Conservation Agriculture and Soil Quality– An Overview

**M.R. Yadav[1]*, C.M. Parihar[3], Rakesh Kumar[1], R.K. Yadav[2], S.L. Jat[3],
A.K. Singh[3], H. Ram[1], R.K. Meena[1], M. Singh[1], V.K. Meena[1],
N. Yadav[4], B. Yadav[2], C. Kumawat[2] and M.L. Jat[5]**

[1]ICAR- National Dairy Research Institute, Karnal-132001, India
[2]ICAR- Indian Agricultural Research Institute, New Delhi-110 012, India
[3]ICAR- Indian Institute of Maize Research (IIMR), New Delhi-110 012, India
[4]Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221005, India
[5]International Maize and Wheat Improvement Center, NASC Complex, NewDelhi-110012, India
*Corresponding author

A B S T R A C T

Conservation agriculture (CA) has potential to changes soil physical, chemical and biological soil quality parameters compared to conventional tillage (CT) systems. The improved bio-physico-chemical soil quality in turn, affect the ecosystem services and sustainability of crop production system through counterbalancing the climate variability with the help of increasing sink for carbon sequestration within the soil. CA can also affect the functional diversity of soil microbes that essential for improved soil quality, crop production and many ecosystem services. In this context, we summarize the current status of know how CA and about the gaps in understanding, and highlight some research priorities for improving soil quality using CA practices. The review comprises of studies from diverse soil and ecologies of the world. There is clear evidence that CA improves soil physical quality by favouring soil aggregation, soil hydraulic conductivity, bulk density (BD) compared to CT. The combination of zero tillage (ZT) with crop residue retention increases chemical quality by improving the soil organic carbon (SOC) storage and macro and micro nutrient dynamics. Long term adoption of CA and residue management has a significant impact on soil fauna and flora communities under diversified crop rotations. The different soil microbes group responds differently to tillage disturbance and changed residue management strategies. However, in general tillage, through direct physical disruption as well as habitat destruction, strongly reduces macro-fauna including both litter transformers and ecosystem engineers. The above outlined evidence for the improved soil quality and production sustainability with well implemented CA systems is clear, although research remains inconclusive on some points. At the same time, the evidence for the degradation caused by tillage systems is convincing especially in tropical and sub-tropical conditions and for biological and physical soil quality. Therefore, even though we do not know how to manage functional CA systems under all conditions, the underlying principles of CA should provide the foundation upon which the development of new practices is based, rather than be considered a parallel option to mainstream research activities that focus on improving the current tillage-based production systems under diverse soil as well as ecological conditions.

Introduction

Tillage is age old, fundamental agro-technical operation, performed to make soil environment favourable for crop growth and development. Through, tillage sometimes can lead to soil degradation resulted into development of compacted soil having low SOC and restricted drainage. CT practices being highly intensive in nature, their continual use for crop production may account for higher labour and fuel cost resulting in lower economic returns to the growers pushing them into perpetual trap of poverty (Jat *et al*., 2012). Moreover, CT along with faulty agricultural practices such as deforestation, poor rangeland management, selection of incongruous crop sequences and burning of crop residues etc, directly and indirectly reported to be associated with wide variety of agricultural challenges such as water and labour crises, extended land degradation, poor soil fertility and agricultural related climate change which put larger pressure on available agricultural land in order to feed out the ever increasing human and animal population (Stocking and Murnaghan, 2001). Therefore, under current scenario, there is an urgent need to identify, demonstrate and to recommend tillage practices which are alternate to CT systems and can address the above mentioned challenges, so that agriculture may emerge as a source of farmers' prosperity. CT practices, particularly under fragile agro-ecosystems, was interrogated first time in the 1930s, when wide areas of United States was devastated due to dustbowls that produced as a result of intensive tillage over this region. This put larger force on US government and as a result the alternative tillage practices to CT systems which mainly involved reduced ion in tillage intensity and residue retention over the surface soil were developed and the term CA was introduced to cover such practices. In 1940s the concept and principles of CA were described in detail by Edward Faulkner in his book "Ploughman's Folly". In 1990s CA spread exponentially, leading to a revolution as a result today it is practising over 156 M ha area worldwide. Though, CA is still far from being over as the creativity of farmers and researchers and we needs more and more improvements to get the full benefits of the system for the soil, environment and the farmers.

CA involves soil management practices that include (1) planting of crops with minimum soil disturbance (2) maintenance of permanent soil cover and (3) diversified crop rotations that improve soil's bio-physico-chemical behaviour, thereby helped us in arresting the land degradation and water pollutions associated with CT practices (Sharma and Behera, 2009). CA include a range of tillage practices i.e. no-tillage, direct-drilling, minimum tillage, ridge tillage that eliminate and/or reduce intensity of tillage operations and aims at retention of maximum crop residue over the soil surface that served as physical berrier against soil erosion (Baker *et al*., 2007). The beneficial effect of CA reflects not only in terms of increased crop productivity and labour saving but it also helps in achieving environmental sustainability beside soil and land regeneration.

CA has been reported to improving crop input-output relationship, conserving natural resources through lowering soil erosion, arresting water losses through reducing soil evaporation, sequestering atmospheric carbon in soil and reducing energy needs of agricultural sector (Jat *et al*., 2005;Yadav *et al*., 2016a). Research evidence suggests that adoption of CA in proper way can address the emerging challenges of agricultural sector and conserve/improve the quality of environment. In this review we evaluate the potential of CA to reimbursement the current issues related to soil quality.

Needs of CA

According to FAO Terra STAT globally around 6140 M ha area of agricultural land, pasture, forest and woodland had been degraded since mid-twentieth century. The unchecked land degradation has been reported to affected a wide range of cultivated area over throughout the globe i.e. Africa (1222 M ha), Asia (2501 M ha), Australia and pacific (368 M ha), Europe (403 M ha), North America (796 M ha) and South America (851 M ha). Uncheked soil erosion, intensive cultivation, deforestation, industrialization are indentified as key reasons responsible for massive land degradation. Among them, intensive cultivation of soil is one of the severe force that reported to be cause extended land degradation through wind (semi-arid tropics areas) and water erosion (humid and sub-humid areas) and it also a major force that known to gave birth to CA practices. Land degradation especially through soil erosion accountable for loss of top fertile soil layer along with carbon and other nutrients leading to formation of soil that composed of lower level of soil organic matter and nutrients. Land degradation has also been reported to being accused for water contamination through enrichment of water bodies with various agro-chemicals that can lead to eutrophication (Verheijen *et al.,* 2009). Under natural conditions annual mean soil formation rate is about 300 to 1400 kg ha^{-1} while annual mean soil loss through erosion is about 300 to 4000 kg ha^{-1} which sometimes under extreme climatic conditions can reach as high as 10000 kg ha^{-1} (Bai *et al*., 2008; Verheijen *et al.,* 2009). Worldwide, soil erosion (water and wind) alone reported to affect around 1643 M ha of total cultivated area out of which 1094 M ha shared by water erosion alone (Lal, 2003). The problem of land degradation through water and wind is more sever in Asia and Africa (sub-tropical world) where its reported to affect nearly 407

and 267 M ha of cultivated area, respectively (Lal, 2003). Soil erosion directly or indirectly linked with some issues related to agricultural soils e.g. loss of top fertile soil, poor soil organic matter status, lower potential for carbon sequestration, larger emission of greenhouse gases (GHG) and enhanced climate change forcing farmers to find out alternate source for their livelihood (Reicosky, 2001). Worldwide, agricultural and its allied activities are well known agents for climatic variability through emission of various GHG to the atmosphere, especially carbon dioxide (CO_2). CT practices has been reported to associate with lower SOC level due to its higher oxidation which leads to emission of CO_2 to the atmosphere that ultimately leads to climate disruption (Basch *et al*., 2012). Usually, large energy required for crop establishment through CT practices which further makes its crucial mean of CO_2 emissions from agricultural sector (Reicosky and Archer, 2007). Under current scenario, to achieve the goal of agricultural sustainability and intensification, there is an urgent need to resolve the above discussed issues associated with intensive crop production. For this purpose, some agronomic management practices e.g. CA practices has been extensively evaluated, demonstrated and found potential alternative to CT and shows great prospective to mitigate these emerging challenges. CA is grounded on the principles of soil rejuvenation, envisioned to maximizing the use efficiency of agricultural inputs e.g. seed, nutrient, water, energy and labour leading to higher profits to the grower (Dumanski *et al.,* 2006). The goals of CA are to optimizing the crop productivity and farm income through maximum use of available resources and their effective recycling in the agro ecosystem while arresting the adverse impacts on environment (Jat *et al*., 2012). It has been widely tested and demonstrated that long term application of CA resulted in better water quality, provided excellent soil erosion

control, and lowered the GHG emissions associated with agriculture production (Kassam *et al.,* 2012).

