Conservation agriculture in soybean (*Glycine max*) - wheat (*Triticum aestivum*) cropping system-A review

V. Karunakaran* and U.K. Behera

ICAR-Indian Agricultural Research Institute, New Delhi-110 012, India.

Recieved: 01-04-2015 Accepted: 10-08-2015

**ABSTRACT**

Conservation agriculture is an important component of the overall strategy for enhancing productivity, improve environmental quality and preserve natural resources for food security and poverty alleviation. Soil tillage is one of the fundamental agrotechnical operations in agriculture because of its influence on soil properties, environment and crop growth. Since continuous soil tillage strongly influence the soil properties, it is important to apply appropriate tillage practices that avoid the degradation of soil structure, maintain crop yield as well as ecosystem stability. The efficiency of input use viz. water, fertilizers, herbicides and others depend on tillage and crop establishment practices. It is therefore, essential that the soil environment be manipulated suitably for ensuring a good crop stand and improve resource-use efficiency. Sustaining production and productivity of any system is of paramount importance by improving the soil's physical, chemical and biological properties. Conventional tillage operations will alter these properties in every cropping cycle thereby affecting the soil system. Resource conservation systems have drawn the attention of agronomists and other crop production scientists to devise innovative tillage and residue management techniques for efficient resource management and sustained productivity. To combat soil loss and preserve soil moisture soil conservation techniques were developed in USA known as conservation tillage (CT), this involves soil management practices that minimize the disruption of the soil’s structure, composition and natural biodiversity, thereby minimizing erosion and degradation, control annual weed and seed bank but also water contamination.

**Key words:** Conservation tillage, Crop establishment, Residue management, Zero tillage.

**Effect of tillage on soybean and wheat performance:** In an experiment conducted at Ohio (USA) by Flowers and Lal (1998) reported that the highest soybean yield of 2.5 t/ha with no till treatment was significantly reduced by 9 and 14% by chisel and mouldboard ploughing respectively and they also reported that no tillage (NT) treatment had lower stand than mould board plough (MP) and chisel plough (CP) treatments. Soybean grain yield was not affected by soil management, but was positively affected by use of hoe-type drills under no-tillage. Fifteen per cent higher grain yield of soybean was reported under no tillage than under mould board plough treatment (Hussain et al., 1998). Yusuf et al. (1999) reported that soybean plants on conventional tillage plots developed rapidly and were visually large for much of the vegetative period but the total dry matter and seed yield did not differ significantly between zero tillage and conventional tillage treatments. Thakur et al. (2000) reported from Vertisols of Madhya Pradesh that different tillage treatments given prior to seeding of soybean did not exhibit any carry over effect on the productivity of rainy season crop of soybean and increased yield of 3.16 and 3.68 % only by minimum tillage and conventional tillage respectively over the untilled plots. Mishra and Singh (2005) reported that the soybean yield in conventional tillage (329 kg /ha) was at par with zero tillage (258 kg /ha). Crop yields of soybean were reduced by soil compaction due to increased resistance to root growth, and decreases in water and nutrient use efficiencies (Voorhees et al., 1985; Lal, 1996). Lal (1996) reported soybean grain yield reduction of 9 and 20 % for axle loads of 10 and 20 t, respectively. The SEY in soybean-wheat system under continuous zero (3.11 t/ha) and conventional (3.12 t/ha) tillage system was almost the same (Mishra and Singh, 2009). Zero tillage and bed planting have been widely adopted by the farmers in more than one million hectares area of Indo-Gangetic plains (Mishra and Singh, 2005). Experience from several locations in Indo-Gangetic plains shows that with zero tillage technology, farmers were able to save on land preparation costs by about Rs 2500 per ha and diesel consumption by 50-60 litres per ha (Chauhan et al., 2003). At Jodhpur, Mishra and Singh (2005) reported the population of *Echinochloa colona* increased, whereas that of *Physalis minima* decreased significantly due to zero tillage.

