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REVIEW ARTICLE

INFLUENCE OF CONSERVATION AGRICULTURE PRACTICES ON PHYSICAL AND CHEMICAL PROPERTIES OF SOIL

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Abstract

Tillage has various negative impact on soil. Minimum soil disturbance, residue retention and appropriate crop rotation are basic principles of conservation agriculture (CA) that significantly improve the soil physical and chemical properties. CA practices improve soil aggregation, bulk density and infiltration in long run due to the presence of carbon pool. The higher amount of SOC in surface soil layer in CA is due to higher accumulation of crop residue which also increase nutrient availability.

Introduction

Tillage is the mechanical disturbance of the soil (through plowing, cultivation or digging) and has been used by farmers since the ancient time (Wells et al., 2000). There are a number of reasons of tillage as it incorporates weed seeds and biomass in deeper layer of soil; incorporates fertilizers, manure and residues to the soil; preparation of a seedbed to facilitate sowing or planting of crops; optimized the bulk density; helps to maintain soil aeration; release nutrients from organic matter in available forms; controls several soil and residue borne diseases and pests through residue incorporation and provides compaction that reduce water infiltration and percolation (Hobbs, 2007). However, it is also well-established that there are various negative impacts of excessive or inappropriate til lage practices (Figure 1).

Conservation agriculture (CA) can be defined as “resource-conserving agricultural crop production system to achieve acceptable profits together with high and sustained production levels while at the same time conserving natural resources and environment” (FAO, 2007).The primary rationale is to protect the natural resources for agriculture (e.g. preventing soil erosion) thereby sustaining and maintenance of agricultural productivity in long run. CA has also a range of secondary benefits to farmers (e.g. cost-savings from mechanization), and environment (e.g. reduced emissions of greenhouse gas, reduction in irrigation water use).

CA has been regarded as management of soil, water and agricultural resources to achieve economic, ecological and socially sustainable agricultural production (Jat et al., 2012). CA is more sustainable agriculture production practice than narrowly-defined 'conservation tillage' (Wall, 2007). Conservation tillage is a widely-used terminology to denote only soil management systems in which at least 30% of the soil surface being covered with crop residues after seeding (Jarecki and Lal, 2003). CA combines the following basic principles (Verhulst et al., 2010 and Jat et al., 2012):

1. Reduction in tillage: The objective is to achieve zero tillage and direct planting without seed bed preparations, but the system may involve controlled tillage seeding systems that normally do not disturb more than 20-25% of the soil surface.

2. Retention of adequate levels of crop residues: The objective is to maintain a permanent vegetative soil cover or mulch to protect the soil from erosion; reduce water run-off and evaporation; improve water productivity and improves soil physical, chemical and biological properties. Optimum amount of residues is vary depending on the biophysical conditions, farming system and cropping system.

3. Use of crop rotations: The objective is to employ diversified crop rotations to break the continuous life cycle of weed, disease and pest; utilize the beneficial effects of some crops on soil conditions and on the productivity of subsequent crops and provide farmers with economically viable cropping options that minimize risk and fulfill household requirements.

Each principle of CA is linked to a specific purpose for sustainable agriculture production system (Figure 2).

2. Influence of CA on physical soil quality

Pores either micro-pores or macro-pores had influence on the infiltration, storage and drainage of water, aeration and the ease of penetration of soil by growing roots. Pores are created and destroyed as a result of both abiotic factors (e.g. tillage, freezing and thawing, drying and wetting) and biotic factors (e.g. root growth, burrowing by fauna) (Kay and VandenBygaart, 2002).

2.1 Bulk density and total porosity

Soil bulk density affects the root penetration as well as soil aeration which has important role in crop growth and development. Bulk density had significant effects on plant growth due to its effect on soil strength and soil porosity. Increasing bulk density, strength tends to increase and porosity tends to decrease, that limit root growth. Bulk density is depends on the soil texture, mineralogy, particle size and structure, organic matter, type of crops and varieties and management practices including tillage, intercultural operations and residues (Reichert et al., 2009).

