International Journal of Plant & Soil Science

33(7): 53-66, 2021; Article no.IJPSS.67744
ISSN: 2320-7035

Carbon Dynamics in Climate Smart Agriculture Precision Land Leveling Practices on Topsoil Microbial Community Changes and Soil Organic Carbon in Cereal Based Cropping Systems of Sub-Tropical India: A Review

R. K. Naresh[1*], M. Sharath Chandra[1], Aryan Baliyan[2], B. Naveen Kumar[3]
Pradeep Kumar Kanaujiya[4], Shakti Om Pathak[2], Pradeep Kumar Singh[1]
and Navneet Kumar[5]

[1]Department of Agronomy, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh., India.
[2]Department of Soil Science and Agricultural Chemistry; Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh., India.
[3]Department of Soil Science and Agricultural Chemistry, Sri Konda Laxman Telangana State Horticultural University, Hyderabad, India.
[4]Department of Agronomy, Acharya Narendra Deva University of Agriculture and Technology, (Kumarganj) Ayodhya, Uttar Pradesh, India.
[5]Aakanksha College Meerapur, Muzaffarnagar, Uttar Pradesh, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2021/v33i730450
Editor(s):
(1) Dr. Francisco Cruz-Sosa, Metropolitan Autonomous University Iztapalapa Campus, México.
Reviewers:
(1) Przemyslaw Barlog, Poznan University of Life Sciences,Poland.
(2) Saeideh Dorostkar, Shiraz University, Iran.
Complete Peer review History: http://www.sdiarticle4.com/review-history/67744

Review Article

Received 25 February 2021
Accepted 30 April 2021
Published 06 May 2021

ABSTRACT

The role of soil microorganisms in the biogeochemical process and nutrient cycling of soil is critical and is colossally impacted by agronomic management practices. In order to establish climate-smart precision land leveling practices in cereal based cropping systems, comprehension of the land

---

**Corresponding author: E-mail: r.knaresh@yahoo.com;*

bacterial local area and supplement nutrient dynamics under differentiating management practices is of most extreme significance. Climate smart agriculture (CSA) practices are gaining traction in subtropical India as a viable alternative to conventional cereal-based cropping systems for reversing natural resource depletion. Sustainable soil management alternatives that sequester carbon in the soil, reduce greenhouse gas (GHG) emissions and help intensify production, all while enhancing the natural resource base. Aggregate-associated soil organic carbon (SOC) contents in 0-15 cm depth were recorded highest SOC at 15-30 cm depth in Precision Land Leveling (PLL) systems as 9.4% for both M-P-MbP$_{LL}$ and M-W-MbP$_{LL}$. Highest PON change in arable cropping system (30.9 & 40.1%) was found in O-W-Mb with precision land levelling plots followed by R-P-O with precision land levelling plots (26.1 & 35.8%) as compared to R-W and S-W system. The values of LFOC in surface soil were 194.7, 187.9, 176.2, 170.9, 168.5, 150.6, 132.8 and 123.8 mgkg^{-1} in R-P-O, R-C-O, M-W-Mb, O-W-Mb, M-P-Mb, R-P-Mb, R-W and S-W with precision land leveling treatments. Therefore, adopting Climate Smart Agriculture Precision Land leveling practices can dramatically boost system productivity in cereal-based cropping systems by improving SOC and soil biological quality. The overview literature accrued indicate that CSA based totally totally management has a remarkable impact on top soil resilience in phrases of relative abundances of bacterial groups, soil organic carbon & to be had plant nutrients and as a result may additionally play a vital function within the sustainability of the extensive cereal based cropping systems.

Keywords: Soil organic carbon; precision land leveling; carbon; conservation agriculture.

1. INTRODUCTION

Soil plays an essential role in the global carbon (C) cycle acting as both source and sink of organic C [1,2]. Soil contains three times more organic C than both plants and atmosphere. According to the importance of soil as a C sink on a global scale, there's difficulty that climate and land use adjustments will turn it right into a C source [3]. such a supply-sink transfer couldn't most effective be brought approximately through a exchange in the physical and chemical state of soil, however also via modifications in soil biota and their interactions with plants [2,4]. Indeed, soil biota plays a pivotal position in soil C dynamics; mainly when it comes to stabilization of soil organic matter (SOM) and persistence of soil organic C (SOC). Climate-Smart Agriculture (CSA) is an technique that sustainably increases crop productivity, system resilience (adaptation), reduces the GHGs emission, and enhances achievement of national food security and development goals [5]. CSA based management practices are emerging as an alternative to reverse the process of natural resource degradation and to maintain the systems sustainability [6]. CSA is based on the concept of conservation agriculture (CA) which involves zero-tillage, crop residue retention; precise water and nutrient management along with efficient crop rotation. In CSA, crop production deals with the management of available agricultural resources with latest management practices and farm machinery under a particular set of edaphic and environmental conditions. CSA based management practices in isolation may or may not play their potential role in adapting to climate risks in rice-wheat (RW) system. Therefore, suitable combinations of these management practices may help in building resilience to extreme climate variability to ensure future food security in the region. CA-based crop management activities in IGP substantially alter soil physical, chemical, and biological properties, leading to changes in the composition and distribution of soil microbial communities [7,8]. In any agro-ecosystem, interactions between soil microbial communities and soil organic matter play an important role in driving soil functions, and the soil microbial biomass definition may help us understand this interaction [9]. Soil microbial biomasses help in regulating nutrients like carbon (C) and nitrogen (N) through the process of immobilization and mineralization and considered as sensitive indicators towards crop management practices [10].

Crop-based agriculture, except pastureland, now covers 1.7 billion hectares worldwide [11]. Agricultural soils are thought to store 111 to 170 Pg C, or around 10% of the earth's total soil C (1500 Pg [11,12]. Part of the reason for the renewed interest in SOC is that it serves as a significant indicator of soil quality [13] and has the ability to act as a C drain [14]. Farming systems that employ best management practises have the potential to increase agricultural productivity, minimize negative environmental impacts, and reduce anthropogenic carbon dioxide emissions by sequestering soil carbon. If the potential benefits of SOC sequestration are to be validated, the underlying processes, energy, and durability of C pools in agricultural lands must be elucidated and accurately quantified.

Cereals are the most important staple crops worldwide including Asia. Rice, wheat and maize provide 60% of the human food globally and these three crops account for more than 90% of Asia's cereal production. In Asia, the population is expected to grow by 40% in 2050 compared to 2000 [15,16]. Thus, this continent is facing a tremendous challenge for meeting food production at the pace of people demand as well as the sustainability of its natural resource base [15,16]. This is becoming even more challenging due to the threat of global warming and deterioration in soil health. Even though the cereal based systems in Asia are highly diverse due to contrasting eco-physical conditions in different regions, there are a few mega-systems that account for a greater share of food production in the continent. These include cropping systems such as rice-rice (RR) in the tropical climate of East and Southeast Asia, rice-wheat (RW) in the intensive agro-ecosystems of China and South Asia, cereals-legumes in South Asia and wheat-fallow and wheat-cotton (WC) in the drylands of China, India and West and Central Asia. Of many rice-based systems, Rice-wheat (RW) is the most widely grown in South Asia alone and covers more than 24 M ha. The wheat-based cropping systems exist in different countries depending on temperature, type of wheat grown (spring, facultative, winter) and water availability [16].