**Effect of ZT vis-à-vis CT on performance of wheat:** Singh et al. (2002a) reported that up to depth of 15 cm the root density of wheat was significantly less (637.7 g/m³) in zero tillage than conventional tillage. But below 15 cm soil depth there was non-significant effect on root density. Under zero tillage, total moisture content in soil profile was higher than...
reduced and conventional tillage throughout the crop growth stages. So, it is concluded that the rooting density was less in surface soil of zero tillage as compared to conventional system but recorded almost similar in deeper soil layers. On an average, the yield of wheat increased steadily by 5.3 % with no tillage. Sen et al. (2002) reported significantly higher yield of wheat under zero tillage than under conventional tillage system. The conservation tillage (no till) for wheat generally resulted in yields that were better than or equal to yields obtained with conventional tillage (Lawrence et al., 1994).

Brar et al. (1982) and Singh (2000) studied the scope of zero tillage in wheat and reported that zero till had statistically similar plant dry matter accumulation, number of effective tillers, ear length, spikelets/spike, test weight, grain yield and straw yield as compared to conventional tillage. Brar et al. (2004) reported from long term experiment that after 25 years wheat yield in maize-wheat sequence remained same in zero tillage and conventional tillage treatments. Mishra and Singh (2009) reported that variation in tillage systems did not influence the grain yield of wheat significantly except in 2002-03, where continuous ZT yielded significantly higher (5.13 t/ha) as compared to CT rotated with ZT (4.28 t/ha). On-station and on-farm trials with ZT wheat in the rice-wheat systems of the Indo gangetic plains (IGP) have shown primarily positive impacts on wheat crop management, particularly through reduced input needs combined with potential yield increases (Erenstein and Laxmi, 2008). The use of ZT significantly reduces energy costs, mainly by reducing tractor costs associated with conventional methods. The use of ZT also allows the wheat crop to be planted sooner would be possible using conventional methods, which significantly reduces turnaround time. Slightly higher uptake of N, P and K in no tilled wheat as compared to conventional flat sowing has also been reported (Singh, 2000). The survey conducted by Erenstein and Farooq (2009) in the irrigated plains of South Asia highlighted that ZT adoption is strongly linked to the wealth of the farm household in the initial diffusion stage.

Effect of crop establishment techniques on performance of soybean and wheat: Ali and Behera (2014b) reported that the performance of soybean was better in raised-bed than flat-bed conventional system of planting. Mishra and Singh (2005) reported conventional tillage (329 kg/ha) being at par with zero tillage (258 kg/ha) produced significantly higher grain yield of soybean as compared to furrow irrigated raised bed (FIRB) (131 kg /ha). The lowest grain yield in FIRB might be due to poor raised-bed formation and collapse of bed during rainy season due to heavy soil. Ridge sowing of soybean has been reported to increase seed yield and profits compared with flat sowing on clay loam and heavy clay soils in other parts of India. Beneficial effects of ridge and furrow method of sowing on soybean yield have been reported through an improved soil aeration, moisture, temperatures, better root development and nitrogen fixation (Tisdall and Hodgson, 1990; Jayapaul et al., 1995; Jain and Dubey, 1998; Raut et al., 2000). Studies conducted by Singh et al. (1986) have shown that ridge and furrow sowing supplemented with irrigation before germination gave significantly higher grain yield (2.29 t/ha) than flat sowing method (1.91 t/ha). The water logging has been major constraint in production of soybean. The raised beds provided excellent drainage during period of intense rainfall in the wet season resulting in lower run off losses, yet capturing and storing water in the furrows during low rainfall (Borrell et al.,1998; Singh et al.,1999) and ultimately higher soybean yield as compared to flat method of sowing. Similarly, from Australia, Van-cooten and Borrell (1999) reported that soybean could be grown well on raised beds. Jayapaul et al. (1995) reported that while working on loamy sand soil reported that ridge sowing recorded significantly higher pod bearing branches, pods per plant and seeds per pods vis-à-vis other crop raising methods. Singh et al. (2004) found non-significant effect of different planting methods on number of pods per plant. Seed yield of 1.30 and 1.37 t/ha was obtained under flat and raised bed sown crop, respectively.