2.1.1 Effect of tillage on bulk density

No till had compact the whole plough pan layer but improves pore functioning with using low load machinery in long run (Horn, 2004).Typically, a layer of 7 to 15–20 cm depth has high bulk density (Dolan et al., 2006),low porosity and high mechanical resistance so referred to as a ‘no-till pan’. The upper layer (0-7 cm) had low bulk density by reducing compaction due to rearrangement of soil particles and aggregates by various processes mainly the residue and mulch (Horn, 2004).The effect of tillage on soil bulk density is remains unchanged in deeper soil layers while in deeper soil layers, soil bulk density is generally similar in no and conventional till (Gal et al., 2007). But a plough pan may be formed by tillage immediately underneath the tilled soil, causing higher bulk density in this horizon (Dolan et al., 2006 and Yang and Wander, 1999). Bulk density was lower only in the top 3 cm layer under no till due to the development of organic mulch and higher microbial activity (Tebrugge and During, 1999). Under no-tillage, a more stable and porous structure can be formed and newly formed pores and rearrangement of soil particles preserved if light machinery are used for intercultural operations (Horn, 2004). Such pores are necessary to sustain proper pore functioning and soil mechanical properties in maintaining the long-term no-tillage.

There is some evidence that the porosity in the top 5 cm of the profile may be greater under no tillage. Dhiman et al. (2001) reported the increased in the bulk density of the soil from 1.50 g cm^{-3} in conventional tillage to 1.58 g cm^{-3} in no till. No till direct seeded rice and zero tillage wheat had significantly higher bulk density in surface layer (0-10 cm) as compared to conventional till systems (puddling in rice and repeated dry tillage in wheat), whereas these were higher under conventional tillage in deeper soil layer (10-20 cm) (Jat et al., 2009). Similarly, Gal et al. (2007) observed higher bulk density in the 0-30 cm layer under zero than under conventional tillage on a silty clay loam in Indiana after 28 years, but no difference in the 30-100 cm layer. Bulk density was 23.02% higher in no till as compared to till plot (1.55 mg m^{-3}) in Boigneville while 14.29% lower in no till in Versailles in 0-10 cm soil depth (Chaplain et al., 2011). Bulk density of the 0-7.5 and 7.5-15 cm depths was greater under no till than the till treatments by 15% (1.14 g cm^{-3} versus 0.99 g cm^{-3}) and 9% (1.41 g cm^{-3} versus 1.29 g cm^{-3}), respectively, in the Black Chernozem and by 18% (1.27 g cm^{-3} versus 1.08 g cm^{-3}) and 13% (1.57 g cm^{-3} versus 1.39 g cm^{-3}) in the Gray Luvisol (Singh and Malhi, 2006)

2.1.2 Effect of residue on bulk density

In general, incorporation and/or retention of crop residues in to the soils reduced bulk density, and compaction of soils (Bellakki et al., 1998). Blanco-Canqui and Lal (2007a) measured bulk density in no till plots that had receiving three levels of wheat straw mulch (0, 8, and 16 t ha^{-1} yr^{-1}) for 10 consecutive years on a silt loam in central Ohio. Straw management had a large impact on bulk density in the surface layer (0-10 cm) but not significant in the 10-20 cm depth. The bulk density under the high-mulch treatment was 58% lower and that under the low-mulch treatment was 19% lower than the bulk density under the un-mulched treatment for the 0-3 cm depth. In the 3-10 cm depth, bulk density under the high-mulch treatment was only 36% lower and that under the low-mulch treatment was 9% lower than under the control. Annual application of 16 t ha^{-1} of rice straw for 3 years decreased bulk density from 1.20 to 0.98 g cm^{-3} in the 0-5 cm layer on a sandy loam (Lal, 2000). Similarly, Blanco-Canqui et al. (2006) reported that maize residue retention at 5 and 10 t ha^{-1} for a period of one year reduced bulk density in the 0-5 cm layer from 1.42 g cm^{-3} (control) to 1.26 and 1.22 g cm^{-3}, respectively, in zero tillage systems in a silt loam.

Li et al. (2007) compared the effects of no till with residue retention and conventional tillage without residue in a 15-year field experiment on the loess plateau of northern China. During the first 6 years of the experiment, bulk density to 20 cm depth was significantly less in the conventional tillage in no till due to heavy machinery and lack of regular soil loosening. In the following 5 years, soil bulk densities were similar, and in the last 2 years it was higher in conventional tillage as compared to no till with residue retention.