Soils' microbial diversity is considered important for ecosystems' functioning, both in relation to direct interactions with plants with respect to nutrient transformations and organic C cycling [17]. Cropping systems are known to affect soil microbial biomass and diversity, which impacts enzyme activity in soil, despite changes in SOC pool and nutrient transformations caused by soil microorganisms [18]. The physico-chemical conditions of soil and measures of its microbial status are manifested by soil enzymatic activities, which are referred to as "sensors" of soil degradation [19]. To depict changes in the soil environment, soil microbial biomass is considered more reactive than the SOC [18,20]. Indeed, the effects of soil management-induced changes can be seen in the microbial biomass and enzymatic activity of the soil [18,20,21]. There is a direct connection between seasonal variations in soil microbial biomass and soil organic matter turnover and nutrient cycling. Understanding the processes of SOC dynamics requires an understanding of soil enzymatic behaviour, which is highly sensitive to changes in soil climate. Soil enzymes respond quickly to changes induced by natural and anthropogenic factors that affect particular C substrate. Soil management activities under various cropping practises have been shown to alter biological processes in the soil, which has an effect on soil quality [22].

Soil is a dynamic and living resource and therefore biologically mediated processes are central to its ecological functions [23]. Land use change has a direct impact on soil nutrient supply and their distribution, and stimulates the biological changes in the rooting zone [24]. Changes in land use system and its management can cause positive and negative impact on the rhizospheres' microbial community [25]. The root exudates and secretions in the rhizosphere vary differentially among plant species grown which serves as a substrate for soil micro-organisms. It is well known that the nutrient demand of crops is different and crop species differ widely with respect to quantity and quality of litter produced [24], This, in turn, has an effect on the diversity and structure of microbes [20]. The changes in land use systems lead to wide variations is above and below-ground ecosystem, often causing depletion in soil C and biodiversity loss [26].

Effective land levelling reduces the work in crop establishment and crop management and increases the yield and quality. Even, it is a process for ensuring that the depths and discharge variations over the field are relatively uniform. As a result, water distributions are uniform in the root zone [27]. There are two land levelling philosophies: (1) to provide a slope which fits a water supply and (2) to level the field to its best condition with minimal earth movement and then vary the water supply for the field condition. The second philosophy is generally the most feasible. Because land levelling is expensive and large earth movements may leave significant areas of the field without fertile topsoil, this second philosophy is also generally the most economic approach [28]. We study the effects of to (i) quantify the relationship between C input and SOC sequestration in whole soil and SOM fractions, and (ii) identify mechanisms of long-term soil C stabilization in cropping systems that represented a gradient of C input levels in this review article.

2. SOIL BIOTIC INDICATORS

Complete biomass, behaviours, functioning, population composition, and interactions of soil-inhabiting macro- and microorganisms that determine the trophic or food web complexity of soil ecosystems are examples of biotic indicators of soil health. The effects of continuous cropping (CC) on soil bacteria and fungi were stated by Pervaiz et al [29]. However, little is known about how other microbial groups, such as viruses and protists, respond to CC in a variety of soil and environmental conditions. Both viruses and protists are microbial environment micro-predators that govern and monitor soil microbial populations and functions, which are critical to soil health and crop yield [29].

3. MICROBIOMIC INDICATORS

Microbiomic Indicators are a collection of indicators that measure the diversity of bacteria in Disease and pest control, crop plant nutrition, and resistance to anthrophonic and climatic changes are all controlled by soil microbial communities [30,31]. They also help with soil aggregation, crop residue breakdown, nutrient mineralization, and fixation, among other abiotic measures of soil health. Continuous cropping (CC), on the other hand, can have a negative impact on a number of soil microbial community parameters and functions.

4. BIOMASS OF MICROORGANISMS OR ABUNDANCE OF MICROORGANISMS

Microbial biomass, or abundance, is an important component of a healthy soil ecosystem, and its composition influences soil quality and crop yields [32,33]. A decrease in soil microbial biomass as a result of continuous cropping (CC) not only reduces the abundance of beneficial microbial taxa, but it may also result in a decline in general soil functions, which are important for soil health and productivity [34]. For example, there is a growing consensus that under CC, the abundance of soil fungi and bacteria increases and decreases over time [35]. The CC, in particular, reduces the abundance of important beneficial bacterial taxa that provide important soil ecosystem services including N-fixation and disease suppression [36]. For example, continuous crop plantation reduces the abundance of important soil fungal taxa (e.g., Gliocladium and Trichoderma spp.) that act as biological control agents against soil-borne pathogens (e.g., Fusarium spp) [37,38]. Long-term CC has also been shown to reduce microbial biomass P [39] and C content in some studies [40].

Furthermore, some classic comparative studies have found lower soil microbial biomass under continuous rather than rotation cropping systems [41,42,43], and these effects have been attributed to lower and higher resources or crop residues for microbes under monoculture rather than mixture cropping systems [41,42,43], and these effects have been attributed to lower and higher [43]. Overall, a decrease in microbial biomass under continuous cropping (CC) can indicate a lower input of organic materials and crop residues into the soil, emphasizing the importance of rising cropping diversity to improve soil organic matter and microbial biomass.

5. COMPOSITION AND DIVERSITY OF MICROBIAL COMMUNITIES

Microbial-driven soil functions, which determine soil fertility and crop productivity, may be influenced by the composition and diversity of soil microbes [31,44,45,46]. Previous research has shown that agricultural intensification can change the diversity, composition, and function of microbial communities in soils under various crop conditions [37,47,48]. For example, CC of tea plants from five to eight years improved the microbial community composition, but it had a negative impact in the long run (50-year-old to 90-year-old) [49]. Another study found that soils with wheat-corn-soybean crop rotations had higher relative abundance of essential bacterial phyla such as Proteobacteria, Actinobacteria, and Firmicutes than soils with continuous soybean cropping [50]. Tea plants' CC also decreased Shannon's diversity index of soil microbial communities [51].

Furthermore, the CC may alter microbial community structure by changing the abundance of specific microbial taxa; for example, Tang et al., [52] found that Actinobacteria were more abundant in agricultural soils when soybean-corn rotation was used rather than continuous soybean cropping. They found that under canola monocultures, rather than wheat monocultures, major changes in the composition of soil microbial communities occurred, implying that CC has a monoculture-specific impact on soil microbial diversity [53]. Another study found that continuous banana cropping reduced soil bacterial diversity and changed the composition of the bacterial population [54]. Similarly, the CC of legume pea plants altered the microbial community composition of soils by reducing the concentration of arbuscular mycorrhizal fungi and gram-positive bacteria [55]. Similarly, the CC of cotton increased the abundance of certain soil fungal taxa like Ascomycota [56], while the differential effects of monoculture cropping systems like soybean [57], peanut [58], and vanilla [59] on soil microbial community composition and diversity have also been stated. Bacillus amyloliquefaciens' effect on soil microbial communities was investigated in a recent study using sorghum–maize rotation, sorghum, and maize CC systems [60]. The bacterial and fungal diversity in rhizosphere soil under continuous sorghum cropping was lower and higher, respectively, than in soil under a sorghum–maize rotation system. They discovered that the CC system increased the abundance of some bacterial phyla, such as Acidobacteria and Gemmatimonadetes, as well as some fungal taxa, such as Basidiomycota. Despite the fact that fungal taxa of the class Tremellomycetes were the most prevalent under CC, the use of B. amyloliquefaciens greatly decreased their abundance in the soil [60]. Under the CC of Panax notoginseng, another research looked into the root-endophytic and rhizospheric bacteria [61]. They discovered that the CC of P. notoginseng decreased rhizospheric bacteria abundance while having no effect on endophytic bacteria. Furthermore, they found that bacterial diversity was higher in healthy rhizospheric soils under P. notoginseng plantation than in contaminated soils. However, the CC increased the abundance of certain bacterial phyla, such as Proteobacteria, Cyanobacteria, Actinobacteria, and Acidobacteria, in general, and the changes in microbial community composition were determined by changes in soil properties such as total P, pH, and soil organic matter contents [61].

