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Impact of long term zero tillage on soil physical properties: A review

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Abstract

Zero tillage is the most imperative pillar of conservation agriculture. Time itself demands adoption of conservation agriculture. For both farmers and the environment, it is a win-win operation. Today, the world is facing a population boom and there is an immediate need to improve agricultural productivity and overall food production on a sustainable basis without sacrificing the atmosphere and natural resources. Though green breakthrough technology, implemented in 1966-67, contributed to food security but extensive agriculture, inefficient and unbalanced use of fertilisers, high-yielding crops, use of heavy machinery, over-cultivation, etc., caused deterioration of soil health and quality and increased air, soil and water contamination for more than five decades. The approach to relating tillage to the physical conditions of the soil is very comprehensive. Tillage helps to create a favourable soil condition for plant growth, but in the long run it has a detrimental impact on soil properties, structure and ultimately on the environment. In the long term, zero tillage has the ability to boost the physical properties and environment of the soil. Holding all of these under consideration, this analysis is compiled to create a perfect tillage scheme, i.e. zero tillage, which eliminates the detrimental effects of tillage and retains land resources and eventually contributes to sustainable agriculture. The influence on the physical properties of the soil, however, depends on the location-specific biophysical environment, such as soil texture, predominant temperature patterns, site characteristics, adoption period, seasonal rainfall variation, and the intrinsic status of soil fertility.

Keywords: Zero tillage, conventional tillage, soil physical properties, sustainable agriculture

Introduction

It is estimated that by 2050 the world population will be about 9.8 billion and 37 percent of which will live in China and India (UN, 2017), requiring an estimated 59-98 percent rise in food demand (Valin *et al.*, 2014) [119], placing more pressure on natural resources. The most significant component of conservation farming is zero tillage. The requirement for an hour is conservation farming. It is a win-win operation for farmers as well as for the environment. Today, the world is facing a population boom and there is an immediate need to improve agricultural productivity and overall food production on a sustainable basis without sacrificing the atmosphere and natural resources. Green revolution technologies implemented in the country during 1966-67 led to food security, intense cropping, insufficient and imbalanced usage of fertilizers, high yielding crop varieties, use of heavy machinery, excess tillage, etc., resulted in soil health and quality degradation. For the next 50 years, five of the top ten issues facing mankind (i.e. food, water, the atmosphere, energy and poverty) are specifically linked to soil health and quality. Accordingly, the implementation of conservation agriculture needs rising concern for food protection through better soil management practices. Conservation agriculture is a resource-saving agricultural crop production mechanism that, in this era of climate change, aims to achieve fair benefit along with high and sustained production levels while simultaneously protecting the environment (FAO, 2010) [34]. Zero tillage, one of the facets of conservation agriculture, refers to soil management schemes that result in crop residues covering at least 30 percent of the soil surface (Jarecki and Lal, 2003) [58]. Zero tillage (ZT) is an important part of conservation agriculture that decreases soil disruption, amplifies physical, chemical and biological properties of the soil, retains soil and water, and decreases the total cost of production (Baker *et al.*, 2007) [8] as compared to conventional tillage (CT). Tillage activity, on the other hand, is synonymous with soil ploughing with certain instruments and implements to monitor weeds and generate a beneficial soil tilth for proper germination of seeds, emergence of seedlings, and plant development and growth (Lal, 1979; Klute 1982; Ahn and Hintze, 1990) [68, 62, 3]. Tillage has been found to compact sub-surface soil in the current mechanised agriculture scenario, limiting root penetration and production, nutrient and water supply, and thus plant growth and yield.