Ghuman and Sur (2001) reported the bulk density in the surface layer (0-10 cm) was significantly lower by 0.05 g cm^{-3} in minimum tillage with residue retention as compared to minimum and conventional tillage without residue. Residue when harvested had 6% higher bulk density in the 0–5 and 5-10 cm soil depths than the treatments with residue returned a silt loam soil with a maize-soyabean cropping system (Dolan et al., 2006).But the trend was reversed in 30-45 cm soil depths, where the treatments with residue returned had 5% higher bulk density than without residues. Roscoe and Buurman (2003) also reported bulk density was higher in the cultivated plots than in no tillage. Contrastingly, in both no till and tillage, retention and/or incorporation of residue had not significant influenced on the bulk density of soil (Singh and Malhi, 2006). Dalal et al. (2011) also reported the residues management practices had not significant influence on the bulk density of vertisol soil of Australia.

Crop residues has improved soil quality in terms of organic carbon and biotic activity (Karlen et al., 1994; Lal, 1989). Residues and organic carbon that are lighter in weight (Logsdon and Karlen, 2004), decomposition product promote more aggregation, root activity in the surface is increased due to better soil moisture in the surface (Shaver, 2010) due to this bulk density s lowered particularly near the soil surface in the no-till system. All these studies indicate that the retention of crop residue in the field is important to prevent compaction and improve the porosity when conventionally tilled fields are converted to no till.

2.2 Infiltration

Infiltration is generally higher in no till with residue retention compared to conventional tillage and no till without residue. Tillage induced changes in porosity which affects total infiltration and infiltration rate. Abid and Lal (2009) observed significantly higher infiltration in no till (I= 71.4 cm) than conventional till (I = 48.9 cm) on silt loam soil. Tillage and residue management also influenced cumulative and steady-state infiltration (Sharratt et al., 2006). Cumulative infiltration over one hour was 77 mm for intensive tillage and 91 mm for no till but the difference is not significant whereas significantly higher steady-state infiltration was observed for no till (70 mm h^{-1}) than intensive tillage (41 mm h^{-1}). Soil cover with the residues had influenced the infiltration. Retention of the straw on the surface also significantly influenced the cumulative infiltration and steady state infiltration (104 mm, 73 mm h^{-1}) as compared to residue removal (84 mm, 54 mm h^{-1}). Ball et al. (1997) reported greater infiltration rates in no till with residue retention after 26 years than after 9 years. Roth et al. (1998) observed complete infiltration of 60 mm rainfall in 100% soil cover while 12 mm rain is infiltrated in case of bare land. After 24 years of experiment, residue retention in no till had 3.7 times higher infiltration than in conventional till with residue burn (Zhang et al., 2007).

The lower infiltration in conventional till as compared to no till is due to breakdown of aggregates and formation of surface seal by the raindrop impact, increased compaction and reduction in pore proportion of the surface soil. In comparison to conventional till plot pores in no till are well connected and protected by the residue cover against raindrop impact and other physical intercultural operations (Blanco-Canqui and Lal, 2007b). Moreover, aggregates are more stable under no till with residue retention compared to conventional till and no till without residue (Li et al., 2007). The residues present in the surface act as a succession of barriers, reducing the runoff velocity and giving more time for infiltration.

Contrastingly, in the Black Chernozem, infiltration rate was lowest (87.0 mm h^{-1}) under no till with residue removal and highest (161.3 mm h^{-1}) under conventional tillage with residue retention (Singh and Malhi, 2006). Lipiec et al. (2006) also reported the similar finding as conventional till plot had the highest infiltration throughout the time of water application. After10 min, the cumulative infiltration being 20.2 cm (infiltration rate of 69.0 cm h^{-1}), it was lower in no till by 58%. Higher contribution of large pores and flow-active porosity throughout the profile in conventional till had increased infiltration rate than in no till system.

3. Influence of CA on chemical soil quality

Tillage, residues and crop rotation had influenced on soil chemical properties like pH, soil organic matter (SOM), nitrogen levels, exchangeable cations which are important from agricultural prospective (Hulugalle et al., 2002).

3.1 Soil organic carbon (SOC)

Improvement of SOM is a desirable aim as it is associated with better plant nutrition, crop performance and soil physical properties (greater aggregate stability, reduced bulk density, improved water holding capacity, enhanced porosity). SOC of surface soil is considered as a primary indicator of soil quality (Reeves, 1997) because it is vital horizon that received the much of seeds, fertilizers and other chemical applied (Verhulst et al., 2010).

