of micronutrients has been found to be significantly affected by the presence of organic matter. The content of micronutrients decreased with the increase in soil depth mainly due to the decline in OC levels and clay content. Under different cropping systems, the plant accumulation of Zn, Cu, Fe and Mn positively correlated with the amount of organic matter. Similarly, the inclusions of short duration crops in different cropping systems influenced various processes in soil which enhanced the diversity and activities of different soil microorganisms.

Future perspectives

Inclusion of short duration crops which add more biomass to the soil, must be practised in the main cropping system in order to improve the nutrient status and microbial activity in the soil which ultimately leads to higher accumulation of macro- and micronutrients in the plants. Farm and farmers' friendly technology should be developed for incorporation of crop residues in the soil. Drafting of agricultural policies, preferring maintenance of soil health, should be prepared.

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Declarations

Conflict of interest Certified that the authors have no any conflict of interest.

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