Present status of CA

The worldwide quantification of CA area is tricky because the statistics on specific CA practices except ZT is not documented. Usually, the area under ZT is used as a proxy for CA (Hobbs and Govaerts, 2010). At present, ZT occupied around 156 M ha worldwide, increasing with the pace of 7 M ha annually (FAO, 2016). Globally, USA (35 M ha), Brazil (31.8 M ha), Argentina (29 M ha), Canada (18.3 M ha) and Australia (17.6 M ha) are five pioneer countries in adoption of CA practices (Table 1). The area under CA has been significant especially in South America, Argentina, Brazil, Paraguay and Uruguay are using the system on about 70% of the total cultivated area.

Table.1 Area under CA in different countries of the world: The area with >30% ground cover qualified for CA (1000 ha) as per FAO, (2016)

S.No	Country	CA area (1000 ha)	S.No	Country	CA area (1000 ha)
1	Argentina	29181(2013)	28	Malawi	65(2013)
2	Australia	17695(2014)	29	Mexico	41(2011)
3	Azerbaijan	1.3(2013)	30	Morocco	4(2008)
4	Belgium	0.268(2013)	31	Mozambique	152(2011)
5	Bolivia	706(2007)	32	Namibia	0.34(2011)
6	Brazil	31811(2012)	33	Netherlands	0.5(2011)
7	Canada	18313(2013)	34	New Zealand	162(2008)
8	Chile	180(2008)	35	Paraguay	3000(2013)
9	China	6 670(2013)	36	Portugal	32(2013)
10	Colombia	127(2011)	37	Moldova	40(2011)
11	Korea	23(2011)	38	Russia	4500(2011)
12	Finland	200(2013)	39	Slovakia	35(2013)
13	France	200(2013)	40	South Africa	368(2008)
14	Germany	200(2013)	41	Spain	792(2013)
15	Ghana	30(2008)	42	Switzerland	17(2013)
16	Greece	24(2013)	43	Syrian Arab	30(2012)
17	Hungary	5(2013)	44	Tunisia	8(2008)
18	India	1500(2013)	45	Turkey	45(2013)
19	Iraq	15(2012)	46	Ukraine	700(2013)
20	Ireland	0.2(2013)	47	UK	150(2011)
21	Italy	380(2013)	48	Tanzania	25(2011)
22	Kazakhstan	2000(2013)	49	USA	35613(2009)
23	Kenya	33.1(2011)	50	Uruguay	1072(2013)
24	Kyrgyzstan	0.7(2013)	51	Uzbekistan	2.45(2013)
25	Lebanon	1.2(2011)	52	Venezuela	300(2005)
26	Lesotho	2(2011)	53	Zambia	200(2011)
27	Madagascar	6(2011)	54	Zimbabwe	332(2013)
	Worldwide	156991			

About 45% of the total area under CA is in South America, 32% in the Northern America, 14% in Australia and New Zealand 4% in Asia and 5% in the rest of the world including Europe and Africa. It seems that European and African countries are still considered as the developing continents in terms of CA adoption. However, due to hard and long lasting research effort of some governmental and private agencies of Europe and Africa i.e. NEPAD (New Partnership for Africa's Development), EC (European Commission), ECAF (European Conservation Agriculture Federation) and ACT (African Conservation Tillage), CA shows significant increment in rate of adoption in recent years. The area under CA is on the increase in all parts of Asia, and large areas of agricultural land are expected to switch to CA in the coming decade in China, Kazakhstan, and most likely in India. In South Asia, the concerted efforts over the past decade of Rice-Wheat Consortium for the Indo-Gangetic Plains (IGP), in countries like Bangladesh, India, Nepal, and Pakistan, now CA practices gaining importance mainly in intensively cultivated irrigated cropping systems. In the rice-wheat cropping system of South-Asia, wheat area under ZT has increased rapidly (Rice-Wheat Consortium, 2006). In India, the CA practices has been extensively tested through the combined efforts of several State Agricultural Universities, Indian Council of Agricultural Research (ICAR) institutes and the CGIAR system promoted Rice-Wheat Consortium on adaption, promotion and development of these practices resulted that now these technologies are finding rapid acceptance by the farmers and covering nearly 2 M ha area under rice-wheat system in IGP belt (Haryana, Punjab and Western Uttar Pradesh). Long term adoption of CA practices has been reported to increase the factor productivity and crop yields, enhanced agricultural sustainability, provided better income to the growers, ensure timeliness of cropping practices, reduction in drudgery, and improved ecosystem services which leads to diverse pattern of productivity, economic, social and environmental benefits from CA technologies. However, technical and financial support from governments, donor agencies and international organizations for CA research and development word wide has increased the adoption and uptake of CA in various countries which is expected to accelerate in the coming years under CA in recent years (FAO, 2013).

Concept of soil quality

Soil quality is one of the basic and fundamental indicators to access the feasibility of any crop management practice for sustainability. As better soil quality helps in maintaining sustainability of crop production system by conserving resource base, optimizing soil conditions and reducing food production vulnerability. Soil quality refers to the goodness of soil, to function within its natural ecosystem boundaries, to sustain agricultural productivity. It also maintains or enhances water and air quality, and support human health and habitation (Arshad and Martin, 2002). Soil health can also be defined as the constant capability of soil to work as a essential commodity for all living system, within particular ecosystem and land-use boundaries, to sustain biological productivity, maintain or enhance the quality of air and water, and promote plant, animal and human health (Doran and Zeiss, 2000). The use of term soil health has also emerged in recent years, as variation in ability of soils to suppress plant diseases is known since many decades (Janvier *et al*., 2007). Van Bruggen and Semenov, 2000 viewed soil health as a dimension of ecosystem health and explained soil health as the resistance and resilience of soil in response to various stresses and disturbances. Thus, there is a

considerable degree of overlap in the meaning of soil quality and soil health (Doran, 2002). Soil health perceptions tend to focus more on biotic components of soil (Anderson, 2003). Likewise term soil quality is related with soil degradation or deterioration in soil health or quality implies loss of the vital functions of soil viz. providing physical support, water and essential nutrients required for growth of terrestrial plants, regulation of the flow of water in the environment and elimination of the harmful effects of contaminants by means of physical, chemical and biological processes (Constanza *et al*., 1992). Soil quality has long been considered as important component of agricultural sustainability and treated as conceptual transformation of the concept of sustainability to be soil system restoration. Within the system of agricultural production, better soil quality related to the capacity of the soil to regulate a high productivity without any kind degradation in soil and environment. Soil quality can be accessed on the basis of physical, chemical and biological characteristics of the soil. With respect to biological soil quality, a high quality soil can be considered a 'healthy' soil. Management factors viz. tillage, residue management and crop rotations can modify soil physical, chemical and biological quality (Karlen *et al*., 1994). A comparative soil quality evaluation is one in which the performance of the system is determined in relation to alternatives. This assessment is useful for determining differences in soil attributes among management practices that have been in place for some period of time (Wienhold *et al*., 2004). The conclusion of aforesaid discussion suggests that the quality and health parameters of soil determine agricultural sustainability and environmental quality, which jointly determine plant, animal and human health (Doran, 2002). The alteration in management practices over long period of time can alter these physical, chemical and biological soil quality parameters and hence

considerably affect the agricultural system productivity. So, it is needful that a dynamic assessment is necessary for determining the direction and magnitude of change in a management practice (Wienhold *et al*., 2004), especially when compared to the common, existing farmer practices and it must be understood that this assessment normally must involve an adequate time frame.