Zhao (1991) reported that soybean grown on beds with three rows 35 cm apart from each bed in a wet land soil recorded significantly higher dry matter and increased seed yield due to better soil aeration ad higher soil temperature. But Raut et al. (2000) obtained significantly higher number of pods/plant in soybean on raised beds with one row, however highest than flat seed was recorded from ridge method with two rows on both sides than flat. Contrary, to this at Ludhiana, Kaur (2003b) found similar yields with one and two rows/bed over two years. Bed planted soybean with one or two rows/bed and paired rows in the flat conventional tillage on a loamy sand soil, produced significantly more pods/plant and grain yield than conventional (45 cm row spacing) flat sowing in 2001, but there were no significant differences during 2002. A study conducted at IARI, New Delhi by Ali and Behera (2014b) reported that the conventional tillage raised-bed recorded the maximum grain yield of soybean (2.3 t/ha). He also reported that the grain yield obtained in zero tillage raised-bed was similar to conventional tillage flat-bed system of planting. There were also reports showing no advantage in bed planting of soybean over flat sowing (Bharambe et al., 1999; Nandurkar et al., 2000; Singh et al., 2004). They observed non significant differences in seed yield of soybean due to ridge and furrow, and broad bed and furrow over flat bed. However, the highest water use efficiency was recorded in broad bed and furrow bed system. Most of the studies conducted so far suggested that equal or significantly higher yield of soybean could be obtained under raised bed planting compared to conventional tillage.
Effect of furrow irrigated raised bed (FIRB)/Bed planting/Broad bed and furrow (BBF) on performance of wheat: In Mexico, planting of wheat on beds and irrigation application in furrows had long been introduced. From a survey work it was concluded that by 1996, 90% of farmers in Mexico had adopted planting of wheat on raised beds. Sayre and Moreno (1997) reported that higher adoption of bed planting in Mexico was due to application of irrigation, less use of herbicides, insecticides and seed besides ease of mechanical cultivation. It was expected that in bed planting availability of nutrients to crop roots increased at optimum supply of water might be helpful in sustaining crop yield with less seed rate, less fertilizer and less water. Similarly, Dhillon et al. (2000) and Singh et al. (2002b) reported that wheat was successfully grown on beds with irrigation application in furrows with higher water use efficiency and savings were recorded in cost of seed and irrigation application time. Kaur et al. (2001a) reported wheat grain yield of bidirectional and bed-planting method was significantly higher than unidirectional (22.5 cm) and strip planting. Kaur (2003a) obtained higher grain yield and water use efficiency of wheat under raised bed planting when the crop was sown on dry beds and irrigation was applied immediately after sowing than when it was sown on beds prepared after applying pre-sowing irrigation. The dry sowing on beds following by irrigation helped to achieve higher germination count and tiller density. Singh (1995) from Hisar, compared the ridge furrow system (1 row in the centre of furrow and 2 on the side of ridges) and flat bed system of planting wheat and obtained similar yield from flat conventional system and bed planted wheat. Singh et al. (2001b) recorded less LAI, CGR and RGR in bed planted durum wheat that bidirectional sowing but reported non-significant differences. Three rows per bed gave higher wheat grain yield under raised bed planting than under conventional flat planting (Hobbs et al., 1997). However, Singh et al. (2002b) reported that in timely sown wheat, there was non significant difference in grain yield between two or three rows per bed. Nonetheless, under late sown conditions (December) three rows per bed resulted in significantly higher wheat yield than two rows per bed. Experiments conducted in different states of north western India showed that planting of two or three rows of wheat per bed produced grain yield similar to flat sowing. However, wheat sown on raised beds with three rows per bed out yielded than when sown with two rows per bed at Delhi (Aggarwal and Goswami, 2003). At Faisiabad (Pakistan) Khan et al. (1987) reported that planting of wheat on raised beds produced more tillers and these increased with nitrogen application. The average grain yield of wheat was 53.0 q/ha with bed planting as compared to 40.0 q/ha with flat planting. The lower tiller and spike density on beds were compensated by more grains/spike and higher grain weight (Singh et al., 2001c and Bhardwaj et al., 2004).