6. ENZYME ACTIVITIES IN THE SOIL

Extracellular enzymes produced by soil microbes and plant roots are diverse, and these enzymes play a key role in catalysing biochemical reactions in the soil [62]. As a result, the degree and magnitude of soil biogeochemical processes are determined by enzyme activity [62,63]. Soil enzymes control a variety of soil ecosystem properties that are influenced by soil, vegetation, and climatic conditions. Soil enzymes can predict the biological health of soil ecosystems in addition to affecting soil edaphic properties. For example, soil sucrase activities were found to have a strong negative relationship with the abundance of important soil-borne pathogens including Fusarium spp [64]. As a result, soil enzymes are regarded as important markers of soil health, sustainability, and function [62,65]. Soil enzyme-driven organic matter processing is important for nutrient cycling and the sequestration of essential elements including soil carbon. Afforded how responsive soil enzyme activities are to land-use changes, a better understanding of soil enzyme sensitivity to continuous monoculture cropping is critical for agricultural soil management in today's scenarios of agricultural intensification and climate change [66]. For example, under CC, soil dehydrogenase activity is known to decrease [67]. Important soil enzymes like urease, alkaline phosphatase, and sucrose could be significantly reduced by the CC of important crops like potato and cotton [68,69]. After 26 years of cropping, Dou et al. [70] examined the effect of CC of sorghum, cotton, corn, and cotton/sorghum rotations on soil enzyme activities. They found that soil enzyme activities like arylsulfatase, alkaline phosphatase, and -d-glucosidase were highest and lowest in soils under sorghum and cotton monoculture cropping, respectively. Overall, soil enzyme activities were lower in monoculture soils than in rotation cropped soils [70]. Similarly, the CC decreased the activities of urease, dehydrogenase, and catalase in agricultural soil in another study [71]. Despite the fact that several examples of the impact of CC on soil enzyme activities have been found, we believe that monoculture cropping can reduce the activities of vital soil enzymes that are essential for soil biological and biogeochemical health.

Significant variation in DHA was also observed in the rhizosphere and bulk soils of various scenarios, according to Jat et al. [72] (Fig. 1). DHA activity was significantly higher in rhizospheric soils than bulk soils before sowing the crop, regardless of cropping method. Rice-based CSA systems (mean of Sc3 and Sc5) had significantly higher DHA activity in rhizospheric soil before sowing (59.6%) and flowering stage (18.7%) than maize-based CSA systems (mean of Sc4 and Sc6) (Fig. 1a and 1c). Before sowing in a maize-based scheme, rhizospheric soil had a 35 percent higher DHA activity than bulk soil. DHA activity was significantly higher in partial CA dependent rice system (PCA-RW, Sc2) (145g TPF g-1 soil hr-1) than others at maximum tillering level, regardless of sampling site (Fig. 1b). DHA activity was 12 percent higher in the rhizosphere of PCA-RW (Sc2) at flowering than in bulk soil (Fig. 1c). In a rice-based CSA system, bulk soils (98 g TPF g-1 soil hr-1) had significantly higher (21%) DHA activity than rhizospheric soils (81 g TPF g^{-1} soil hr^{-1}) after crop harvest (Fig. 1d).

7. SOIL MACRO-ORGANISMS ABUNDANCE, DIVERSITY AND COMPOSITION

Soil macro-organisms include several invertebrate animal companies, inclusive of mites, nematodes, and earthworms, while these organisms show a tremendous complexity in their biotic and abiotic interactions within the soil surroundings. these organisms pressure many trophic (predation) and non-trophic (competition, facilitation) interactions, which universal decide their pinnacle-down consequences on soil microbial groups inside the soil meals net. those organisms may also affect several essential soil procedures which includes the decomposition of crop residues, mineralization, and damage down of humic substance, bioturbation, bio-engineering of soil structure, immobilization of nutrients, nutrient cycling, and biological N-fixation. however, alas, the CC coupled with detrimental and homogenous farm control practices may additionally negatively affect the composition, range, and functioning of those organisms considering they are extra touchy to agriculture-driven soil disturbances [73,74,75].

8. SOIL EARTHWORMS

As one of the most common soil invertebrate organisms, earthworms are known as the natural engineers of soil ecosystems due to the reality they can regulate the soil biophysical houses to boom soil fitness and crop productions. They play a high role in enhancing the soil conditions, consisting of breakdown of organic substance, soil aggregation, aeration, nutrient biking and sequestration, microbial network composition, and functioning [76,77]. in the meantime, earthworms are taken into consideration to be touchy to the climatic prerequisites [78], soil moisture, herbal depend [79,80], physicochemical residences [81], nutrient assets [82], heavy metals [83], natural pollution [84,85], and trophic interactions (predation) [86]. The repeated tillage practices beneath CC may additionally moreover have an effect on their abundance and functioning inner the agricultural soils [87]. moreover, it's additionally normally perceived that traditional CC practices decrease the biodiversity of soil earthworms extra than

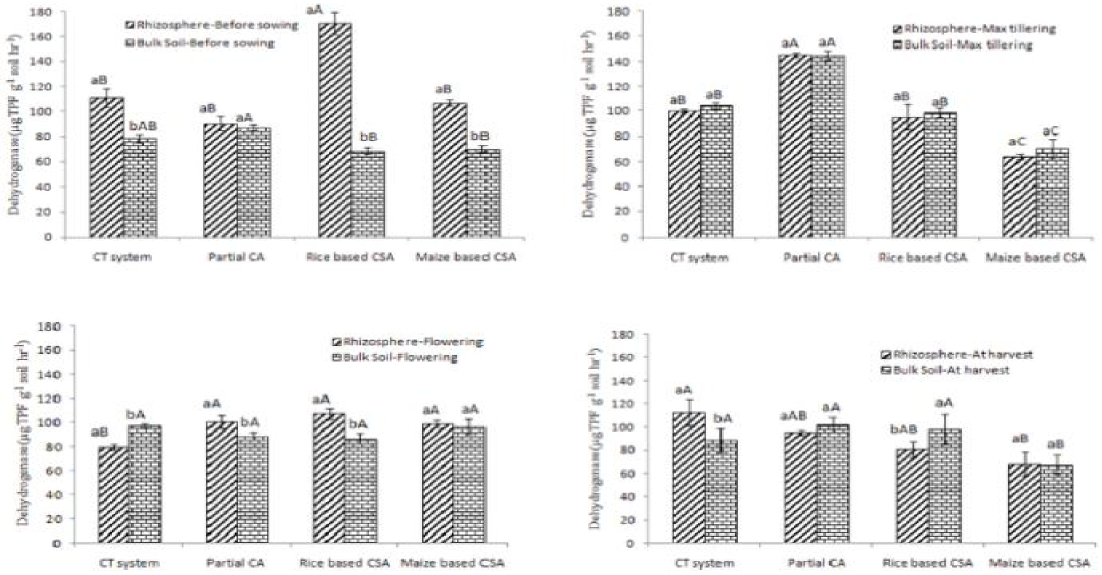


Fig. 1. Dehydrogenase activity in the rhizosphere and bulk soils (g TPF g-1 soil hr^{-1}) Under different tillage, residue, and crop rotations, a) before sowing the crop, b) at full tillering, c) flowering stage of the crop, and d) after harvesting the crop. [Source: Jat et al., [72]]