The artificial inversion of the soil does not take place as the tillage is not used over the years, and hence the soil-plant system reaches a physical balance. In addition, as a result of decreased soil organic matter, extensive tillage operations typically increase soil erosion, environmental contamination and soil depletion (Srinivasan *et al*., 2012) [113]. With the advent of herbicides for weed control, several scientists have promoted the implementation of zero tillage to minimise organic matter degradation, sub-surface compaction and better soil environment for root penetration and proliferation, increased fertiliser and water supply resulting in improved pant growth and yield. There is a major lack of a systemic technique for linking tillage activities to physical soil conditions. Tillage has been used to prepare the seed bed, incorporate fertiliser, compost and residues into the soil, alleviate compaction and control weeds in agriculture (Phillips *et al*., 1980; Leij *et al*., 2002) [92, 70]. Tilling the soil, however, is destructive and can facilitate soil erosion, high rates of moisture loss, soil structure deterioration and depletion of soil nutrients and stocks of C. Zero tillage reduces the detrimental effects of tillage, retains soil wealth and can contribute to the accrual of most of the soil C lost during tillage (Paul *et al*., 1997; Paustian *et al*., 1997a, b; Lal *et al*., 1998; Ogle *et al*., 2003) [97, 89, 90, 69, 83]. Hobbs *et al*. (2008) [52] recorded changes in soil quality by improving soil structure and improving soil biological activities, nutrient cycling, soil water holding capacity Therefore, long-term zero tillage practises in a nut shell may strengthen the physical properties of the soil.

In coping with the never-ending challenges associated with human life, research plays a critical role. A greater interpretation of the real world is gained by more and more experimentation. Hundreds or thousands of studies discuss the same topic from multiple angles due to the cumulative existence of research (Shoemaker *et al*., 2003) [105]. Moreover, findings are often incredibly variable, and exceedingly difficult to grasp, leading to widely fragmented processes in various areas of the world. To create a summary, narrative analyses will outline the extraordinarily varied scientific outcomes. In order to quantitatively assess the outcome through related primary studies and the source of variance between these findings, a review cumulates and summarises all the available literature on a given subject (Olkin, 1995) [85] (Gurevitchet *et al*., 2018) [46].

Conventional and conservation tillage

Conservation tillage is now considered a promising alternative to traditional tillage method (Teklu, 2011) [116]. Conservation tillage Conservation tillage activities are becoming economically and ecologically viable alternatives, including zero tillage or minimum soil disturbance and residue accumulation on soil surface, as they save resources and have optimal soil conditions for sustainable crop production and reduced cultivation costs. Better root growth and productive use of water and nutrients can be encouraged by improved soil physical quality. Long-term zero laying increases the status of soil organic carbon and modifies soil pore geometry, which essentially affects simple physical parameters such as bulk density, aggregate resilience, potential for water retention, etc. The results of zero tillage, however, are highly variable across climate, soil type and depth, cropping method, and differ greatly with the method 's period of adoption. Tillage can be characterised as the physical manipulation of soil by a variety of cultivation operations aimed at generating a soil environment favourable to plant growth, either manually or through complete machinery (Lal, 1979; Klute 1982; Ahn and Hintze, 1990) [68, 62, 3]. Conventional tillage is the conventional cultivation process where, with tractor-driven ploughs (primary tillage implements), a few inches of the upper soil is completely inverted, followed by subsequent smoothening of the soil surface by secondary tillage implements. The traditional tillage method is connected with two elements, the inversion of soil and the burial or destruction or burning in situ of crop residue. Conversely, restoration tillage does not invert the surface, creating 'zero' or 'minimum' surface disruption. Conservation tillage is classified as any tillage and planting method, according to the Conservation Technology Information Center (CTIC), that leaves at least 30 percent of the soil surface covered by residue after planting. Conservation agriculture includes three principles: (1) direct planting of crops with minimum soil disturbance (no-till or minimum till), (2) permanent soil covering or covering crops with crop residues (at least 30% of soil surface), and (3) crop rotation (different crops in rotation, pulse / legume inclusion) (FAO, 2011; Hobbs *et al*., 2008) [35, 52]. As one would assume, the effect on soil physical characteristics of traditional and conservation tillage could differ greatly. Nevertheless, the shift varies widely with climate, land, agro-management and adoption period of tillage method (Mondal *et al*., 2018b) [81].