Frequency and intensity of tillage had significant influence on disintegration and decomposition of organic matter including residues (Singh and Ladha, 2004). No till resulted in higher SOC content in surface layers and sharp decline with depth (Alverez et al., 1995) but higher SOC content in the deeper layers in case of conventional tillage with residue incorporation (Jantalia et al., 2007 and Thomas et al. 2007). No till had 3.86-31% higher organic matter as compared to conventional (Machado and Silva, 2001 and Balota et al., 2004).Significantly higher SOM in 0-10 cm soil depth under no-till, but it was lower in the 10-15 cm depth compared to conventional system in Uzbekistan (Nurbekov, 2008 cited in Jat et al., 2012). However, some studies have reported increase in carbon content with no tillage even up to depth of 40 cm compared to conventional (Balota et al., 2004). Crop residues incorporated in to the soil decompose very fast as compare to residue present in surface (Singh and Ladha, 2004). Generally in no till, reduced till and strip till system where soil destruction is reduced and residues are present in surface or near surface resulted higher SOM than the residue incorporated into the soil as in case of conventional tillage.

The mean SOM in the 0-5 cm soil layer was 18.8 g kg^{-1} for no till with straw cover which is significantly greater than 14.3 g kg^{-1} observed on the conventional tillage plot but this differences decline in deeper layers. It was 14.1 g kg^{-1} for 5-10 cm and 9.6 g kg^{-1} for 10-20 cm and still significantly higher than the traditional (12.4 g kg^{-1} and 7.4 g kg^{-1} respectively). But it was not significant in 20-30 cm (He et al., 2009). Thierfelder and Wall (2012) in Zimbabwe recorded significantly higher SOC on direct-seeded treatments in 0-20 cm. Conventional ploughing had only 6% higher carbon (from the initial site mean of 6.5 Mg ha^{-1} in 2004 to 6.9 Mg ha^{-1} in 2008), whereas direct seeding had increased SOC by 104% (13.3 Mg ha^{-1}) over 4 years of period.

Zibilske et al. (2002) observed significantly higher SOC under no till in top 0-4 and 4-8 cm, which was 57.8% and 15.1% greater than that of plow till after nine years of experimentation. In the 8–30 cm depths, the organic C concentration was not different among tillage systems. Similarly, Tabaglio et al. (2009) recorded the significantly higher organic carbon in the top most layer 0-5 cm in favors of no-tillage (NT = 13.9 g kg^{-1}vs CT = 10.3 g kg^{-1}) during four years of experimentation but in lower depth differences were not significant. After 11 years of another experiment in Texas, Dao (1998) observed SOC increased by 65, 17, and 7 % in no till compared to over plow-till soil in the 0-5, 5-10 and 10-20 cm depths. In the 0-5 cm depth, differences in SOM between the no till and plow treatment were highly significant as no-till resulted in 33% higher than plow (23.9 g kg^{-1}) (Gal et al., 2007). No-till also resulted in significantly higher (9%) organic carbon in the 5–15 cm depth (26.6 g kg^{-1}). Further increasing the sampling depth had lower organic carbon under no till system.

After 43 years continuous experiment on corn, SOM content in 30 cm top layer was significantly greater under no till (80.0 Mg ha^{-1}) than under chisel tillage (45.3 Mg ha^{-1}) and mold board plough till (44.8 Mg ha^{-1}) (Ussiri and Lal, 2009). About 68–74% of SOC is concentrated on 0-30 cm depth that originated from corn residues. The effect of tillage on SOC concentration was significant after both 5 and 15 years after experimentations in the surface (0–10 cm) soil layer but not in the deeper (10–30 cm) layers. SOC concentration in the upper soil layer was 29% and 44%

higher in NT than in CT in 1998 (NT = 13.0 g kg^{-1}vs CT = 10.1 g kg^{-1}) and 2008(NT = 15.5 g kg^{-1}vs CT = 10.8 g kg^{-1}), respectively. Within the 20 years of experiment SOC content had increased by 21% in NT (gain of 0.61 Mg SOC ha^{-1} year^{-1}) whereas decreased by 2% in CT (loss of 0.06 Mg SOC ha^{-1} year^{-1}) (Mazzoncini et al., 2011).