conservation cropping practices [88]. Moreover, the especially better abundance, biomass in step with individual, and species range of earthworms have been seen in the soil under wintry climate wheat plantation in an organic rather of traditional cropping system [89], which may additionally additionally advocate that ordinary agronomic practices may additionally moreover enlarge the impact of monoculture cropping on soil earthworms. furthermore, higher abundance and range of earthworms have been connected to better quantities of natural depend in the monocultures of natural in place of traditional cropping [89]. Even although there is not a whole lot research at the functional ecology of earthworms in monoculture cropping structures, current studies suggests that agricultural intensification inside the structure of monoculture cropping may additionally moreover negatively have an effect on the composition, diversity, and functioning of soil earthworms, relying on soil, crop, and environmental conditions.

9. ABIOTIC INDICATORS OF SOIL HEALTH

The abiotic signs of soil health include however aren't limited to soil aggregation, combination balance, organic C and organic matter contents, nutrient cycling and sequestration, the composition of soil exudates and metabolites, nutrient stability, and other critical properties including pH and cation exchange capacity (CEC). Those properties are not best linked with each other and alter soil biodiversity, but these can also impact other critical physicochemical strategies consisting of aeration, infiltration, gaseous change, soil bulk density, and strength, and so forth. The CC ought to probably modify or disturb these properties, as mentioned beneath [29].

10. AGGREGATION AND STRUCTURE OF SOIL

The soil's physical health is decided by way of soil structure, which is described because the aggregation of soil minerals and particles into each large and macro-mixture-size lessons. The soil aggregation and mixture balance adjust several physical and chemical approaches, together with soil compaction, pore geometry, nutrient cycling, water, air infiltration, erosion, drainage, nutrient leaching, root penetration, electricity, organic activities, and crop productiveness [90,91]. therefore, soil aggregate balance is used as an essential physical indicator of soil shape and health [92]. however, CC may cause soil degradation with the aid of dismantling the soil shape. for instance, the continuous soybean cropping reduced the soil mixture stability [93]. A latest look at suggested the effect of different cropping structures including non-stop corn (CC), soybean-corn rotation (SC), corn-soybean rotation (CS), fallow corn (FC), and fallow soybean (FS) on soil aggregates stability [94]. Their outcomes showed that the CS and FS treatments notably more desirable the imply weight diameter (MWD) and fractal measurement (D). these treatments additionally stronger MWD and geometric imply diameter (GMD) in the water-solid aggregates (WSAs), as compared to the CC treatment. moreover, rotation treatments additionally multiplied the water-solid aggregates balance charge (WSAR), further to decreasing the aggregates destruction (PAD) extra than the CC remedy. furthermore, rotation as opposed to CC treatments more suitable the share of macro-aggregates [94], accordingly suggesting that CC may negatively have an effect on soil aggregation, combination stability, and the composition of combination-size lessons. but, the impact of CC on soil shape may range among plants. Naresh et al. [95] suggested that macro-aggregates improved below a slit open transplanted rice in zero until with precision land leveling and zero till wheat seeding with residue retained rotation than other crop establishment methods. Bulk and combination associated C improved in 0 until or reduced till systems with extra accumulation in macro-aggregates. Moreover, mean weight diameter (MWD) improved through 21 and 37% in huge raised-bed with precision land leveling and ZT with precision land leveling structures, compared with puddle trans-planted rice, the development in MWD circuitously shows the potential for increasing soil C under zero-tillage and raised-mattress than that of conventional tillage. Tillage operations spoil soil aggregates and reveal soil organic carbon (SOC) for de-composition. 0-until will increase soil aggregation through decreasing soil disturbance and increasing soil organic matter, and possibly the boom of fungi that bind soil debris and micro-aggregates together [96].

11. ORGANIC CARBON AND ITS FRACTIONS

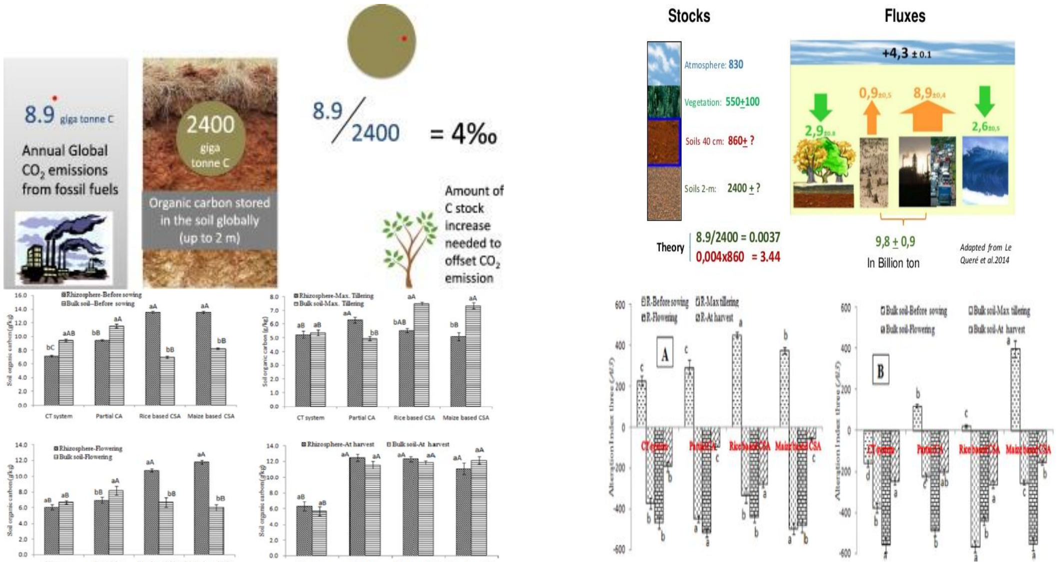
The cultivated soils of rice–wheat had drastically greater (64.8%) recalcitrant C pool, in contrast with soils under cotton–- wheat cropping system. Relative preponderance of these four fractions of variable oxidizability in the uncultivated and cultivated soils follows an order: Fract. 1<Fract. 2<Fract. 3<Fract. 4. The Fract. 1 was the smallest fraction, comprising 12.4%–16.8% of TOC; and used to be appreciably greater in the uncultivated, compared with cultivated soils. The stable C pool (Fract. 3 and Fract. 4) comprised 68.8% of TOC in the uncultivated soils, in contrast with 68.5% in rice–- wheat, and 61.9% in cotton–wheat soils.