Impact of zero tillage on soil physical properties

Bulk density

Bulk density of soil is exaggerated by conventional tillage practices which includes repeated soil manipulation than zero tillage which involves minimum soil disturbances. Bulk density of soil, the most central physical property plays a crucial role in the relationship between soil moisture-soil air and soil root growth and thus affects crop growth and yield. Due to its interaction with other soil properties, such as porosity, air permeability, penetration resistance, soil moisture, hydraulic conductivity, etc., it is considered a crucial parameter for soil quality evaluation (Doran, 1996) [30]. The bulk density of soil is related to soil compaction and agricultural management problems (Strudley *et al*., 2008) [114]. Bulk density of agricultural fields undergoes significant transformations through agricultural activities and rainfall and/or irrigation events during the crop growth period. Surface soil typically has the lowest bulk density after tillage, which continues to rise with time due to the rearrangement of particles and aggregates after irrigation or runoff events (Osunbitan *et al*., 2005) [86]. From seeding to harvesting, the surface layer has maximal variation (Logsdon, 2012; Liu *et al*., 2014) [74, 73]. Soil bulk density can be greatly influenced by natural soil cycles such as the freezing-thawing cycle, the swelling and shrinking process, and soil erosion (Oztas and Fayetorbay, 2003; Hamza and Anderson, 2005; Logsdon, 2012) [49, 74, 49]. However, conflicting findings have been recorded by studies concerning the effect of zero tillage on soil bulk density. A higher bulk density was observed in some studies in zero tilled soil than conventionally tilled (Bhattacharyya *et al*., 2006 a; Fuentesa *et al*., 2009) [13, 39], zero tillage was found in some experiments to lower bulk density (Lafond *et al*., 1992; Ghuman and Sur, 2001) [67, 42] while no difference in bulk density was found in some studies (Goel and Verma, 1993; Ferreras *et al*., 2000) [44, 37] under the two tillage practices (Lafond *et al*., 1992; Ghuman and Sur, 2001) [67, 42]. Grant and Lafond (1993) [67] observed that, relative to traditional tillage, the bulk density of a hard claysoil improved in the region of 10 cm of soil due to zero tillage. Dam *et al*. (2005) [26] recorded the impact of zero tillage, minimum, and conventional tillage on sandy loam soil in central Canada over 11 consecutive years of maize production. Zero till plots had greater bulk density for 10 cm depth than other tillage practices in most of the years. In another analysis, only in the 5-10 cm soil layer, where conventionally tilled soil had a lower bulk density than direct drill and reduced tillage, the impact of tillage was significant. In the deeper soil layer, however, the tillage systems did not consistently affect bulk density. Yang *et al*. (2005) [126] observed that zero tilled soils were dense in the top 5-20 cm relative to conventionally tilled soils based on 16 years of zero tillage study in which maize and soybean were rotated annually. In comparison, traditional tilled soils in 30-40 cm were denser than zero tilled soils. On clay soils, Zero till is particularly desirable, both to mitigate compaction and to induce natural structure formation. It is well understood that many variables such as soil type, tillage history, residue coverage, atmosphere, etc. impact the soil bulk density (Wander *et al.*, 1998; Halvorson *et al.*, 2000) [121, 48]. There are, however, two ways of thinking regarding the influence of tillage on soil bulk density. One group of authors has reported higher bulk density in ZT system than in CT, while another group has concluded lowering of bulk density through ZT practice. The bulk density (0-10 cm) in a sandy loam soil increased in zero tillage by 8% over a period of 4 years (Bogunovic *et al.*, 2018) [15] and at 30-40 cm depth, situation was reversed where conventional tillage recorded 6% higher bulk density than zero tillage. However, on seventh year, ZT recorded lower bulk density than that in CT on the surface layer. This suggested that although bulk density increases initially in ZT, continuation of ZT practice may reduce soil bulk density possibly due to creation of bio-pores, root growth and faunal activities in undisturbed soil layer. Soil compaction in CT at lower depth (30-40 cm) could be due to formation of tillage-induced hard layer. This happened due to long-term repeated ploughing to the same depth (confined to upper 10 or 15 cm of soil). Aggarwal *et al.* (2006) [1] and Ahmad *et al.* (2018) [2] hreported Hardpan formation just below the plough layer. In Karnal, Haryana Choudhary *et al.* (2018) [23] conducted a participatory research study of a farmer in a clay loam soil. They observed that after three years, bulk density was 9% and 3% higher in CT than ZT in rice-wheat and maize-wheat, respectively in 0-10 cm soil layer. Rice-wheat system noted significantly higher bulk density than maize-wheat because of the puddling (in rice) effect (Gathala *et al.*, 2011b) [41]. Badagliacca *et al.* (2018) [7] reported higher bulk density in ZT than CT after twenty years in a clay soil in wheat/wheat and faba bean/wheat rotation. No change in soil bulk density between CT and ZT was found after 3 years in a loam to sandy clay loam soil over a variety of cropping sequence (Das *et al.*, 2018) [23]. In a long term field experiment (28 years), ZT recorded 7 per cent lower bulk density of soil than CT under continuous corn, corn-soybean and corn-soybean-meadow rotations. The authors concluded that lower bulk density in ZT was due to higher concentrations of crop residue stored on the surface of the soil. Due to the implementation of distinct tillage methods, Soraccoet *al*. (2012) reported no improvement in soil bulk density. Time of measurement of bulk density can influence the outcomes significantly. Measurement just after tillage operation can generate a significantly lower BD value in CT practices than ZT. Osunbitana *et al.* (2005) [86] noticed 55-61% increase in surface soil bulk density in comparison to initial value after 8 weeks of tillage operations.