CA and soil quality

Soil physical quality

Studies reveal that adoption of CA practices leads to significant improvement in soil physical environment and thereby soil quality over time (Lal, 2005; Verhulst *et al*., 2010). However, effects of CA on soil physical properties can vary from location to location depend on the tillage system and their intensity, agro-climatic condition and type of soil. For example, ZT systems which maintain residue retention over soil surface resulted in significant change in soil physical environment, especially in upper few centimetre of the soil (Anikwe and Ubochi, 2007). The beneficial effect of CA in term of better soil quality is reflects through improvement in physical soil properties like lower bulk density (BD), higher aggregate stability, enhanced water holding capacity and better soil structure.

Soil structure and aggregation

Among the physical factors, soil structure is one of the most important parameter that have strong correlation with soil quality and most often used to test the suitability of different tillage practices for crop production. In general, the degree of stability of aggregates is treated as sinonomious with soil structure (Bronick and Lal, 2005). Usually, soil structure stability is refer to the ability of aggregates to remain intact when exposed to

different biotic and abiotic stresses while soil aggregation is a dynamic process that depends on various agents such as soil fauna, roots, inorganic binding agents and environmental variable (Six *et al.*, 2004; Kay and Vanden Bygaart, 2002) and measures of aggregate stability are useful means for assessing soil structural stability. Soil Aggregation and their stability have great influences on water holding capacity, nutrient dynamics as well as on soil tilth (Hillel, 2004). Therefore, aggregated soil structure is most desirable characteristics for higher crop productivity. Soil management practices such as tillage can influence the quantity and persistence of binding agents, which may lead to aggregate formation or breakdown depends on tillage system chosen. Therefore, soil aggregation and structural stability can be used to evaluate agricultural management practices and select those that optimize crop growth and minimize soil and nutrient loss. Many studies shows that CA practices have been associated with higher stable aggregates in the surface soil than CT and this correspondingly results in high total porosity under CA. Intensive tillage in case of CT disrupts soil aggregates, fragments root and mycorrhizal hyphae, which are act as major binding agents for micro-aggregates leading to lower soil aggregation and structural stability in CT over CA (Wang *et al.*, 2015). Moreover, residue removal besides intensive disturbance in CT may also leads to interruption of different aggregate formation process over time (Six *et al.*, 2001). The intensive disruption of soil aggregates attributed to redistribution of the SOM which can influence the stability of macro-aggregates. In contrast, greater soil macro-aggregation due to reduced soil disturbance and maintenance of residue cover is important reason for higher aggregate stability with CA practices (Filho *et al.,* 2002). For example, Parihar *et al*. 2016 reported that continuous adoption of CA practices i.e. ZT and Permanent bed (PB)

along with residue retention over seven year resulted into 23 to 32.5 % higher water stable aggregates, 47.1 to 53.4 % higher mean weight diameter and 28.5 to 33.9 % higher geometric mean diameter compared to CT in 0-15cm soil depth, respectively. The lesser soil disturbance under CA practices reduces oxidation of SOC and hence improves storage of SOC, microbial diversity to the soil which enhances above listed physical soil parameters (Gathala *et al.*, 2011; Jat *et al*., 2013; Limon-Ortega *et al.*, 2002). Likewise, Bhattacharya *et al*. 2013 reported that continuous adoption ZT for 4 years at the fixed site had a greater proportion of large macroaggregates and mean weight diameter and their stability than CT in 0-5 cm soil depth. The intensive mechanical disruption of macroaggregates of soil which might have exposed previously protected SOC against oxidation leads to decline in aggregates size in CT (Pinheiro *et al.,* 2004; Kumari *et al.,* 2011). However, ZT promoted macro-aggregation, especially within the surface soil layer because of residue retention and less disruption of aggregates. The beneficial effects of ZT in term of better structural stability may also be partly due to higher activity of soil microbes such as earthworms and higher microbial biomass than in CT (Nyamadzawo *et al*., 2009). It has been widely reported that SOC have major role in aggregation and their stability, the retention of residue of previous crop over soil surface leads to buildup of SOC thus, improve soil structure and aggregation stability (Marcolan *et al.,* 2007; Madari *et al.,* 2005; Wright and Hons, 2005).

Crop residues received from previous crop has been reported to be associated with development of new soil aggregates through facilitating formation of nucleation centre which is essential for the formation of new aggregates by accelerating the pace of microbial activity at the point where these soil

aggregates are developed (De Gryze *et al.*, 2005). Govaerts *et al.* 2007 reported that the mean weight diameter and stability of soil aggregates was significantly higher with residue retention and decreased with decreasing amounts of residues under rainfed PB planting system at subtropical highlands of Mexico. Similarly, Wang *et al.* 2015 from China, also reported the beneficial effect of residue management under semi-arid climate where the practice of residue retention significantly increased mean weight diameter and stability of soil aggregates in the magnitude of 16.1–40.3%, 10.1–36.0%, 11.0–36.3% compared to residue removal in 0–10, 10–20, 20–30 cm soil depth, respectively. Similar outcome were obtained by Limon-Ortega *et al.* 2006, while working in an irrigated system, where the soil aggregates obtained from PB system showed higher rate of dispersion with residue removal while lowest where all residue was retained over the soil surface. In CA, the practice of residue retention over soil surface has not only reported to accelerate the pace of aggregate formation, but also known to act as strong binding agent therefore reduce the breakdown of aggregates by arresting the problem of soil erosion by protecting them against raindrop impact.

Cropping systems are often known to have strong influence over soil aggregation and their stability. Altering crop rotation can influence SOC by changing quantity and quality of organic matter input (Govaerts *et al.*, 2009) and thus indirectly has the potential to alter soil aggregation. For example, inclusion of legumes in crop rotations can influence soil aggregation and their stability because of the higher binding capacity of their fine roots as well as organic substances that released from legumes roots are known to contribute to the formation of new soil aggregate (Hillel, 2004). Numerous studies proved that ZT, with inclusion of legume crops and/or retention of legume residue

under intensive crop rotations can increase SOC, improve aggregation as well as their stability, and preserve the nutrients for plant and soil micro-organisms (Jacobs *et al.*, 2009). For example, Raimbault and Vyn, 1991 reported that inclusion of legume under maize based intensive rotations had higher proportion of fine aggregates as well as and soil aggregate stability. Similar results also reported by Bissonette *et al.,* 2001 with inclusion of mungbean in barley-maize rotation that resulted into 6.7% higher mean weight diameter of soil aggregates in mould-board ploughing system and 33.3% in chisel ploughing system, compared to the maize monoculture. However, an another study shows positive effect of the incorporation of legume residues by tillage rather than leaving them on the soil surface, which could result in better contact between soil particles and soil microbes in maize-wheat cropping system (Christopher *et al.*, 2009; Zhao *et al.*, 2012). In, Parihar *et al.*, 2016 reported that inclusion of chickpea and mungbean in intensive maize based rotation attributed significantly higher water stable aggregates, mean weight diameters and geometric mean diameter compared to continual maize and maize succeeding by mustard in rotations under north-western Indo-Gangetic-Plains (IGP) of India. These finding of higher water stable aggregates with inclusion of legume in intensive crop rotations are in close agreement with Six *et al.*, 2002 and Biswas *et al.,* 2009. Inclusion of legumes in intensive maize based rotation might result in higher SOC due to faster and easier decomposition of lower C: N ratio legume residues and root nodules which ultimately favour higher physical soil quality. The similar relationships of SOC with soil aggregation properties were also reported by several other researchers elsewhere (Srinivasarao *et al.*, 2013; Filho *et al.*, 2002; Six *et al.*, 2002; Pinheiro *et al.*, 2004). Thus enhancement in SOC content is important for better soil aggregation.