Minasny et al. [97] observed that high C sequestration rates can be achieved for soils with low initial SOC stock (topsoil less than 30 t C ha^{-1}), and at the first twenty years after implementation of best management practices. In addition, areas which have reached equilibrium will not be able to further increase their sequestration. We observed that most research on SOC sequestration solely consider topsoil (up to 0.3 m depth), as it is viewed to be most affected through management techniques. As a strategy for climate change mitigation, soil carbon sequestration buys time over the subsequent ten to twenty years while different tremendous sequestration and low carbon technologies turn out to be viable. The challenge for cropping farmers is to find disruptive technologies that will further improve soil condition and deliver increased soil carbon. Patra et al. (2019) [98] found out that the imply stratification ratio (SR) (i.e., a ratio of the concentrations of SOC and TN inside the soil floor to those in a deeper layer) of SOC and TN for zero-five:5-10, 10-15, 15-20, 20-25 and 25-30 cm had been discovered better (> 2) below CA practices compared to intensive tillage primarily based conventional agricultural practice (< 2). No-till CA-based rice-wheat-mungbean machine stored the very best amount of SOC (25.32 Mg ha^{-1}) whereas decreased till CA-based totally rice-wheat-mungbean system stored maximum amount of TN (three.21 Mg ha^{-1}) at zero-30 cm soil depth.

Jat et al. [72] observed that rice and maize based CSA (45%) and PCA-RW (37%) recorded significantly higher SOC over conventional practices (Fig. 2a). Before sowing, rhizosphere soils of CSA based rice and maize systems recorded 90% (in rice rhizosphere) and 63% (in maize rhizosphere) higher SOC over their respective bulk soils. Whereas 18–24% higher SOC was observed in bulk soils under CT (rice crop) and PCA-RW system (rice crop) over rhizosphere soils (Fig. 2a). At maximum tillering stage, considerably higher SOC was found in bulk soils under CSA primarily based rice (36%) and maize (44%) primarily based device over rhizosphere soils but about 21.4% decrease SOC was once found in bulk soils over rhizosphere soil beneath PCA-RW system (Fig. 2b). At flowering stage, greater SOC attention used to be discovered in rhizosphere soils in contrast to maximum tillering stage irrespective of situations (Fig. 2c). But in bulk soils, significantly lower SOC were observed in rice (11%) and maize (18%) based system whereas PCA-RW system recorded 66% higher SOC compared to the bulk soil at maximum tillering stage (Fig. 4c). At harvesting stage, higher SOC was observed in all the scenarios irrespective of sampling locations except the bulk soil under CT system which registered 14% lower SOC compared to the bulk soil under flowering stage (Fig. 2d). Higher SOC under CSA and PCA based rice and maize systems was due to higher residue load which supplies organic carbon to soils in addition to carbon input from plants through roots, rhizodepositions, secretions etc. Generally rhizosphere soil is characterized by higher amount of very labile carbon and lower contents of mineral nitrogen as well as other nutrients with 19–32 times higher number of microorganisms compared to bulk soil. In bulk soil (away from roots), all the nutrients are mostly available with limiting easily available carbon for microbial growth. However, alteration index three diverse considerably among the crop increase levels and rhizosphere and bulk soil beneath exceptional managements (Fig. 2B). Lower values of *AI3* indicated better soil quality. In rhizosphere soil, lowest *AI3* (-516) was observed at flowering stage of partial CA based system whereas in bulk soil rice based CSA system recorded lowest *AI3* (-567) at maximum tillering stage. Significantly higher *AI3* values were recorded before sowing of crop irrespective of sampling location (Fig. 2B).

12. ENHANCE SOIL AND BIOMASS CARBON STORAGE

Soil carbon inventory displays the long-time period equilibrium between carbon inputs (rhizodeposition, crop residues and exogenous natural products) and carbon losses by way of mineralization. increasing carbon stocks in soils has been considered as a promising option for mitigating climatic alternate for decades [99]. growing C stocks in agricultural soils can be carried out by way of reducing the C mineralization charge, increasing C input and combining both levers. decreased tillage has frequently been taken into consideration as a management exercise fostering C garage



(A)

(B)

Fig. 2. (A): Soil organic carbon (g/kg) in the rhizosphere and bulk soils a) before crop sowing, b) at full tillering, c) flowering stage of crop, and d) after crop harvesting under various tillage, residue, and crop rotations. (B): Alteration index three (A/3) in A) rhizosphere and B) bulk soils before sowing of crop, maximum tillering, flowering stage and after harvesting of crop under different tillage, residue and crop rotation [Source: Jat et al., [72]

through lowering mineralization charge. additional C garage beneath reduced tillage isn't always located. It does not arise or is even lowered if biomass manufacturing (and therefore C enter through crop residues) is likewise decreased [100]. The impact of decreased tillage on carbon stocks also depends on climatic conditions, with less additional C storage underneath moist climate seeing that mineralization of crop residues remaining on soil surface is desired [101]. Furthermore, no-till might also increase N_2O emissions in poorly-aerated soils [102] so that all GHG resources should be considered when assessing reduced tillage as a mitigation option (better C storage in soil if any, less CO_2 emissions via tractors, feasible impact on N_2O emissions). Therefore, the identification of soil, climate and agronomical situations below which decreased tillage can improve the general GHG finances of cropping systems remains an essential mission for destiny agronomical research. increasing C inputs may be finished via recycling greater organic product or by using growing subject biomass production and recycling.