Penetration resistance

Penetration resistance which is measured by a cone penetrometer imitates the elongation of plant roots and the resistance offered by the soil against growth of the root system. Mechanical impedance caused by soil compaction (surface and/or subsurface) limits root growth and proliferation in deeper soil layers, and thus restricts the water and nutrient availability. Variations in penetration resistance in soil generally happen due to differential management practices (Whitmore *et al.*, 2011) [125]. A penetrometer resistance value of 2 MPa has been suggested as the threshold value for inhibiting root growth and indicates where mechanical resistance becomes a major limitation for root development, unless cracks, bio-pores, decayed root channels or fissures are prevalent in soil for roots to exploit (Bengough *et al.*, 2011). Mechanical impedance is a major problem of soil that affects the crop productivity across countries (FAO, 2015) [36]. Globally, soil compaction affects 4per cent of the land area. (Oldeman, 1992; Soane and van Ouwerkerk, 1994). The compaction of soil is a hidden problem, as it occurs below the soil surface and impairs water and air exchange with growing roots (Mc Garry and Sharp, 2003) [79]. Effects of compaction are long lasting or even be permanent unless corrective measures are taken (Håkansson and Lipiec, 2000). Continuous use of intensive tillage practice for many years leads to soil compaction particularly at the subsurface. Initial soil condition like soil type, moisture content, bulk density and aggregate stability also play major role in the extent of soil compaction (Imhoff *et al.*, 2004; Horn *et al.*, 2005; Materechera, 2009). The process is exacerbated by the presence of low amount of soil organic matter content (FAO, 2015) [36]. Soil penetration resistance is a result of interplay between soil compaction (mechanical impedance) and water content (soil water matric potential). Penetration resistance varies with water content in soils (Kukal and Aggarwal, 2003) [64]. Therefore, even a compacted soil can behave normally in presence of higher water content. With drying, soil strength increases rapidly (Whalley *et al.*, 2005; Whitmore and Whalley, 2009) [124]. In a survey with 19 soils (texture varying from loamy sand to silty clay loam), 10 and 50% of the soils had a penetration resistance value > 2 MPa at a matric potential of as low as -10 and -200 kPa, respectively, which highlights the magnitude of problem of soil compaction on root elongation (Bengough *et al.*, 2011) [10]. In the field, soil water content increases following irrigation or rainfall event and then decreases due to drainage and evapotranspiration, causing a continual variations in mechanical impedance and soil water matric potential (Bengough *et al.*, 2011) [10]. Puddling in rice in rice-wheat cropping system of South-east Asia has been extensively reported to cause degradation of soil aggregates and favours the formation of compact subsurface hard layer (Aggarwal *et al.*, 2006; Kumar *et al.*, 2014a; Kukal and Aggarwal, 2003; Singh *et al.*, 2014) [1, 64, 65]. Crop residue which is retained on the soil surface can protect the soil surface layer from compaction (Thomas *et al.*, 1995) [117]. Evaluation of long-term (> 20 years) soil penetration resistance under continuous spring wheat cultivation showed substantially higher resistance in ZT up to a depth of 10-15 cm and consequently a decrease in resistance (Jabro *et al.*, 2009) [57]. Soil strength in ZT plots reached as much as 3 MPa in the profile (150 cm) in central Spain (López-Fandoe*t al.*, 2007) [75]. Zero tillage sub-soiling had a surprising and immediate impact on soil strength up to 30 cm from surface depth, and the cone index decreased dramatically relative to ZT, but the cone index did not indicate any distinction between treatments above 40 cm depth. Bogunovic *et al.* (2018) [15] noted that during seeding, penetration resistance in ZT was significantly higher up to a depth of 30 cm than CT, but during flowering, the trend reversed. A few more studies also reported large differences in soil impedance immediately after tillage which reduced rapidly thereafter, and became similar with ZT at the end of the season (Yavuzcan *et al.*, 2005) [127]. This shows the vulnerability of CT to re-compaction of the soil with time. Soil compaction was, however, found to improve the soil water retention and root growth in sandy type of soil (Fabrizzi *et al.*, 2005) [33]. Soil compaction damages the function of sub soil by hindering root growth and reducing water and gas exchange (Mc Garry and Sharp, 2003) [79]. It also reduces macro-porosity, movement and retention of water and nutrients, and adversely affects the crop yield (Sidhu and Duiker, 2006; Drewry *et al.*, 2008) [106, 31]. In Punjab, root biomass was decreased by 50–68 percent in highly puddled soil (Kukal and Aggarwal, 2003) [64]. If the adoption of conservation tillage improves the soil structure and reduces the effect of soil compaction, this can be an option to sustain or improve the productivity and economic viability of rice-wheat system (Hobbs *et al.*, 2008) [52]. In order to measure soil penetration resistance as a function of bulk density, soil water content and soil depth, Aggarwal *et al.* (2006) [1] used multiple regression analysis. Soil water content alone was observed to lead to differences of 59 percent. For the sandy clay loam soil of the western Indo-Gangetic Plains, the soil water content and bulk density combined led to a 93-96 percent difference in penetration resistance.