Hydraulic conductivity

Hydraulic behavior of the soil was found to be significantly and positively correlated with the total soil macro-pores and tillage practices has potential to alter macro-pores of the soil by affecting setting and consolidation of soil particles over time (Rasse *et al.,* 2000). Hydraulic conductivity would be expected to be higher in ZT compared to CT due to the larger macropore conductivity as a result of the increased number of biopores (Eynard *et al.*, 2004; McGarry *et al.*, 2000). However, the reported outcomes are mix in nature which might be partly due to difficulty in measuring hydraulic conductivity under presence of residue cover over the surface in ZT that interfere with measurement instruments or the removal of undisturbed samples and cores that may attribute high variation in values of hydraulic properties of the soil (Strudley *et al.*, 2008). Moreover, the depth of soil sampling, soil texture, gradient of soil, tillage system and amount of residue retention are also known to create large differences in soil hydraulic conductivity and water-holding capacity (Blanco-Canqui *et al.*, 2006). Many researchers have found that ZT significantly improved saturated and unsaturated hydraulic conductivity owing to either continuity of pores or flow of water through very few large pores (Bhattacharya *et al.* 2006). Greater number of macro-pores, little soil disturbance to soil and presence of litter of well decomposed residues formed by accumulated organic matter is main cause of better hydraulic conductivity under CA practice over CT (McGarry *et al.*, 2000; Osunbitan *et al.*, 2005). Likewise, Kahlon *et al.*, 2013 and Chen *et al.* 2014 found that reduced tillage significantly increased the initial soil infiltration capacity over CT which resulted in higher saturated and unsaturated hydraulic conductivity of the soil as compared to CA. Parihar *et al.* 2016 reported, that after seven year of adoption the saturated conductivity of the a sandy loam soil increased by 14.3 and 11.2 % in PB planting and 11.1 and 12.0 % in ZT in 0-15 and 15-30 cm soil layers, respectively, compared to CT in north western IGP of India. The increase in saturated conductivity under PB and ZT was mainly attributed to decrease in BD and increase in effective pore volume (Rasool *et al.*, 2007; Li *et al.*, 2011) due to better soil aggregation.

Singh and Malhi, 2006 reported that after six years of adoption of different tillage and residue management practices over two different soil texture i.e. Black Chernozem and a Gray Luvisol at Alberta, Canada, the saturated hydraulic conductivity of Black Chernozem was significantly lower (33%) under ZT than under rotovetor tillage. However, the practice of residue retention improved saturated hydraulic conductivity of Black Chernozem soil in both ZT and rototillage system while, the steady-state infiltration rate of Gray Luvisol, was not significantly affected by tillage and residue management. The exact quantification regarding impact of residue management on hydraulic conductivity of soil is very tricky task, largely because of the difficulty in measuring hydraulic conductivity when residue is present over the soil surface. The residue present over the soil surface may cause variation in soil hydraulic conductivity in two ways either by interfering with installation of measurement instruments or by causing obstacles in the removal of undisturbed samples and cores. In general the practice of residue retention in combination with ZT or independently reported to improved soil hydraulic behaviour over time. The positive effects of residue retention on soil hydraulic conductivity are largely due to the production and preservation of greater number of macropores by undisturbed root channels, decaying organics in upper soil surface as well as subsurface, and presence

passageways of soil microbes such as earthworm and faunal. The diversified crop rotations also significantly affected the saturated conductivity and it increased by 9.3 and 5.9 % with inclusion of legumes in maize based intensive rotations compared to monoculture. The lowest hydraulic conductivity under maize monoculture may be due to higher BD and lower aggregate stability compared legume inclusion.

Soil bulk density

The beneficial effect of CA based tillage and residue management in terms of lower bulk density is more subjected to the topsoil (0-15 cm) (D'Haene *et al*., 2008; Gál *et al*., 2007; Thomas *et al*., 2007). Continuous adoption of CT may be lead to formation of plough pan underneath the furrow slice, attributed to higher BD in this horizon in tilled situations compared to CA (Hernanz *et al*., 2002; Dolan *et al*., 2006). Reduction in intensity of tillage operations through adoption of CA practices would be expected to result in a progressive reduction in soil compaction over time (Kay and Vanden Bygaart, 2002). It has been reported that long term application of CA practices associated with lower soil BD and penetration resistance. More aggregated and friable soil due residue retention and minimum soil disturbance of soil leading to lower compaction which accounted for lower soil BD under CA compared to CT (Jat *et al*.,2013;Obalum and Obi 2010; Blanco-Canqui *et al*., 2006). For example, after long-term adoption tillage practices (24 years) the soil BD was 28.2% higher in CT than ZT (Utomo *et al*., 2013). Parihar *et al*., 2016 reported that after adoption of CA practices for seven years, the soil BD lowered by 4.3 to 6.9 % in 0-30 cm soil profile than CT. The decrease in soil BD under CA could be due to higher SOC, better aggregation, increased root growth and biomass (Salem *et al.,* 2015). Further, inclusion of legumes in intensive maize based rotations resulted into

significantly lower soil BD compared to monoculture of maize. The higher SOC and differential chemical composition of crop residues and root biomass brings out differential addition of SOC (Congreves *et al*., 2015) that leads to difference in soil BD. The similar findings of lower BD due to pulses inclusion were also reported by Verhulst *et al*. 2011 and Thierfelder *et al*. 2012. After 7 years of adoption, the soil PR decreased by 15.9 to 27.1 % in ZT and 15.8 to 30.7 % in PB compared to CT in 0-50 cm soil depth. The compaction caused through development of plough pan and higher BD under CT practices enhances the soil resistance which might contribute to higher soil PR in repeated tilled soil (Saha *et al*., 2010). Similar to tillage practices, inclusion of legumes in intensive maize based rotations resulted into significantly lower soil PR compared to monoculture of maize (Parihar *et al*., 2016). Unger and Jones, 1998 also reported that the PR differed due to crop rotations, being lower for continuous wheat (1.79 MPa) than for wheat-fallow (2.32 MPa) or wheat-sorghum-fallow (2.42 MPa). Residue retention had a significant impact on soil BD in the in upper soil surface (0-10 cm) while the difference at deeper soil depth (10-20 cm) cm were not found significant (Blanco-Canqui and Lal, 2008). Annual application of rice straw reduced the soil BD by 58% in 0-3 cm and 36% in 3-10 cm soil depth as compare to unmulched treatment. Likewise, Lal, 2000 found that application rice straw decreased soil BD from 1.20 to 0.98 Mg m^{-3} in the 0-5 cm layer on a sandy loam. Similar results were also reported by Blanco-Canqui *et al*., 2006.