However, there are some situations where the performance of wheat on beds has been inferior to that on conventional tillage flats due to reduced tillering during vegetative stage due to water deficit stress in sandy loam soil (Sharma et al., 2002a). Beds confer additional advantages including reduced germination of Phalaris minor, reduced irrigation water requirement (30-50 %), and reduced water logging (Sharma and Swarup, 1988; Gill et al., 1983). Aggarwal and Goswami (2003) reported a 10-fold reduction in weed density on beds. Plants did not lodge in bed planting causing more silica content in bed sown wheat crop (Kaur et al., 2001b). In the Yaqui Valley in northwestern Mexico, over the past 25 years, more than 95% of the farmers have switched from using conventional technology and flood irrigation on the flat to planting on raised beds. Here one to four rows are planted on top of the bed, depending on the bed width and crop. Irrigation water flows in the furrows between the beds. Bed planting provides a natural opportunity to reduce compaction by confining traffic to the furrow bottoms (Sayre, 2004). Research findings over the past one and half decades have shown that wheat could be grown successfully on beds in Northwest India, with similar or higher yields and lower irrigation water use than for conventional sowing (Singh, 1995; Kaur et al., 2001a; Singh et al., 2002b; Kaur, 2003a; Aggarwal and Goswami, 2003).

Effect of residue management on crop productivity and soil fertility: Agricultural residues mainly stems, leaves, chaff and husks that remain in fields after crops are harvested for their grain, seed, fibre, or other higher value products, are currently receiving much emphasis for their soil erosion-control benefits. This is especially true when they are retained on or near the soil surface by using conservation tillage methods. Conservation tillage systems for which crop residues are retained on the soil surface reduce soil erosion, runoff of surface water, summer time soil temperatures, number of trips across fields and machinery costs, enhance water retention and at the same time increase net returns to the farmers. Tillage practices that involve management of crop residues on the soil surface are not new but the term “conservation tillage” has only been used to describe these practices for the last 20-30 years. Various types of conservation tillage systems have been developed with the extreme form being no-tillage (also called zero tillage or direct drilling). With no tillage all previous-crop residues are retained on the soil surface with seeding of the next crop accomplished by opening a narrow slit in the soil for seed placement. A major advantage of maintaining crop residues on soil surface is improved soil water conservation by reduced runoff of surface water and improved soil surface conditions that allow more time for greater water infiltration. Kushwaha and Singh (2005) reported that retention of a fraction (25–40%) of crop residues from the previous crop and its incorporation in the soil through minimum tillage, in
addition to the normal application of chemical fertilizers, could be an ideal crop production practice in cereal-based tropical agro-ecosystems, as it enhances crop productivity and grain yield in the succeeding crop, and also improves soil fertility. In the residue-retained treatments, microbial immobilization of available-N during the early growth of crops, and its pulsed release later during the period of greater N demand, probably enhances the degree of synchronization between crop demand and N supply. Residue retention is necessary in no-till systems and Govaerts et al. (2009c) have shown that similar improvements in soil quality (increased direct infiltration in the soil) and crop yields can be achieved with partial or with full residue retention. Crop residue application aids nutrient recycling, improves soil structure, and accumulates organic matter in the soil (Agboola and Unamaka, 1991). The maintenance of the organic-matter layer of tropical soils is the key to maintaining the fertility of these soils. It provides a ready reservoir of nutrients. An exploration of the practice of residue management of crops to trap and store nutrients and enhance soil organic-matter accumulation has been advocated (Francis and Adipala, 1994). About half of the nutrients exported through grain or tuber production are recycled via crop residue application (Unger, 1997). Agbim and Adeoye (1991) have reported that crop-residue application aids supply of P to the soil and serves as a source of organic matter to the soil, support the observed check on organic matter depletion.