Soil aggregation

Zero tillage increases the amount of stable macro-aggregates (Kumari *et al.*, 2011; Mondal *et al.*, 2018a) [80, 66]. Retained surface residue or cover crops in zero tillage can reduce the impact of rain and wind and thus protects the aggregates from erosion. Residue retention increased microbial and enzyme activity and promotes larger microbial community (Fonte *et al.*, 2012; Mangalassery *et al.*, 2015; Zuber and Villamil, 2016) [38, 77, 91], favouring the formation and stability of aggregates (Paustian *et al.*, 2000; West and Post, 2002; Pulleman and Marinissen, 2004; Six *et al.*, 2004; Kumari *et al.*, 2011; Mondal *et al.*, 2018a) [91, 122, 93, 66, 66, 80, 81]. Soil aggregation is considered as the most widely accepted indicator for evaluation of soil structure. Aggregates are formed through the process of flocculation and cementation of mineral particles in the presence of organic as well as inorganic substances (Six *et al.*, 2000b; Bronick and Lal, 2005) [110, 19]. The formation and destruction of soil aggregates has a great bearing on soil physical health and C dynamics (Six *et al.*, 2000b) [110]. A well-aggregated soil has a better potential to improve the agronomicproductivity and offer greater resistance against erosion by water or wind (Yu *et al.*, 2016).Agricultural management (like tillage, fertilization, seeding etc.) has direct effect on soil quality (Madari *et al.*, 2005) [76]. The physical alteration of the soil due to compaction and erosion, which is primarily due to repetitive tillage, may be seen as a major negative effect of current agricultural practises (Esteve *et al.*, 2004; Bronick and Lal, 2005; Hamza and Anderson, 2005) [32, 19, 49]. Repeated tillage breaks down the solid aggregates in conventional tillage and thus accelerates the turnover of macro-aggregates (Six *et al.* 2000b) [110]. Moving water or wind can quickly transport the scattered aggregates, contributing to soil degradation, depletion of organic matter and plant-available nutrients. Oxidation of organic binding materials is also accelerated by soil interference (Shepherd *et al.*, 2001, Balesdent *et al.*, 2000; Six *et al.*, 2000a) [103, 9, 108]. In this context, the best example to be cited could be wet tillage in puddle transplanted rice, which also forms a hard sub-surface layer. During their feeding and casting practises, several authors have documented the beneficial role of earthworms for the production of macroaggregates (Bossuyt *et al.*, 2005; Kawaguchi *et al.*, 2011; Arai *et al.*, 2013) [20, 60]. Compared to surrounding soil, earthworm casts have a higher level of organic carbon and water resilience (Arai *et al.*, 2013; Arai *et al.*, 2017) [4-5], thereby contributing to soil quality. CT activities are reported to have a adverse impact on earthworms that cause either physical injury or decrease in earthrow biomass (Boström, 1995; Johnson-Maynard *et al.*, 2007; Briones and Schmidt, 2017) [17, 59, 18]. Stronger accumulation in wheat-corn-fallow or wheat-sorghum-fallow was reported under NT relative to wheat-fallow with more crop residue return (Shaver *et al.*, 2002) [102]. Increases in aggregate stability in soils containing higher straw concentrations was observed by Blanco-Canqui and Lal in 2007. In a 5-year continuous field trial, Ghuman and Sur, 2001 [42], tracked the physical properties of the sandy loam soil (Fluvisol) and recorded a higher mean weight diameter of soil aggregates in residue-treated NT than NT without residue and CT. Protection of crop residue surface layers as mulch against the action of dropping raindrops may have contributed to improved soil structure accumulation and improvement (Dabney *et al.*, 2004) [24]. Due to a 21 percent rise in organic matter, aggregates were 30 percent more stable without tillage than under chisel plough in the top 5 cm soil layer (Sasal *et al.*, 2005) [98].