13. CONCLUSIONS

The review paper concluded that conservation agriculture coupled with precision land leveling practices in intensive cereal based cropping systems serves as fully validated Climate Smart Agriculture (CSA). The crucial role of soil bacterial composition & diversity and their interactions with available soil nutrients further provides insights for building resilience against climatic risks. Precision land leveling with cereal primarily based cropping systems resulted in markedly higher soil labile organic carbon pools in Rice-Wheat and Sorghum- Wheat cropping system with traditional land leveling, and it could be a appropriate management approach to enhance or restore soil quality. The surface soil layer had substantially higher levels of all soil health parameters than subsurface layer, presumably due to higher retention of crop stubbles, fallen leaves and root biomass. The improved proportions of percent, LFOC, MBC in SOC and that of PON, LFON, and DOC with the adoption of precision land leveling and cereal primarily based cropping systems indicate that the improvement in labile types of each C and N changed into exceedingly rapid than rice- wheat or cereal based totally mono-cropping with traditional land leveling practices suggesting that energetic C and N pools replicate changes because of land leveling practices. hence, usage of precision land leveling and inclusion appropriate cropping pattern ought to hold the soil health beneath intensive agriculture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Osuri AM, Ratnam J, Varma V, Alvarez-Loayza P, Astaiza JH, Bradford M, Sankaran M. Contrasting effects of defaunation on aboveground carbon storage across the global tropics. Nature Communications. 2016;7:1135.
2. Schuur EAG, McGuire AD, Schadel C, Grosse G, Harden JW, Hayes DJ, Vonk JE. Climate change and the permafrost carbon feedback. Nature. 2015;520:171–179.
3. Bond-Lamberty B, Bailey VL, Chen M, Gough CM, Vargas R. Globally rising soil heterotrophic respiration over recent decades. Nature. 2018;560:80–83.
4. Bender SF, Wagg C, Van der Heijden MGA. An underground revolution: Biodiversity and soil ecological engineering for agricultural sustainability. Trends in Ecology and Evolution. 2016;31:440–452.
5. Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R. Climate-smart agriculture for food security. Nat. Clim. Chang. 2014;4(12):1068.
6. Govaerts B, Sayre KD, Goudeseune B, De Corte P, Lichter K, Dendooven L, Deckers J. Conservation agriculture as a sustainable option for the central Mexican highlands. Soil Tillage Res. 2009;103(2):222–230.
7. Jat HS, Datta A, Sharma PC, Kumar V, Yadav AK, Choudhary M, Choudhary V, Gathala MK, Sharma DK, Jat ML, Yaduvanshi NPS, Singh G, McDonald A. Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. Arch. Agron.Soil Sci. 2017;64:531–545.
8. Choudhary M, Sharma PC, Jat HS, Dash A, Rajashekar B, McDonald AJ, Jat ML. Soil bacterial diversity under conservation agriculture-based cereal systems in Indo-Gangetic Plains. 3 Biotech. 2018;8:304. Abailable:https://doi.org/10.1007/s13205-018-1317-9
9. Stockdale EA, Murphy DV. Managing soil microbial biomass for sustainable agro-ecosystems. In: Tate KR. (Ed.), Microbial Biomass: A Paradigm Shift in Terrestrial Biogeochemistry. World Scientific, London. 2017;67–101.
10. Gosai K, Arunachalam A, Dutta BK. Tillage effects on soil microbial biomass in a rainfed agricultural system of northeast India. Soil Tillage Res. 2010;109:68–74.
11. Paustian K, Andre O, Janzen NH, Lal R, Smith P, Tian G, Tiessen H, Van Hoordwijk M, Woomer P. Agricultural soil as a C sinks to offset CO_2 emissions. Soil Use Manage. 1997;13:230–244.
12. Eswaran H, Van Den Berg E, Reich PF. Organic carbon in soils of the world. Soil Sci. Soc. Am. J. 1993;57:192–194.
13. Lal R. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO_2 enrichment. Soil Tillage Res. 1997;43:81–107.
14. Bruce JP, Frome M, Haites E, Janzen H, Lal R, Paustian K. Carbon sequestration in soils. In Proc. Soil and Water Conservation Society's Carbon Sequestration in Soils Workshop, Calgary AB. SWCS, Ankeny, IA. 1998;21–22.
15. Rosegrant MW, Koo J, Cenacchi N, Ringler C, Robertson RD, Fisher M, Cox CM, Garrett K, Perez ND, Sabbagh P. Food security in a world of natural resource scarcity. The role of agricultural technologies. Publisher(S): International Food Policy Research Institute (IFPRI). 2014;250.
16. Jat ML, Jat HS, Agarwal T, Bijarniya D, Kakraliya SK, Choudhary KM, et al. A compendium of key climate smart agriculture practices in intensive cereal based systems of South Asia. International Maize and Wheat Improvement Center (CIMMYT), New Delhi, India. 2020;42.
17. Adak T, Sachan RS. Effect of co-inoculation of Sinorhizobium meliloti and Bacillus megaterium on yield and nutrient uptake of fenugreek (*Trigonella foenum-graecum* L.) in Mollisol soil. J Med Arc Pl Sci. 2009;31:124–130.
18. Sharma S, Vashisht M, Singh Y, et al. Soil carbon pools and enzyme activities in aggregate size fractions after seven years of conservation agriculture in a rice–wheat system. Crop Pasture Sci. 2019;70(6):473–485. DOI:10.1071/CP19013
19. Baum C, Leinweber P, Schlichting A. Effects of chemical conditions in re-wetted peats temporal variation in microbial

biomass and acid phosphatase activity within the growing season. Appl Soil Ecol. 2003;22(2):167–174.

20. Benbi DK, Brar K, Toor AS, et al. Total and labile pools of soil organic carbon in cultivated and undisturbed soils in northern India. Geoderma. 2015;237–238:149–158.
21. Shipton PJ. Monoculture and soilborne plant pathogens. Monocult. Soilborne Plant Pathog. 1977;15:387–407.
22. Benbi DK, Brar K, Toor AS, et al. Soil carbon pools under poplar based agroforestry, rice-wheat, and maize-wheat cropping systems in semi-arid India. Nutr Cycl Agroecosyst. 2012;92(1):107–118. DOI:10. 1007/s10705-011-9475-8
23. Li XG, Li YK, Li FM, et al. Changes in soil organic carbon, nutrients and aggregation after conversion of native desert soil into irrigated arable land. Soil Till Res. 2009;104(2):263–269. DOI:10.1016/j.still.2009.03.002
24. Singh P, Benbi DK. Nutrient management effects on organic carbon pools in a sandy loam soil under ricewheat cropping. Arc Agron Soil Sci. 2018;64(13):1879–1891. DOI:10.1080/03650340. 2018.1465564
25. Notaro K, de Medeiros EV, Duda GP, et al. Agroforestry systems, nutrients in litter and microbial activity in soils cultivated with coffee at high altitude. Sci Agric. 2014;71(2):87–95.
26. Doran JW, Zeiss MR. Soil health and sustainability: Managing the biotic component of soil quality. Appl Soil Ecol. 2000;15(1):3–11. DOI:10.1016/S0929- 1393(00)00067-6
27. Ayranci Y, Temizel KE. Volume equalization method for land grading design: Uniform sloped grading in one direction in rectangular fields. Afr J Biotech. 2011;10(21):4412-4419.
28. Walker WR. Guidelines for designing and evaluating surface irrigation systems. FAO Irrigation Drainage Papers. Rome, Italy.1989;45:158.
29. Pervaiz ZH, Iqbal J, Zhang Q, Chen D, Wei H, Saleem M. Continuous cropping alters multiple biotic and abiotic indicators of soil health. Soil Syst. 2020;4:59.
30. Saleem M. Microbiome community ecology: Fundamentals and applications; Springer: Berlin/Heidelberg, Germany; 2015. ISBN 978-3-319-11665-5.
31. Saleem M, Hu J, Jousset A. More than the sum of its parts: Microbiome biodiversity as a driver of plant growth and soil health. Annu. Rev. Ecol. Evol. Syst. 2019;50:145–168.
32. Treseder KK. Nitrogen additions and microbial biomass: A meta-analysis of ecosystem studies. Ecol. Lett. 2008;11:1111–1120.
33. Eisenhofer R, Minich JJ, Marotz C, Cooper A, Knight R, Weyrich LS. Contamination in low microbial biomass microbiome studies: Issues and recommendations. Trends Microbiol. 2019;27:105–117.
34. Han W, Kemmitt SJ, Brookes PC. Soil microbial biomass and activity in Chinese tea gardens of varying stand age and productivity. Soil Biol. Biochem. 2007;39:1468–1478.
35. Liang Y, Lin X, Yamada S, Zhou M, Inoue M, Inosako K. Cucumber productivity and soil degradation in recropping system in greenhouse. Commun. Soil Sci. Plant Anal. 2012;43:1743–1748.
36. Kirkegaard JA, Sarwar M, Wong PTW, Mead A, Howe G, Newell M. Field studies on the biofumigation of take-all by Brassica break crops. Aust. J. Agric. Res. 2000;51:445–456.
37. Meriles JM, Gil SV, Conforto C, Figoni G, Lovera E, March GJ, Guzmán CA. Soil microbial communities under different soybean cropping systems: Characterization of microbial population dynamics,soil microbial activity, microbial biomass, and fatty acid profiles. Soil Tillage Res. 2009;103:271–281.
38. Perez-Brand án C, Huidobro J, Grümberg B, Scandiani MM, Luque AG, Meriles JM, Vargas-Gil, S. Soybean fungal soil-borne diseases: A parameter for measuring the effect of agricultural intensification on soil health. Can. J. Microbiol. 2013;60:73–84.
39. Katsalirou E, Deng S, Gerakis A, Nofziger DL. Long-term management effects on soil P, microbial biomass P, and phosphatase activities in prairie soils. Eur.J.Soil Biol. 2016;76:61–69.
40. Zhou X, Gao D, Liu J, Qiao P, Zhou X, Lu H, Wu X, Liu D, Jin X, Wu F. Changes in rhizosphere soil microbial communities in a continuously monocropped cucumber (*Cucumis sativus* L.) system. Eur. J. Soil Biol. 2014;60:1–8.
41. Anderson TH, Domsch KH. Carbon assimilation and microbial activity in soil. Z. Pflanz. Bodenkd. 1986;149:457–468.
42. Insam H, Parkinson D, Domsch KH. Influence of macroclimate on soil microbial