CA and soil chemical quality

Soil organic carbon

Declining fertility status of cultivated lands due to declining level of SOC is a major

anxiety especially in Asian and African countries left their soils with lower crop productivity and resource use efficiency. SOC being keystone to soil quality also reported to an important indicator of agricultural sustainability. Restoring SOC is important not only to achieve food security and soil quality but also to offset the negative impact of agricultural related climate change (Lal, 2004). Many researchers claimed that intensive tillage practices increases oxidation of SOC although the rate is climate and soil dependent, leading to lower SOC content over time. The loss of SOC can be ameliorated or minimized through long term adoption of CA practices that reduces its oxidation by causing less mixing of the soil. Another reason for accumulation of SOC under CA is presence of residue mulching which act as physical cover against soil erosion. Therefore, one would expect a substantial enrichment of SOC under CA compared to CT, especially in soils with relatively low initial organic matter status (Halvorson *et al.*, 2002). Among the CA practices, over last three decades, ZT have been intensively tested, applied and demonstrated in order to maintain or improve the stock of organic carbon in soil and reduce CO_2 emissions (Dimassi *et al.*, 2014). A comparative analysis of SOC under different medium and long term studies revealed that ZT accounted higher SOC in the tune of 3.86-31.0% over conventional tillage (Balota *et al.*, 2004; Govaerts *et al.*, 2009). They also suggested that to achieve the beneficial effect of ZT in terms of higher SOC, its long term implementation is essential. Likewise, Machado *et al.* 2001 found that adoption of ZT resulted into significant increase in total carbon (30%), active carbon pool (10%), and passive carbon pool (18%) compared to CT (Aziz *et al.* 2015). The higher SOC under ZT might be due to increased soil aggregation that can store more carbon over CT. Thus, ZT is recognized as promising strategy to maintain or even improve SOC stocks in soil

(Bayer *et al.*, 2000). Adoption of CA practices (PB and ZT) over long run (7 years) recorded significant higher SOC (23.6 to 35.3 %) than the CT under 0-15 cm (Parihar *et al.*, 2016). The intensive tillage in case of CT increased organic matter decomposition and enhanced its oxidation (Balasdent *et al.*, 2001; Balota *et al.*, 2003; Thomas *et al.*, 2007) that leads to lower SOC under CT compared to CA. In contrast, the crop roots remain intact in the root zone due to non-disturbance of the soil under CA practices (PB and ZT) which might facilitate enhancement of SOC through their decay. The enhancements in SOC due to CA practices were also reported by Baker *et al.,* 2007; Thomas *et al.*, 2007 and Kaiser *et al.,* 2014.

Usually, SOC changes proportionally to the amount of crop residues returned to the soil, agronomic management practices that influence yield and affect the residues returned to soil are likely to influence SOC (Campbell *et al.*, 2000). Returning more crop residues associated with an increase in SOC concentration of the soil (Wilhelm *et al.*, 2004). Some studies suggested that apart from tillage system chosen, crop rotations also known to have significant positive impact on SOC. For example, Amado *et al.*, 2001 reported significantly more SOC when leguminous cover crops added to the rotation in conjugation with ZT. Besides enriching with SOC, legumes also added a substantial quantity of N to the soil, which results in increased biomass production of the succeeding crops (Bayer *et al.*, 2000). Long term inclusion of legumes in intensive maize based rotations resulted into 18.9 and 20.4 % higher SOC in 0-30 cm soil depth compared to monoculture of maize (Parihar *et al.*, 2016). This might be due to differences in quantity and chemical composition of crop residue biomass and/or root exudates among the residues of cereals and legumes (Congreves *et al.*, 2015). Further, the lower

C:N ratio of legume residue caused rapid decomposition and hence attributed to higher SOC compared to monoculture of maize. The results of some of long-term experiments have suggested that to get the full benefit of ZT in terms of higher it should be used in conjugation legume in crop rotations (Bolliger *et al*., 2006). Crop rotation with legume component and ZT tends to build up of SOC in the soil (Greenland and Adams 1992). For example, Calegari *et al*. 2008 found that no tillage with winter cover crops resulted in the greatest SOC content, most closely to native undisturbed forest. Thierfelder *et al*. 2015 found 31% greater SOC with inclusion of cowpea and sun hemp in maize based crop rotations. Saha and Ghosh, 2013 also reported the positive effects of legume residue application in cereal cropping systems on soil carbon content.

Formation of higher soil micro-aggregates under CA is considered as major mechanism of carbon sequestration in soil (Six *et al*., 2000). Carbon sequestration accountable when net addition of SOC through crop residues exceeds carbon removal in term of crop harvest harvested, microbial respiration, carbon emissions from fuel and the manufacture of chemical fertilizers, etc.). To achieve positive carbon stock in the soil, we must need to either increased carbon inputs to the soil, decreased oxidation of SOC, or a combination of both (Paustian *et al*., 2000; Follet, 2001). CA as retained a significant portion of crop residue on soil surface rather than mixing into the soil as under CT, facilitate slower decomposition of organic matter on one hand and reduce CO_2 emission from the soil on other leading to net fixation or sequestration of carbon in the soil (Bot and Benites, 2005).

Nutrient dynamics

Tillage, residue management and crop rotation can strongly affect the nutrient dynamics of any soil through their effect on mineralization and recycling of soil nutrients (Galantini *et al*., 2000). It is believed that long-term adoption of CA practices can lead to higher buildup of nutrients in top soil due to larger nutrient mineralization potential of soil as compared to CT (Rasmussen 1999; Duiker and Beegle, 2006). The benificial effect of CA in terms of higher nutrient availability partly may be due to crop residues retention over soil surface in comparison with incorporation of crop residues with CT (Ismail *et al*., 1994) and partly due to arresting their leaching losses by reducing decomposition of surface placed residues (Balota *et al*., 2004; Kushwaha *et al*., 2000). However, the response of soil chemical fertility to different tillage practices is reported to be varying with location to location, soil type, cropping systems, climate, fertilizer and other agronomic management practices (Rahman *et al*., 2008).

Effects of CA on soil nitrogen (N) content usually in line with those observed for SOC, as the N cycle is inextricably linked to the carbon cycle (Bradford and Peterson, 2000). Intensive tillage reported to increases disruption of soil structure, making SOC more accessible to soil microbes (Six *et al*., 2002, Beare *et al*., 1994) and increasing mineralization of N from active and physically protected N pools (Christensen *et al*., 2000). Higher amount of stable microaggregates and increased levels of physical protection of carbon as well as N were repoted under PB planting compared to CT (Lichter *et al*. 2008).

Govaerts *et al*. 2006 found that after long term adoption of CA (26 cropping seasons) in an input responsive well irrigated production system, the N mineralization was higher in PB with residue retention than in CT with residues incorporation. ZT with residue retention over long run can enhances the supplying power of soil that leads to higher

soil available N as compared to CT. The composition (C:N, lignin, polyphenols and soluble C content) of residues will affect their decomposition as the CN ratio together with initial N, lignin, and polyphenols is one of the most often used criteria for residue quality and its rate of decomposition (Hadas *et al*., 2004; Nicolardot *et al*. 2001).

During the decomposition of organic matter, inorganic N can be immobilized (Zagal and Persson, 1994), especially when organic material with a large CN ratio is added to the soil. N immobilization can occur as a consequence of cereal residue retention, especially during first few years of implementation of CA (Erenstein, 2002). Many literature advocate that CA practices associated with lower level of soil N because of greater immobilization by the residues left on the soil surface (Bradford and Peterson, 2000). This temporary but higher immobilization of N under CA reduces N losses by reducing the chance of leaching and denitrification of mineral N (Follet and Schimel, 1989).