Soil Porosity

Knowledge of geometry of soil pore and distribution is fundamental for understanding of water and air movement in soil. Hydraulic characteristics of a soil entirely depend on distribution of pore size. Soil pores of different shape, continuity and size affect the infiltration, maintain the balance of air-water ratio, and determine the ease of a soil for root growth (Kay and Vanden Bygaart, 2002; Pagliai and Vignozzi, 2002; Sasal *et al.*, 2006) [61, 88, 97]. To note, the principle of structural hierarchy is interested in water flowing into linked pores (Dexter *et al.*, 2008) [29]. Again, tillage has a heavy effect on soil porosity (Shipitalo *et al.*, 2000; Lipiec *et al.*, 2006) [106, 72]. It is understood that aggregates are broken down by tillage leading toobliteration of pore continuity, and gradually soil pores are formed by rearrangement of soil particles after rain or irrigation. On the other hand, biological activity is the dominant factor of pore formation in no-tilled soil. No tillage favours the formation of decayed root channel, bio-pores, burrows by earthworm and other macro-fauna, and network of macro-pore, cracks and other structural voids through which most of the water flows deeper down the soil profile (Gerke, 2006; Jarvis, 2007). Pore geometry has a prominent role in compressibility of soils. The macro-pores that are created through tillage are unstable in nature and mostly efficient immediately after the tillage (Dexter, 2004b) [28]. In contrast, pore network in NT is less susceptible to destruction and supports water drainage and aeration despite compaction (Wahl *et al.*, 2004; Schäffer *et al.*, 2008b) [120]. The CT system generally brings lower bulk density and greater porosity especially in the plough layer, while NT increases the surface soil density and decrease total porosity. Changes in overall porosity depending on the type of soil are due to the change in pore geometry. The soil moisture state and pore stability as modified by tillage systems are the factors that determine the rate of water absorption and transmission at the time of measurement. Wahl *et al.* (2004) [120] reported higher amount of macro-pore (>1 mm) in CT in 0-30 cm soil layer, but, the vertical continuity of macro-pore was greater in conservation tillage. A soil's ability to achieve ecological functions in an agroecosystem can be predicted from air and water permeability. Air permeability is more sensitive and can be an indicator of change in pore system due to different management practices (Schjønning *et al.*, 2013). Both air and water permeability prefer continuous macro-pores (Iversen *et al.*, 2003) [56] and possible predictor of one another (Blanco-Canqui *et al.*, 2007) [14], although soil compaction can severely restrict the air-water flux (Reichert *et al.*, 2009; Schjønning *et al.*, 2013) [95] and adversely affect the root growth (Krebstein *et al.*, 2014) [63]. Increased capillary porosity in minimal or no-tillage enhanced the watercapacity of soil (Glab and Kulig, 2008). Increased capillary porosity in CT tillage was also reported (Tangyuan *et al.*, 2009) [115]. In New Zealand silt loam soil, overall porosity under NT declined after 10 years (Horne *et al.*, 1992) [54], whereas for both silt loam and sandy loam of the north-western Canadian prairies the amount of micro-pores was slightly lower in conventional tillage as compared to NT (Azooz *et al.*, 1996) [6]. Better aggregate stability resulted in greater average porosity than CT in the NT method (Busari *et al.*, 2015) [20]. Therefore, the undesirable effects of higher bulk density were offset by a greater number of macro-pores and pore continuity in reduced or NT. Only larger pores (> 6 mm) were adversely affected by soil compaction, not total pores (Capowiez *et al.*, 2009) [21]. In the 30 cm deep plane, considerably less pores were reported than in the above and below layers. NT resulted in lower macro-pore (> 30 μm) volume on sandy and silty loam soils under comparable conditions, but greater volume on sandy loam soil (Schjønning and Rasmussen, 2000) [100].