biomass. Soil Biol. Biochem. 1989;21:211–221.

43. Wardle DA. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. Biol. Rev. 1992;67:321–358.
44. Sahib MR, Pervaiz ZH, Williams MA, Saleem M, De Bolt S. Rhizobacterial species richness improves sorghum growth and soil nutrient synergism in a nutrient-poor greenhouse soil. Sci. Rep. 2020;13:41598.
45. Shahbaz M, Kätterer T, Thornton B, Börjesson G. Dynamics of fungal and bacterial groups and their carbon sources during the growing season of maize in a long-term experiment. Biol. Fertil. Soils; 2020.
46. Chen D, Saleem M, Cheng J, Mi J, Chu P, Tuvshintogtokh I, Hu S, Bai Y. Effects of aridity on soil microbial communities and functions across soil depths on the Mongolian Plateau. Funct. Ecol; 2019.
47. Zhu S, Wang Y, Xu X, Liu T, Wu D, Zheng X, Tang S, Dai Q. Potential use of high-throughput sequencing of soil microbial communities for estimating the adverse effects of continuous cropping on ramie (*Boehmeria nivea* L. Gaud). PLoS ONE 2018;13:e0197095.
48. Liu Z, Liu J, Yu Z, Yao Q, Li Y, Liang A, Zhang W, Mi G, Jin J, Liu X. et al. Long-term continuous cropping of soybean is comparable to crop rotation in mediating microbial abundance, diversity and community composition. Soil Tillage Res. 2020;197:104503.
49. Xue D, Yao H, Huang C. Microbial Biomass, N Mineralization, Nitrification, Enzyme activities, and microbial community diversity in tea orchard soils. Plant Soil. 2006;288:319–331.
50. Zhu YB, Shi FY, Zhang R, Wu YP. Comparison of bacterial diversity in rotational and continuous soybean cropping soils in Heilongjiang. Acta Phytophylacica Sin. 2014;41:403–409.
51. Zhao J, Wu X, Nie C, Wu T, Dai W, Liu H, Yang R. Analysis of unculturable bacterial communities in tea orchard soils based on nested PCR-DGGE. World J. Microbiol. Biotechnol. 2012;28:1967–1979.
52. Tang H, Xiao C, Ma J, Yu M, Li Y, Wang G, Zhang L. Prokaryotic diversity in continuous cropping and rotational cropping soybean soil. FEMS Microbiol. Lett. 2009;298:267–273.
53. Lay CY, Bell TH, Hamel C, Harker KN, Mohr R, Greer CW, Yergeau É, St-Arnaud M. Canola root–associated microbiomes in the Canadian prairies. Front. Microbiol. 2018;9.
54. Sun J, Zou L, Li W, Wang Y, Xia Q, Peng M, Sun J, Zou L, Li W, Wang Y, et al. Soil microbial and chemical properties influenced by continuous cropping of banana. Sci. Agric. 2018;75:420–425.
55. Jeffries P, Gianinazzi S, Perotto S, Turnau K, Barea JM. The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. Biol. Fertil. Soils. 2003;37:1–16.
56. Xi H, Shen J, Qu Z, Yang D, Liu S, Nie X, Zhu L. Effects of long-term cotton continuous cropping on soil microbiome. Sci. Rep. 2019;9:1–11.
57. Li C, Li X, Kong W, Wu Y, Wang J. Effect of monoculture soybean on soil microbial community in the Northeast China. Plant Soil 2010;330:423–433.
58. Li X, Ding C, Zhang T, Wang X. Fungal pathogen accumulation at the expense of plant-beneficial fungi as a consequence of consecutive peanut monoculturing. Soil Biol. Biochem. 2014;72:11–18.
59. Xiong W, Zhao Q, Zhao J, Xun W, Li R, Zhang R, Wu H, Shen Q. Different continuous cropping spans significantly affect microbial community membership and structure in a vanilla-grown soil as revealed by deep pyrosequencing. Microb. Ecol. 2015;70:209–218.
60. Wu AL, Jiao XY, Fan FF, Wang JS, Guo J, Dong EW, Wang LG, Shen XM. Effect of continuous sorghum cropping on the rhizosphere microbial community and the role of Bacillus amyloliquefaciens in altering the microbial composition. Plant Growth Regul. 2019;89:299–308.
61. Tan Y, Cui Y, Li H, Kuang A, Li X, Wei Y, Ji X. Diversity and composition of rhizospheric soil and root endogenous bacteria in Panax notoginseng during continuous cropping practices. J. Basic Microbiol. 2017;57:337–344.
62. Schloter M, Dilly O, Munch JC. Indicators for evaluating soil quality. Agric. Ecosyst. Environ. 2003;98:255–262.
63. Hussain S, Siddique T, Saleem M, Arshad M, Khalid A. Impact of pesticides on soil microbial diversity, enzymes, and biochemical reactions; Academic Press: Cambridge, MA, USA. 2009;102(Chapter5):159–200.

ISBN 0065-2113.