Numerous studies also showed P stratification in soil under different tillage systems where ZT system associated with higher concentration of P due to preferential movement of P in the soil (Abdi *et al*., 2014). Moreover, the shallower incorporation of crop residues and fertilizer P as well as small P losses due to water erosion under CA leads to higher P contents in the surface soil. Piegholdt *et al.* 2013 also reported 15% higher total P content in the top soil (0-5 cm) of ZT plots as compared to CT due to larger P addition from decomposition of residues retained on the soil surface. Likewise, higher P levels in ZT than in CT were reported by other researchers (Du Preez *et al*., 2001; Duiker and Beegle, 2006). The higher values of available P under CA practices largely due to reduced mixing of the fertilizer P with the

soil, leading to lower P-fixation. This is a benefit when P is a limiting nutrient, but may be a threat when P is an environmental problem because of the possibility of soluble P losses in runoff water (Duiker and Beegle, 2006). Franzluebbers *et al*., 1995 suggested that adoption of ZT leads to redistribution of P compared CT because of direct result of surface placement of crop residues that leads to accumulation of SOC and microbial biomass near the surface. Franzluebbers and Hons, 1996 and De Oliveira and Pavan, 1996 also observed higher P levels, probably due to the accumulation of P in soil and the higher SOC content of the soil. Roldan *et al*., 2007 reported that available P was not affected by tillage system and crop rotations.

CA practices can conserves and increases availability of K, near the soil surface where crop roots proliferate (Franzluebbers and Hons, 1996). According to Govaerts *et al.,* 2007 PB had 1.65 and 1.43 times higher concentration of K in the 0-5 cm and 5-20 cm respectively, than CT. Ismail *et al.,* 1994 also reported higher extractable K levels at the soil surface with ZT as tillage intensity decreased. Du Preez *et al.,* 2001 observed increased levels of K in ZT compared to CT, but this effect declined with depth. Govaerts *et al.,* 2007 found that the K concentration in both the 0-5 cm and 5-20 cm soil layers increased significantly with increasing residue retention under PB planting compared to CT. No effect of crop rotation on K concentrations was observed by Roldan *et al.,* 2007. However, Yadav *et al.,* 2016 reported that after seven years of CA the highest amount of N, P and K (219.8, 24.9 and 203.1 kg ha^{-1}) in 0-15 cm soil surface was recorded under PB planting while minimum amount of available N, P and K were observed under CT. The recycling of the higher amount crops residue of previous due to higher biomass yield in PB treatments lead to addition of more nutrients compared to CT. While, in case of CT the stover/ straw get

incorporated in deep soil layer and which leads to rapid decomposition and might also lead to leaching of mineralized nutrients in much deeper soil layers which in turn reduces the available these nutrients in CT. Moreover, the chelating of these nutrients with organic matter in non-disturbed soil leads the improvement of soil nutrient status in different soil depths (Borie *et al.,* 2006; Singh *et al.,* 2014) and thus causes enhancement of soil NPK status. The similar findings of enhancement in available nutrients due to CA practices in soil were also reported by Graham *et al.,* 2002; Borie *et al.,* 2006 and Wang *et al.,* 2008 for N; Malhi *et al.,* 2011 for P and Du Preez *et al.,* 2001 and Govaerts *et al.,* 2007 for K. The enhancement in available NPK status due to ZT and PB practices was also reported by Parihar *et al.,* 2011. Most research reported that tillage practices does not affect extractable Ca and Mg levels of soil (Govaerts *et al.,* 2007; Duiker and Beegle, 2006) primerily in the condition where CEC is associated with clay particles (Duiker and Beegle, 2006). However, Edwards *et al.,* 1992 found higher extractable Ca with CA than CT due to the higher levels SOC under CA. The Ca concentrations were higher in the 0–5 cm layer of ZT than in the deeper layers in the work of Duiker and Beegle, 2006 but the reverse was true for mouldboard tillage. This could be attributable to the tillage after the last lime application (calcitic limestone) in the mouldboard treatment.

Increasing supply to food crops of essential micronutrients might result in significant increases in their concentrations in edible plant products, contributing to consumers' health (Welch, 2002). Micronutrient (Zn, Fe, Cu and Mn) tend to be present in higher levels under ZT with residue retentions compared to CT, especially near the soil surface (Franzluebbers and Hons, 1996). In contrast, Govaerts *et al.,* 2007 reported that tillage

practice had no significant effect on the concentration of extractable Fe, Mn and Cu, but that the concentration of extractable Zn was significantly higher in the 0-5 cm layer of PB planting compared to CT with full residue retention. Similar results were reported by Du Preez *et al.,* 2001 and Franzluebbers and Hons, 1996. Residue retention significantly decreased concentrations of extractable Mn in the 0-5 cm layer in PB compared to CT (Govaerts *et al.,* 2007). However, according to Peng *et al.,* 2008, the Mn concentration was higher under CA as compared to CT due to increased SOC content.

CA and biological soil quality

Soil being richest source of living organism represents one of the most diversified habitats over earth. It has been estimated that 1 gram of soil contain millions of living organism (bacteria, fungi, mycorrhiza, protozoa, nematodes, earthworms, mites, enchytraeidsants, termites, beetles and spiders etc) (Hawksworth, 1991; Hawksworth and Mound, 1991). Improvement in ecosystem function and services of arable soils through enhancement of microorganism diversity is well known thus the microbial biomass and their functional diversity is used as sensitive indicator to access the soil quality (Médiène *et al.,* 2011). Since, due to exponential increase in global population, the demands for food are likely to increase substantially, the major challenge for present population is to enhance the food production with the use of soil management practices that can maintain soil biodiversity. Intensive cultivation of soil for longer period leads to reduced microbial biodiversity compared to uncultivated soils and/or less disturbed soil. Impact assessment of tillage practices on soil microbial diversity and to understand ecosystem functions and services that are linked with soil microbes is main challenge for development of strategies toward conservation of soil biodiversity of

agro ecosystem (Brussaard *et al.,* 2007; Giller *et al.,* 2005; Temme and Verburg 2011). In this aspect CA practices were widely tested and have potential to reach the goal of safe productivity conserving or sustaining soil biodiversity (Holland 2004).

The soil organic matter (quantity, quality and its distribution in the soil) is major factor that strongly affect diversity, biomass and activity of soil microorganisms as it is the basic food source for soil biota (Wardle 1995). CA practices such as ZT and reduced tillage systems are known to reduce land degradation through arresting soil erosion and enhance SOC which sustains soil health (Dao, 1993; Woods and Lenne, 1997). Usually, the microbial diversity is negatively correlated with intensity of tillage (Kladivko, 2001; Jinbo *et al.,* 2007). The impact of soil tillage over microbial parameters of soil mostly determined through climate, location and below as well as above environmental conditions. Therefore, one should consider all these factors before choosing tillage practices for crop production. The following sections review implications of soil tillage on soil microorganisms. To assess the impact of soil tillage on soil diversity the microbes of soil soil fauna divides into following groups (A) Microfauna (i.e. Bacteria, Mycorrhiza, Protozoa, Nematods, etc.) (B) Mesofauna (Enchytraeidae, Collembola, Acarina, Protura and Diplura) (C) Macrofauna (Gastropoda, Lumbricidae, Arachnida, Isopoda, Myriapoda, Diptera, Lepidoptera, Coleoptera) (Lavelle 1997).

Microfauna

Microfauna includes a wider range of soil microbes that mostly engaged in utilizing low molecular weight organic compounds of the soil solution. This class of microorganism plays many important roles in variety of functions soil. Soil tillage, has strong impact on bio-chemical behavior of soil imparted through mechanical manipulation of soil subjected (Hassen *et al.,* 2007). Long term adoption of CA supposed to be enhancing not only the biological activity but also their biomass and diversity compared to CT (Lupwayi *et al.,* 2001). Soil bacteria represent an important group of microbes, their activities and diversity very with soil to soil and tillage practices and crop rotations reported to have strong effect on them, especially, the *Rhizobium* bacteria that engaged in biological N_2- fixation (Ferreira *et al.,* 2000). For example, Dogan *et al.,* (2011) reported that adoption of ZT with residue retention resulted into significantly higher number of effective nodules as compare to CT with burnt residue. The lower value of nodules in CT plots where plant residue was burnt may be due to destruction of *Rhizobium* bacteria's because of higher temperatures of soil. Moreover, the diversity and activity of *Rhizobium* bacteria's has been reported to negatively correlate with intensity of soil tillage (Ferriera *et al.,* 2000 and Hassen *et al.,* 2007). Many researchers reported that long-term adoption of CA encouraged diversity of *Agrobacterium* spp. and *Pseudomonas* spp. (Hoflich *et al.,* 1999). Many similar studies conducted in different agro-ecological conditions and locations were resulted that CA had positive effects on soil microbial activities (Hassen *et al.,* 2007). The lower levels of SOC which is most important for maintain vital functions and diversity of soil microbes, reported as key reason for lower functional diversity of soil microbes with CT. The similar results of lower soil microbial activity with decreased levels of SOC were also reported by Patra *et al.,* 2008. Many reports suggested that residue buildup was also a reason for abundance of bacteria under CA (Hammesfahr *et al.,* 2008 and Ceja-Navarro *et al.,* 2010).