Soil Temperature

Results of various studies have shown that modifying soil thermal conductivity and diffusivity has a effect on the quantity of residue associated with the zero tillage scheme. In order to reduce the fluctuation of diurnal and seasonal variation in soil temperature as observed in bare soil by interrupting radiation exchange between the atmosphere and the soil, crop residues on the surface have been recorded (Chen and McKyes, 1993; Raine and So, 1993; Gajri *et al.*, 1994; Bhatt and Khera, 2006) [22, 94, 40, 12]. The primary element in the calculation of soil temperature seemed to be residue cover (Beyaert *et al.*, 2002) [11]. Microclimate changes caused by soil surface residue cover result in decreased heat input into the soil, thus reducing the temperature of the seed zone. In cold areas, this could impact seedling emergence and development under no tillage (Munawar *et al.*, 1990) [82]. Management of residues such as removing residues from the middle of the planting row but retaining the same in the inter-row space will increase the heat input into the surface of the soil, increase the temperature of the seed zone soil and boost the efficiency of no tillage method in cold regions (Hares and Novak, 1992a;b) [50-51]. The hydro-thermal regime was favourably moderated by no tillage treatment with mulch on the soil, resulting in higher root growth, nutrient uptake and maize and wheat grain yields (Sharma and Acharya, 1994) [20]. In the submontaneous tract of Punjab, lower soil temperature was reported in mulched as opposed to unmulched treatments (Bhatt and Khera, 2006) [12]. In the early stages, mean soil temperature was lower without tillage in maize and wheat, adversely affecting their initial development (Fabrizzi *et al.*, 2005) [33]. Under minimal tillage, the maximum soil temperature was higher than without tillage, but the minimal soil temperature was comparable for both tillage systems. Therefore, no tillage contributed to a decrease in thermal amplitude relative to minimum tillage (Sarkar and Singh, 2007) [96]. Soil temperature was lower by 20C at 2.5 cm depth on totally covered plots in a loamy soil in Michigan, USA, and SWC above 50 cm was higher than those in bare soil (Dadoun, 1993) [25]. Under strip tillage (1.2–1.40C), soil temperature rose over no tillage in the top 5 cm and stayed similar to the soil temperature of the chisel plough (Licht and Al-Kaisi, 2005; Bhatt and Khera, 2006) [71, 12]. This rise in soil temperature has led to a change relative to no tillage in the plant emergence rate index under strip tillage.

Conclusion

The 1960s Green Revolution improved food production, but due to industrial cultivation, heavy field equipment, unnecessary irrigation usage, and indiscriminate use of fertilisers and pesticides, there were strong confrontational impacts on the climate, including loss of SOC stock, increased chances of soil erosion and salinization degradation, and deterioration of physical properties of the soil. Due to the unparalleled increase in the world population and rapid economic growth, the number of food-insecure individuals may increase. In addition, due to rise in popularity, soil depletion, urbanisation, and other competitive uses, the per capita cropland region is also diminishing. The stratagem is therefore to balance food production demand with the need for soil regeneration and elimination of the environmental footprint of agroecosystems and this can be done by following sustainable methods such as zero tillage. The plan is to improve soil quality by restoring SOC stock, improving the productivity of inputs for usage, narrowing the yield gap and introducing sustainable agroecosystem intensification systems. The goal is to produce more from less land, less water use, less fertiliser and pesticide input, and less energy consumption. In order to transform scientific information into reality, the much needed paradigm change would also entail defining and enforcing effective policies. Zero tillage, properly applied, is one of the best solutions with the ability to maximise all physical resources of the land, preserve soil and water, and retain productivity. By designing site-specific packages and informing the agricultural community and the general public about the merits of zero tillage and stewardship of soil resources, its use can be expanded. Finally, in a nut shell we concluded that long term zero tillage practices had potential to improve the soil physical properties and preserves soil resources for sustainable agriculture.

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