At the end of 15 years, the SOM content in no till with straw cover was 0.3 g kg^{-1} higher than initial concentration; it was decreased by 0.2 g kg^{-1}in conventional tillage with straw removal. SOM was increased by 40.29% from 13.9 g kg^{-1} in upper layer (0-5 cm) and by 14.29% from 14.7 g kg^{-1} in 5-10 cm while decreased by 20.14% from 13.9 g kg^{-1} in 10-20 cm and 35.05% from 9.7 g kg^{-1} in 20-30 cm depth under no tillage with straw cover but no significant changes observed in conventional tillage with straw removal (Wang, 2008). Contrastingly, the SOC levels decreased after 12 years under the no till system by 6% in surface soil (0-15 cm), 14% in the upper undisturbed subsoil (15-75 cm) and by 10% in the entire root zone (0-75 cm) and sharply decreased under the conventional till system by 12% in the tilled zone, 20% in the subsoil and by 16% for the entire root zone (Olson et al., 2005).

The higher amount of SOC in surface soil layer in no-till might be due to higher accumulation of crop residue that derived carbon and lesser exposure of previous crop roots even after the crop harvest that reduced the oxidative losses of roots (West and Post, 2002). While conventional tillage cause the grater incorporation of residues in the soil, its physical breakdown, overturning of soil and increase aeration, improve soil residue contact and disruption of soil aggregates that leading to oxidation of SOM and erosion which lowers SOC content in the surface soil (Six et al., 2002a; Roldan et al., 2003 and Grant, 1997). Conventional tillage incorporates residue into moister environment where decomposition is fast as compared to residues left in soil surface (Halvorson et al., 2002). The rate of decomposition of residue also depends on amount and composition of residue and soil characteristics where residue applied (Trinsoutrot et al. 2000).

3.2 Nutrient availability

Nature and frequency of tillage, residue management practices had significant effects on nutrient content, its distribution and transformations (Galantini et al. 2000). The nutrient distribution, availability on soil in no till is similar to the SOC content and distribution as increased nutrient availability on and near soil surface as compared to conventional tillage (Duiker and Beegle 2006).

3.2.1 Nitrogen availability

Significantly higher total nitrogen was recorded under no till and permanent raised beds compared to conventional till (Govaerts et al., 2007). Thomas et al. (2007) recorded that the total N of 10 cm depth under no-till was 21% higher than for conventional till. The total nitrogen content was correlated with amount of residue applied (Graham et al., 2002).

Mineral nitrogen uptake by plants is also depends on decomposition and mineralization. Lower nitrogen mineralization (Silgram and Shepherd, 1999) and greater immobilization is observed when residues left on and near soil surface in case of no till (Rice and Smith, 1984) which reduced nitrogen availability. Greater immobilization in CA practices had demand the higher initial N fertilizers requirements but this initial rate can be decreased over time because of reduced losses by leaching, surface run off, erosion and build-up of a larger pool of mineralized organic N (Schoenau and Campbell, 1996).

Tillage increases aggregate disruption, better soil and organic matter contact that increased microbial decomposition of SOM (Six et al., 2002b) and nitrogen mineralization (Kristensen et al., 2000). The incorporated residues decompose 1.5 times faster than surface placed residues (Balota et al., 2004). CA practices like no till, minimum till and permanent raised beds with residue retention resulted in more stable aggregates (Lichter et al., 2008) and more initial nitrogen immobilization. Greater immobilizations of nitrogen can lower the crop yield and nitrogen fertilizers recovery in initial years but benefits crop yield and lower nitrogen losses through leaching, surface runoff and denitrification (Randall and Iragavarapu, 1995).

Compared to initial year, total nitrogen (0-30 cm) improved by 21.3% on no till with straw cover while it decreased by 11.9% on traditional tillage with straw removal after 15 years of experiment. In the 0–5 cm layer, total nitrogen under no tillage with straw cover was increased by 81.25% compared to traditional tillage with straw removal, while in the 5–10 cm layer total nitrogen was increased by only 16.44% and in 10-30 cm layer the total nitrogen differences were not significant (Wang, 2008).