Being a sensitive bioindicator of soil quality as well as ecosystem services and their fundamental loci in soil food webs (Neher

2001), the soil nematodes have been widely studied biological parameter of the soil (Yeates, 2003; Sanchez-Moreno *et al.,* 2011), and used to analyze soil food web dynamics in ecosystems (Ferris and Matute, 2003; Briar *et al.,* 2007; Sanchez Moreno *et al.,* 2011 and DuPont *et al.,* 2009). The impact assessment of tillage on nematode dynamics is relatively easy due to quick assessment about diversity, body weight and length therefore its used as descriptive indicators of soil quality (Fiscus and Neher, 2002; Ferris, 2010; Mills and Adl, 2011). Soil nematodes communities play a critical role in wider range of soil functions. The most of free-living nematodes communities are known for nutrient recycling and attributed for nearly one third of the total nitrogen mineralisation (Griffiths, 1994). Soil water have strong impact on functions of the soil nematodes as its act as a medium for their movement. Beside, soil moisture, their function and diversity largely susceptible to soil structure, porosity and compaction, and therefore soil tillage. However, the response of soil nematode communities to tillage can very not only with functional groups of nematode but also other factors such as the cropping and retention of crop residues (McSorley and Gallaher, 1995; LopezFando and Bello, 1995). For example, Zhang *et al.,* (2012) reported that maximum nematode dynamics found under treatment that retained 100% crop residue followed by in treatments having 50% residue and least in residue removal for both no tillage and deep tillage. Moreover, specific genus of soil nematode found to be respond specific to particular tillage and residue management. For example, the direct abrasion and changes in soil structural change caused after mechanical manipulation of soil in case of tillage while their larger influence on various nutrient recycling in case of crop residue were known to different specific mechanism attributed for specific response of soil nematode communities (Kladivko, 2001 and Rahman *et*

al., 2007). Reduced tillage resulted into higher numbers of nematodes and mites compared with conventional tillage and it proved that population as well as functions of soil microorganism can be limited through intensive soil tillage. However, soil nematodes and mites, responded deferentially to the tillage practices that may lead to reduction or stimulation (Wardle 1995). The differential respond of these organisms attributed due to type of soil, climate, location and tillage system chosen. Usually, the response of mite to tillage system is closely similar to soil nematodes therefore their dynamics in soil were greatly correlated with each other. As we know that in agro-ecosystem most soil nematodes are known as bacterial and fungal feeders and soil mites were fungivorous therefore they lies the tropic level immediately above bacteria and fungi (Carter *et al.,* 2009).

Mesofauna

Mesofauna are known to play a critical role not only in improving soil fertility but also in stabilizing the soil structure by encouraging the rate of microaggregates formation of soil. Mesofauna represent a range of tropic levels and known to feed on plant litter and soil microbes (microflora and mesofauna) (Miyazawa *et al.,* 2002). Potworms (Enchytraeidae), is known to share largest portion of mesofauna and its dynamics and function strongly depends on levels of SOC. Due to their small size and higher reproductive potential, the potworms diversity were reported to be unaffected by tillage (Didden *et al.,* 1994). However, vertical distribution of potworm reported to strongly affected through tillage and under CA, they are most abundant near the soil surface but are more evenly distributed under CT ploughed fields. Springtails (Collembola) and Acari (mites) also play a critical role in nutrient recycling, especially, when organic

manures were used as major source of nutrient that encourage their preferred fungal food (Reeleder *et al.,* 2006). Due to their relatively larger size, they are more easily sampled so effects of tillage and crop rotations over their diversity and functions can be more visible (Wardle 1995). For example, ZT reduced the abundance of Collembola in sub surface soil (Moore *et al.,* 1985). However, with ZT the population of Collembola and crypostigmatic mites was significantly higher at the soil surface (0–3 cm) (Vreeken-Buijs *et al.,* 1994). Moreover, the vertical distribution of the microarthropods depends on soil tillage and compaction and CA practices reported with the higher density of macropores, which facilitating vertical distribution of microarthropods (Schrader and Lingnau, 1997).

Reeleder *et al.,* 2006 reported that mite population in soil was more affected by crop rotation as compared to tillage practice, with higher populations in a system with a rye cover crop than in with fallow.

The effect of tillage practices and residue retention over mites population was reported to be variable and different groups of mites known to respond differently to tillage systems. It has been reported that the prostrigmatic, cryptostigmatid and mesostigmatid mites population were inhibited under CT compared CA practices. However, the diversity of astigmatid mites may be inhibited by tillage but known to recover within short span of time after tillage (Reeleder *et al.,* 2006). Some individuals may killed by abrasion caused by extreme physical disturbance during intensive tillage operation or by being trapped in soil clods are after tillage (Kladivko, 2001) that leads to lower functional diversity of this group of microbes with CT.

Macrofauna

This group includes a range of microbes that known to be more sensitive to agro-ecosystem services (Chan 2001). Tillage, due to their large size had strong negative effect on their population through direct physical disruption as well as habitat destruction (Kladivko 2001). In addition, residue incorporation in case of CT further could limit recolonization of soil biota through redistribution of their food source as well as greater water and temperature fluctuations. Lumbricidae (earthworms) that represent a major group of macrofunna, known to modify the soils structure by the creation of burrows, which can control infiltration and drainage, and combined with the binding ability of casts, decrease the risk of erosion (Arden-Clarke and Hodges, 1987). Earthworms mainly engaged in mixing of organic matter and formation of humus, alter the nutrient dynamics, and encouraging microbial activity. Many studies suggested that earthworm diversity is directly affected through tillage practices, but the impact can varies with species, soil type, climate and type of tillage practices (Chan 2001). CT, that cause intensive soil inversion can exposes earthworms to predation and desiccation (House and Parmelee 1985) and known to cause more damage especially deep burrowing (anecic) species of earthworms (Kladivko *et al.,* 2001). However, CA especially combined with residues retention has been reported to increase the earthworm diversity near soil surface (Kladivko, 2001). Earthworm casts associated with formation of stable organo-mineral complexes that promote soil macroaggregate stability and reduce loss of nutrients (Six *et al.,* 2004). The activity of earthworm in soil is also reported to be directly correlated with infiltration and they improve it through enhanced soil surface roughness and increased soil macroporosity (Blanchart *et al.,* 2004). Long term adoption

of CA leads to significant enhancement in earthworm activity i.e. over 10 years it was 36% higher under CA compared CT (Jordan *et al.,* 2000). CA practices shown their positive effect on earthworm populations under may be especially drier climates Pacific North West, whether earthworm activity was recorded six times higher after 30 years of adoption (Wuest, 2001). The gastropods, isopods and myriapods are other major member of macrofauna and being large in size, considered the most sensitive to tillage practices and as a result, they are present in soils subjected to deep tillage (Ekschmitt *et al.,* 2005). These microbes are known to feed on green organic matter and their faeces encourage microbial activity leading to the formation of soil aggregates and humus. CA practices have reported to encouraged the functional diversity of these groups by as most of the crop residues remain available on the soil surface and physical structure is retained due to reduces soil disturbance which facilitating their movement within the soil. The soil also acts as a rich source of a range of predatory arthropods, especially the members of Coleoptera and Arachnida. Tillage has both direct effect (by causing mortality and indirect effects (by modifying their habitat and the availability of prey). Termites and ants respresent an important groups of siol microbes under arid and semi-arid regions where earthworms are normally absent or scarce (Lobry de Bruyn and Conacher, 1990). In general, both ant as well as termites was reported to improve soil infiltration by enhancing soil aggregation and porosity (Nkem *et al.,* 2000). Some group of termites also having tendency of feeding on soil and help in formation of microaggregates either through production of faecal pellets or by mixing the soil with saliva (Bignell, 2010). However, the amount of crop residue that incorporated or retained on the soil surface is act as main force which largely decide the stability of soil structure (Six *et al.,* 2004).