64. Wang S, Ren J, Huang T, Qiao G, Hu H, Li W, Wu F, Pan K. Evaluation of soil enzyme activities and microbial communities in tomato continuous cropping soil treated with Jerusalem artichoke residues. Commun. Soil Sci. Plant Anal. 2018;49:2727–2740.
65. Liu G, Zhang X, Wang X, Shao H, Yang J, Wang X. Soil enzymes as indicators of saline soil fertility under various soil amendments. Agric. Ecosyst. Environ. 2017;237:274–279.
66. Nottingham AT, Turner BL, Whitaker J, Ostle N, Bardgett RD, McNamara NP, Salinas N, Meir P. Temperature sensitivity of soil enzymes along an elevation gradient in the Peruvian Andes. Biogeochemistry. 2016;127:217–230.
67. Zhou X, Gao D, Liu J, Qiao P, Zhou X, Lu H, Wu X, Liu D, Jin X, Wu F. Changes in rhizosphere soil microbial communities in a continuously monocropped cucumber (*Cucumis sativus* L.) system. Eur. J. Soil Biol. 2014;60:1–8.
68. Acosta-Martínez V, Burow G, Zobeck TM, Allen VG. Soil microbial communities and function in alternative systems to continuous cotton. Soil Sci. Soc. Am. J. 2010;74:1181–1192.
69. Qin S, Yeboah S, Cao L, Zhang J, Shi S, Liu Y. Breaking continuous potato cropping with legumes improves soil microbial communities, enzyme activities and tuber yield. PLoS ONE. 2017;12.
70. Dou F, Wright AL, Mylavarapu RS, Jiang X, Matocha JE. Soil enzyme activities and organic matter composition affected by 26 years of continuous cropping. Pedosphere. 2016;26:618–625.
71. Wacal C, Ogata N, Basalirwa D, Sasagawa D, Ishigaki T, Handa T, Kato M, Tenywa MM, Masunaga T, Yamamoto S. et al. Imbalanced soil chemical properties and mineral nutrition in relation to growth and yield decline of sesame on different continuously cropped upland fields converted paddy. Agronomy. 2019;9:184.
72. Jat HS, Datta A, Choudhary M, Sharma PC, Dixit B, Jat ML. Soil enzymes activity: Effect of climate smart agriculture on rhizosphere and bulk soil under cereal based systems of north-west India. European Journal of Soil Biology. 2021;103:103292.
73. Bunemann EK, Schwenke GD, Zwieten LV. Impact of agricultural inputs on soil organisms—A review. Soil Res. 2006;44:379–406.
74. Lata JC, Barot S, Leloup J, Lerch T, Nunan N, Raynaud X. Biodiversity and ecological functioning of soils. In Soils as a Key Component of the Critical Zone 6; John Wiley & Sons, Ltd.: Hoboken, NJ, USA. 2018;39–56.
    ISBN 978-1-119-43827-4.
75. Ney L, Franklin D, Mahmud K, Cabrera M, Hancock D, Habteselassie M, Newcomer Q, Dahal S, Subedi A. Sensitivity of nematode community analysis to agricultural management practices and inoculation with local effective microorganisms in the Southeastern United States. Soil Syst. 2019;3:41.
76. Amador JA, Gorres JH. Microbiological characterization of the structures built by earthworms and ants in an agricultural field. Soil Biol. Biochem. 2007;39:2070–2077.
77. Hickman ZA, Reid BJ. Increased microbial catabolic activity in diesel contaminated soil following addition of earthworms (Dendrobaena veneta) and compost. Soil Biol. Biochem. 2008;40:2970–2976.
78. Edwards CA. Earthworm ecology in cultivated soils. In Earthworm Ecology: From Darwin to Vermiculture; Satchell, J.E., Ed.; Springer: Dordrecht, The Netherlands. 1983;123–137.
    ISBN 978-94-009-5965-1.
79. Curry JP, Byrne D. The role of earthworms in straw decomposition and nitrogen turnover in arable land in ireland. Soil Biol. Biochem. 1992;24:1409–1412.
80. Crittenden SJ, Eswaramurthy T, De Goede RGM, Brussaard L, Pulleman MM. Effect of tillage on earthworms over short- and medium-term in conventional and organic farming. Appl. Soil Ecol. 2014;83:140–148.
81. Lavelle P. Earthworm activities and the soil system. Biol. Fert. Soils 1988;6:237–251.
82. Fraser PM, Haynes RJ, Williams PH. Effects of pasture improvement and intensive cultivation on microbial biomass, enzyme activities, and composition and size of earthworm populations. Biol. Fertil. Soils. 1994;17:185–190.
83. Spurgeon DJ, Hopkin SP. Risk assessment of the threat of secondary poisoning by metals to predators of earthworms in the vicinity of a primary smelting works. Sci. Total Environ. 1996;187:167–183.

84. Chen J, Saleem M, Wang C, Liang W, Zhang Q. Individual and combined effects of herbicide tribenuron-methyl and fungicide tebuconazole on soil earthworm Eisenia fetida. Sci. Rep. 2018;8:1–9.
85. Zhang Q, Saleem M, Wang C. Effects of biochar on the earthworm (*Eisenia foetida*) in soil contaminated with and/or without pesticide mesotrione. Sci. Total Environ. 2019;671:52–58.
86. Churchfield S, Hollier J, Brown VK. The Effects of small mammal predators on grassland invertebrates, investigated by field exclosure experiment. Oikos 1991;60:283–290.
87. Emmerling C. Response of earthworm communities to different types of soil tillage. Appl. Soil Ecol. 2001;17:91–96.
88. Wang Z, Liu L, Chen Q, Wen X, Liao Y. Conservation tillage increases soil bacterial diversity in the dryland of northern China. Agron. Sustain. Dev. 2016;36:28.
89. Feledyn-Szewczyk B, Radzikowski P, Stalenga J, Matyka M. Comparison of the effect of perennial energy crops and arable crops on earthworm populations. Agronomy. 2019;9:675.
90. Nunan N, Wu K, Young IM, Crawford JW, Ritz K. Spatial distribution of bacterial communities and their relationships with the micro-architecture of soil. FEMS Microbiol. Ecol. 2003;44:203–215.
91. Rabot E, Wiesmeier M, Schlüter S, Vogel HJ. Soil structure as an indicator of soil functions—A review. Geoderma 2018;314:122–137.
92. Almajmaie A, Hardie M, Acuna T, Birch C. Evaluation of methods for determining soil aggregate stability. Soil Tillage Res. 2017;167:39–45.
93. Karlen DL, Hurley EG, Andrews SS, Cambardella CA, Meek DW, Duffy MD, Mallarino AP. Crop rotation effects on soil quality at three Northern corn/soybean belt locations. Agron. J. 2006;98:484–495.
94. Zhou M, Liu C, Wang J, Meng Q, Yuan Y, Ma X, Liu X, Zhu Y, Ding G, Zhang J, et al. Soil aggregates stability and storage of soil organic carbon respond to cropping systems on Black Soils of Northeast China. Sci. Rep. 2020;10:1–13.
95. Naresh RK, Singh SP, Kumar D, Dhaliwal SS et al. Evaluation of precision land leveling: Resource utilization and sustainability of rice-wheat cropping systems in North Western India. Eco Ens & Cons. 2015;21:S101-S112.
96. Alvaro-Fuentes J, Lopez MV, Cantero-Martinez C, Arrue JL. Tillage effects on soil organic carbon fractions in Mediterranean dryland agroecosystems. Soil Science Society of America Journal. 2008;72: 2:541–547.
97. Minasny B, Malone BP, McBratney AB, Angers DA. Soil carbon 4 per mille. Geoderma. 2017;292:59-86.
98. Patra S, Julich S, Feger KH, Schwärzel K, et al. Effect of conservation agriculture on stratification of soil organic matter under cereal-based cropping systems. Archiv Agron Soil Sci. 2019;65(14): DOI: 10.1080/03650340.2019.1588462
99. Lal R. Sequestering carbon in soils of agro-ecosystems. Food Policy. 2011;36:S33– S39.
100. Virto I, Barre P, Burlot A, Chenu C. Carbon input differences as the main factor explaining the variability in soil organic C storage in no-tilled compared to inversion tilled agrosystems. Biogeochemistry. 2012;108:17–26.
101. Dimassi B, Mary B, Wylleman R, Labreuche J, Couture D, Piraux F, et al. Long-term effect of contrasted tillage and crop management on soil carbon dynamics during 41 years. Agriculture, Ecosystems and Environment. 2014;188:134–146.
102. Rochette P. No-till only increases N2O emissions in poorly-aerated soils. Soil and Tillage Research. 2008;101:97–100.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/67744