3.2.2 Phosphorus

After the 16 years of experimentation, the available P under no till with straw retention (NTSC) was 97.5% higher than under conventional till with straw removal (TTSR) in the 0-5 cm layer. In the 5-10 and 10-20 cm soil layers, the P content was 19.75% and 54.06%, respectively, lower under NTSC than under TTSR. In the 20-30 cm layer and the differences were not significant (Wang, 2008).The topsoil accumulation of P in NTSC is attributed to the limited downward movement of particle bound P in no-till soils and the upward movement of nutrients from deeper layers through nutrient uptake by roots (Urioste et al., 2006).Numerous studies have reported higher extractable P levels in no tillage than in tilled soil (Duiker and Beegle 2006, Franzluebbers and Hons, 1996; Edwards et al., 1992;and Follett and Peterson, 1988) and this is due to reduced mixing of the fertilizer P with the soil, leading to lower P-fixation. After 20 years of no till experiment Ismail et al. (1994) found extractable P was 42% greater at 0-5 cm, but8-18% lower at 5-30 cm depth compared with conventional tillage in a silt loam. P concentrations were higher in the surface layers of all tillage systems as compared to deeper layers, but most strikingly in no tillage (Duiker and Beegle2006).

Due to higher proportion of residues in the surface under no till system had increased microbial biomass that lead to higher P content (Franzluebbers et al., 1994). But Roldan et al. (2007) reported that available P was not affected by tillage system, soil depth or type of crop.

3.2.3 Potassium content

No tillage with residue retention had increased K availability, on the surface soil where density of crop roots had higher (Franzluebbers and Hons, 1996). Permanent raised beds with residue retention had 1.65 and 1.43 times higher K concentration in 0-5 cm and 5-20 cm surface layer, respectively, than conventional tilled raised beds with residue retention Govaerts et al. (2007). Concentration of K in 0-5 cm layer is higher than in 5-20 cm layer in both tillage systems. Many researchers have found higher K concentration at surface as decreasing the tillage intensity (Ismail et al., 1994; Unger, 1991and Du Preez et al., 2001). The differences in K concentration were decreasing with increasing in depth. Some authors have observed that accumulation of K in soil surface is not depended upon tillage practices (Duiker and Beegle, 2006; Matowoet al., 1999 and Hulugalle and Entwistle, 1997).

The available P and K in surface 0-5 cm layer of minimum tillage were 3.5 times greater than those for the 5-15 cm layer (Robbins and Voss, 1991). Due to a lack of mechanical incorporation of fertilizers in no till or minimum till system, the relatively immobile nutrients P and K remains concentrated in the upper 5 cm soil layer of minimum tilled plots (Shear and Moschler,1969; Triplett and Van Doren, 1969; Fink and Wesley, 1974; and Ismail et al.,1994).

The altered nutrient availability under no till is due to surface placement of crop residues in comparison with incorporation of crop residues with tillage (Ismail et al., 1994; and Unger, 1991). Slower decomposition of surface placed residues (Balota et al. 2004, Kushwaha et al., 2000) may prevent rapid leaching of nutrients through the soil profile, which is more likely when residues are incorporated into the soil. The density of crop roots is usually greater near the soil surface under no till system compared to conventional tillage (Qin et al. 2004) which on decomposition increased the nutrient availability.

CONCLUSION

CA practices improve soil aggregation, reduce bulk density in long run due to the presence of carbon pool and improvement of soil structure. Infiltration is generally higher and runoff reduced under CA as residues present in surface prevent crust formation on surface, reduce runoff velocity and more elapse time for infiltration. The higher amount of SOC in surface soil layer in CA is due to higher accumulation of crop residue which also increase the availability of mineral nutrition.