The cereal-dominated crop rotation practices in India excessively deplete the organic matter and nutrient content of soil following the removal of crop residues. Due to economic considerations, major emphasis has been given in these agro-ecosystems to maximizing the grain yield (a fraction of total net productivity) rather than to the total biological productivity. The impact of previous crop residues on the level of soil fertility in the subsequent crop has received scant attention in crop production systems (Singh and Kushwaha, 2000). Lal and Kimble (1997) estimate that retention of even a small fraction of the total annual world production of crop residue in association with tillage reduction, could sustain crop productivity and soil fertility in agro-ecosystems. The application of organic matter in the form of plant residues has long been known to improve the properties of soils, especially the soil organic matter content (Blevins and Frye, 1993). Crop residue management has long been relatively neglected by the R&D community but has recently received increased attention in the quest for sustainable agriculture and its potential contribution to soil fertility, soil organic matter, soil structure and soil health (Bijay-Singh et al., 2008). The efficiency of conservation tillage to improve water storage is universally recognized. In residue no-till farming systems, it is difficult to manage high residue covers and to carry out appropriate seed and fertilizer placement (Mrabet, 2002).

**Soil physical parameters as influenced by tillage and crop establishment techniques:** Verhulst et al. (2011) in their study reported that most of the physical soil parameters measured were significantly affected by tillage-straw system, only bulk density showed no effect. 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. Across soil textures varying from sandy loam to clay loam, bulk density was greater under zero than under mouldboard tillage in the top 20 cm of the soil profile (Kay and VandenBygaart, 2002). Gwenzi et al. (2009) stated that the conversion from conventional tillage to minimum tillage and no-tillage had no noticeable effects on bulk density even after six years. In another study, Bell and Raczkowski (2008) reported that no-tillage increased bulk density of a sandy loam from 1.3–1.5 g/cm³ within a year due to natural setting and consolidation. Hu et al. (2007) in their four years study at Luancheng, China reported that NT significantly increased the topsoil (0-5 cm) bulk density (BD), while reduced tillage (RT) maintained a lower BD as CT. Therefore, NT increased the topsoil bulk density remarkably, which indicated that the soil compactness under NT was increased after 4 years. In a long-term experiment at a fixed site in Heilongjiang province, China, five different tillage systems were compared for their effects on the bulk density. The treatment of reduced tillage had a lower bulk density in summer than the other treatments (Yu and Zhang 2007). After 20 years of experiments on a Cambic Chernozem in Iasi county, Romania, Jitareanu et al. (2006) observed ploughing at a depth of 20 cm resulted in settling of the soil layer at the depth of 19-27 cm, causing the increase in bulk density at 1.52 g/cm³ whereas, in case of chisel tillage, the bulk density decreased from 1.41 to 1.33 g/cm³. A study conducted by Ram et al. (2010) at PAU, Ludhiana reported that soil bulk density recorded in NT/NT (1.50 g/cm³) was significantly higher than sequential fresh bed and permanent bed treatments.

Hydraulic conductivity (HC) of soil was found to be positively and significantly related with the total macro pores of soil (Meek et al., 1992). Hydraulic conductivity and infiltration can be improved and evaporation can be decreased by no-tillage and crop residue cover (Li et al., 2011). Unsaturated hydraulic conductivity increased more with increasing matric potential (less negative) in NT than in CT. Bhattacharyya et al. (2007) observed increments in hydraulic conductivity up to 45-cm depth after 8 years of farmyard manure application in a silty clay loam soil of India. Saturated hydraulic conductivity (Ksat) values in all the studied soil depths were significantly greater under ZT than those under CT (range from 300 to 344 mm/day) and the unsaturated conductivity (k(h)) values at 0–75 mm soil depth under ZT were significantly higher than those computed under CT at all the suction levels, except at %10, %100 and %400 kPa suction (Bhattacharyya et al., 2006).
In the highlands of Mexico, higher direct infiltration rates were recorded in zero tillage with residue retention than under conventional tillage, although the infiltration rate in conventional tillage was considerably higher than zero tillage without residue retention (Govaerts et al., 2009a). Residues left over the soil also slow the flow of surface runoff, thus increase the opportunity for water to infiltrate. Crop-residue treatments improve soil properties by increasing the porosity of the soil and result in an increase in infiltration (Benjamin et al., 2003). Application of crop residues, however, increased the infiltration rate even in the conventional tillage (Sarkar and Kar, 2011). Crop-residue treatments improve soil properties by increasing the porosity of the soil and result in an increase in infiltration (Green et al., 2003). The Alfisols of India usually undergo severe hardening in dry seasons, and proper tillage with crop-residue application is very useful to create a favourable soil zone for root proliferation and to increase the rainfall infiltration in winter (Sharma et al., 2005).