Ants well known agent which can change soil bio-physico-chemical behaviour of soil by enhancing SOC turnover, causing pedoturbation and by reducing Ca, Mg, K and Na concentrations, especially in boundaries of their hills and paths in soil (Nkem *et al.,* 2000). It has been hypothesized that nutrients stored in active mounds of ants are not readily accessible to plants as well as agents of soil organic matter decomposition, therefore ants cause redistribution of nutrients in the soil when their mound is abandoned. CA practices such as ZT in combination with proper residue retention have been recognised as key management practices which favour ants and termites populations in agro-ecosystems.

Microbial biomass carbon (MBC)

MBC is a breathing part of the soil organic matter which plays a critical role in nutrient transformation and not only a good source of carbon, nitrogen, phosphorus and sulfur but also improves the physico-chemical environment of soil (Angers *et al.,* 1992). Continuous use of CA based management practices leads to reduction in soil disturbance which can stimulate soil microbial biomass and improve its metabolic rate, resulting in better soil quality, which in turn, can increase crop productivity (Hungria *et al.,* 2009). These favorable effects of CA based tillage practices such as zero tillage; permanent bed planting and residue retention on soil microbial populations are mainly due to improved soil aeration, favorable soil microclimate, lower temperature and moisture fluctuations and higher accumulation of carbon in surface soil (Doran 1980). Salinas-Garcia *et al.,* 2002 reported that MBC were significantly affected by various crop establishment tillage, primarily into upper 0-5 cm soil surface which was 25–50% greater with ZT and minimum tillage than with CT. Likewise, Gonzalez-Chavez *et al.,* (2010) reported that NT soils had nearly double

contents of MBC and microbial biomass nitrogen as compared to CT. Dong *et al.,* 2009 also reported that the mean annual MBC was highest in the ZT with residue, while lowest in CT without residue. Similarly, Silva *et al.,* 2010 consistently found higher values of MBC and microbial biomass nitrogen up to more than 100 % under NT in comparison to CT. NT soils with crop residue addition had more available substrates than CT and this promotes microbial growth and assimilation of nutrients, leading to an increase in soil microbial biomass and activity of such soils (Buyer *et al.,* 2010). Cartert and Rennie, 1982 observed that the surface depth under zero tillage was enriched in MBC which was l4-28% higher in comparison to the corresponding depth under CT, while the reverse phenomenon was observed at lower depths.

Soil enzymatic activity

Tillage disturbs the natural state of soil and lower enzymatic activities would be expected under intensively tilled soils due to higher oxidation of soil organic matter under these crop management practices (Melero *et al.,* 2011). CA based tillage increase the enzymatic activities in the soil profile, probably due to of similar vertical distribution of organic residues and microbial activity and these positively altered soil enzymes which play significant role in catalyzation of reactions obligatory for organic matter decomposition and nutrient cycling as well as involved in energy transfer, improvement of environmental quality and crop productivity (Dick, 1994).

Soil fluorescein di-acetate (FDA) hydrolysis is a measurement of the contribution of several enzymes, mainly involved in the decomposition of organic matter in soil. Hence, the higher the values of FDA hydrolysis are a sign of positive soil health

and microbial activity. Vargas *et al.,* 2009 had been noticed higher levels of fluorescein di-acetate (FDA) hydrolysis under ZT than CT systems. Likewise, higher activities of FDA hydrolysis also noticed by Seifert *et al.,* 2001. Soil Dehydrogenase (DH) enzymes are one of the main components of soil enzymatic activities participating in and assuring the correct sequence of all the biochemical routes in biogeochemical cycles (Ladd 1985).It is predominantly an intracellular enzyme, mainly used as an index of metabolic activity of microbial community in soil. Dehydrogenase activity represents the intracellular flux of electrons to O_2 and is due to the activity of several intracellular enzymes catalyzing the transfer of hydrogen and electron from one compound to another (Nannipieri *et al.,* 2003). Roldan *et al.,* 2007 reported higher dehydrogenase and phosphatase in the 0-5 cm soil layer with ZT than CT. Likewise, Singh *et al.,* 2009 reported that the dehydrogenase enzyme activity of soil under permanent bed planting method registered significantly higher (62%) than CT. Another important soil enzyme is phosphatases which play a key role in phosphorous cycle by solubilizing organic and inorganic phosphates into available forms that increases the available phosphorus to crop plants (Wyszkowska and Wyszkowski 2010). Hota *et al.,* 2014 noticed that incorporation of organic residues along with ZT showed greater acid phosphatase activities than the CT without residue.

In conclusion, CA improves soil aggregation compared to CT systems in a wide variety of soils and agro-ecological conditions. The conversion of CT to CA by adopting ZT/PB planting technology can result in lower soil BD. The reported research advocated a variable effect of CA on hydraulic soil properties therefore more research is needed to determine the effect of the adoption of CA on hydraulic soil properties in different soils

and agro-ecological conditions. The combination of ZT with crop residue retention increases the SOC sequestration in soil. Especially when crop diversity and intensity are increased, evidence points to the validity of CA as a carbon storage practice and justifies further efforts in research and development. As the C-cycle is influenced by CA also the N cycle is altered. Adoption of CA systems with crop residue retention may result initially in N immobilization. However, rather than reducing N availability, CA may stimulate a gradual release of N in the long run and can reduce the susceptibility to leaching or dentrification when no growing crop is able to take advantage of the nutrients at the time of their release. Also crop diversification, an important component of CA, has to be seen as an important strategy to govern N availability through rational sequences of crops with different CN ratios. Tillage, residue management and crop rotation have a significant impact on micro- and macronutrient distribution and transformation in the soil. The altered nutrient availability may be due to surface placement of crop residues in comparison with incorporation of crop residues with tillage. CA practices increases availability of nutrients near the soil surface where crop roots proliferate. Slower decomposition of surface placed residues prevents rapid leaching of nutrients through the soil profile. The response of soil chemical fertility to tillage is site-specific and depends on soil type, cropping systems, climate, fertilizer application and management practices. However, in general nutrient availability is related to the effects of CA on SOC. CA induces important shifts in soil fauna and flora communities. The different taxonomic groups of soil microbes respond differently to tillage disturbance and changed residue management strategies. The needed yield increases, production stability, reduced risks and environmental sustainability can only be achieved through management practices that result in an increased soil quality in combination with improved crop varieties. The above outlined evidence for the improved soil quality and production sustainability with well implemented CA systems is clear, although research remains inconclusive on some points. At the same time, the evidence for the degradation caused by tillage systems is convincing especially in tropical and sub-tropical conditions and for biological and physical soil quality. Therefore, even though we do not know how to manage functional CA systems under all conditions, the underlying principles of CA should provide the foundation upon which the development of new practices is based, rather than be considered a parallel option to mainstream research activities that focus on improving the current tillage-based production systems under diverse soil as well as ecological conditions.

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