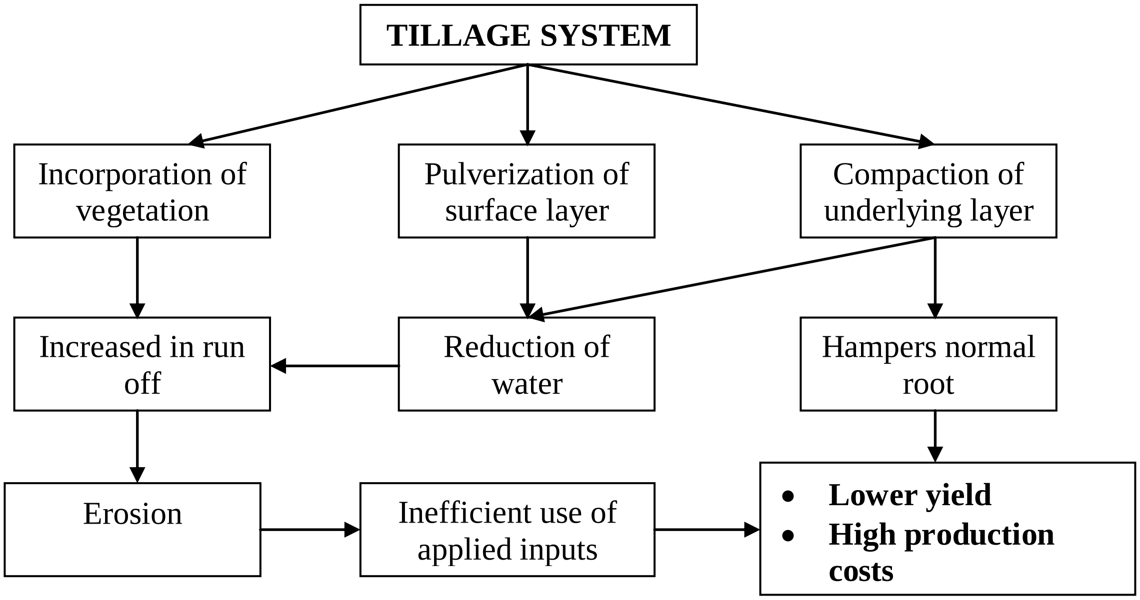

Figure 1: Negative impacts of inappropriate tillage practices (Hobbs, 2007 and modified)

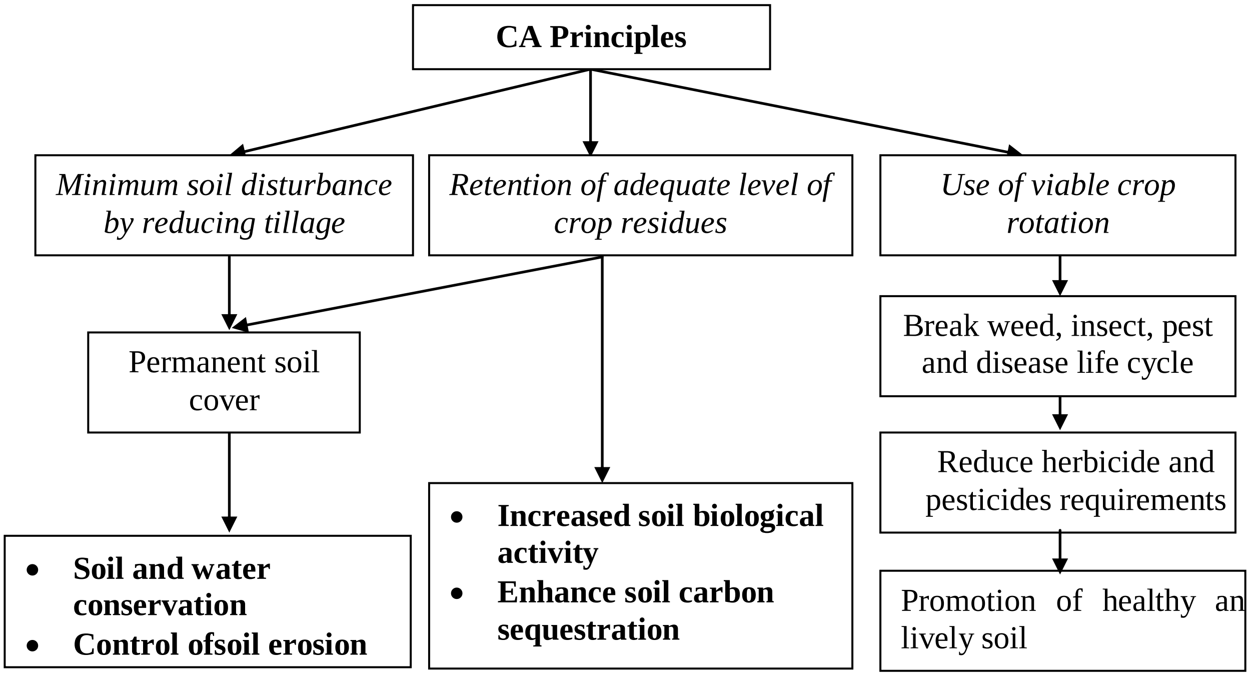

Figure 2: Specific purpose of conservation agriculture principles (Derpsch, 2005; Hobbs, 2007; Hobbs et al., 2007).

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