Increasing water storage within the soil profile is necessary to increase plant available soil water. The management of soil through tillage changes the water storage and evaporation losses. De Vita et al. (2007) stated that higher soil water content under no-till than under conventional tillage indicated the reduced water evaporation during preceding period. They also found that across growing season, soil water content under no-till was about 20 % greater than under conventional tillage. Almaraz et al. (2009) reported that the NT system had, in most of the cases, slightly higher moisture levels than CT but significant differences were not detected. Sharma et al. (2011) reported that no tillage retained the highest moisture followed by minimum tillage, raised bed and conventional tillage at different soil depths. Crop residue mulching can significantly reduce soil evaporation (Steiner, 1989).

Aggregation is a dynamic process that depends on various agents such as soil fauna, roots, inorganic binding agents and environmental variables. Macro aggregates are gradually bound together by temporary (i.e., fungal hyphae and roots) and transient binding agents (i.e., microbial and plant-derived polysaccharides) as the decomposition of soil organic matter takes place (Six et al., 2004). Zero tillage with residue retention improves soil structure compared to conventional tillage (Govaerts et al., 2007). Research on conservation agriculture showed that no-till with stubble retained treatment had more water stable aggregation (Zhang et al., 2009). Retaining crop residues on the soil surface lead to an increase of soil organic carbon, which gives rise to improved soil aggregate stability (Limon-Ortega et al., 2002) and the return of biological diversity to the soil, particularly earthworms (Chan 2001). Fresh residue forms the nucleation centre for the formation of new aggregates by creating hot spots of microbial activity where new soil aggregates are developed (De Gryze et al., 2005). The retention of crop residues at the soil surface does not only increase the aggregate formation, but it also decreases the breakdown of aggregates by reducing erosion and protecting the aggregates against raindrop impact, an effect that is lost when the residues are burned. Greater soil macro-aggregation in no-till systems due to reduced disturbance normally caused by ploughing has been reported by several authors (Filho et al., 2002). The presence of crop residue within no-till improved soil aggregation, agreeing with Lal (1984) who observed that crop residue and reduced tillage drastically reduced soil detachment and its transport through runoff. Numerous studies showed that no-tillage practices, with crop residues left on the soil surface increase SOC, improve soil aggregation, and preserve the nutrients for plant and soil microorganisms. There was no significant difference in dry aggregate distribution between CTB-incorporated and PB-straw retained, but aggregates were weaker to resist water slaking in the CTB resulting in a lower MWD obtained through wet sieving and a higher dispersion index. Reports on literature on the effect of residue on water stable aggregates (WSA) are also mixed. Unger (1997) found no difference in MWD of WSA between no-till and cultivated Torrentic Paleustolls in Texas. However, he observed that in some cases the percentage of small aggregates was larger in the no-till than on the plough till treatment. In a study on a high clay orthic Humid Gleysol in Canada, Angers and Mehuys (1988) observed a decrease in MWD of WSA after four years plough till compared with no-till. No tillage increased the proportion of the macro aggregates (>2 mm) at 0-5 cm but not at 5-15 cm depth. The majority of SOC and SON storage under both CT and NT was observed in the largest aggregate size fractions (>2 mm, 250 mm to 2 mm). The use of NT significantly improved soil aggregation and SOC and SON sequestration in surface but not sub-surface soils (Alam et al., 2005). Better soil structure and soil physical properties, namely macro-porosity, aggregate stability and higher infiltration have been reported under conservation tillage, when compared with conventional tillage. However, little information on long term changes of these properties under conservation tillage is available. As many of these soil qualities are associated directly or indirectly with soil organic carbon levels, the lack of significant increase in the latter suggests that many of these improvements may not be sustainable in the longer term, particularly in dry areas (Chan et al., 2003).

Aggregated soil structure is the most desirable condition for plant growth (Hillel, 2004) because it has a beneficial influence on soil moisture status, nutrient dynamics, and soil tilth (Oades, 1984). According to Tisdall and Oades (1982) roots and hyphae are the major binding agents for macro aggregates (>0.25 mm), while humic compounds promote microaggregate (<0.25 mm) formation.
Agricultural practices influence the quantity and persistence of binding agents, which may lead to aggregate formation or breakdown. Thus, soil aggregation can be used to evaluate agricultural management practices and select those that optimize crop growth and minimize soil nutrient loss. Tillage disrupts soil aggregates mechanically and fragments root and mycorrhizal hyphae, which are major binding agents for micro aggregates (Tisdall and Oades, 1982). Also tillage hastens SOM decomposition and reduces the soil carbon content by increasing the access of micro-organisms to SOM upon aggregate destruction (Elliott, 1986; Oades, 1988).

Wright and Hon (2004) reported that NT management increased soil aggregation, produced higher concentrations of organic C and N (sand-free basis) in macro-aggregates and stored more soil organic carbon (SOC) and soil organic nitrogen in the 0 to 15 cm depth than CT. Crop can influence aggregation because the roots, specially fine roots, and organic substances released from the roots may contribute to aggregate formation. In addition, crops with a higher water demand during growth period are expected to affect soil aggregation because water uptake by roots causes differential dehydration, shrinkage and numerous small cracks (Hillief, 2004). Cropping systems that include crop rotations are often beneficial for soil aggregation. Barley-forage rotation increased mean weight diameter (MWD) by 6.7% in mould board ploughing system and 33.3% in chisel ploughing system, compared to the barley monoculture (Bissonnette et al., 2001). In Brazil Marcolan et al. (2007) reported that by tilling the soil at lime incorporation after four years of no-tillage, bulk density and porosity improved, but the aggregate stability decreased. They further reported four years under no-tillage were necessary to recover the original aggregate stability condition. Soil physical attributes were more uniform in conventional tillage, but the aggregate stability in the surface layer was lower and was related to organic carbon content.

**Soil chemical parameters as influenced by tillage and crop establishment techniques:** Long-term tillage can cause a loss of 20 to 50% of original soil organic carbon (SOC) levels, whereby most of this loss occurs at the beginning of tillage practices i.e., first years to decades. No tillage (NT) has an important place within the soil/vegetation management practices envisaged for SOC sequestration, it is widely recognized that it should be complemented by other measures aiming at increasing OM production and nutrient cycling (i.e., INM, improved cropping systems with legumes, intercrops, etc.) (Lal, 2004). Soil organic C is an important index of soil quality because of its relationship to crop productivity (Lal et al., 1997). As SOC changes are generally directly related to the quantity of crop residues returned to the land, agronomic practices that influence yield and affect the residues returned to soil are likely to influence SOC (Campbell et al., 2000). Others reported an increase in SOC due to addition of organic sources of nutrients along with high inputs of NPK fertilizers (Karunakaran et al., 2010).

Tillage treatments did not affect SOC significantly, although OC values with conservation tillage were numerically higher than with conventional tillage but it may become significant when tillage is practiced over a longer period of time (Sharma and Acharya, 2000). Decomposition rates of soil organic matter are lower with minimal tillage and residue retention, consequently organic carbon content increases with time (Gwenzi et al., 2009). Tillage practice can also influence the distribution of SOC in the profile with higher soil organic matter (SOM) content in surface layers with zero tillage than with conventional tillage, but a higher content of SOC in the deeper layers where residue is incorporated through tillage (Jantalia et al., 2000). Alvarez (2005) found that the accumulation of SOC under reduced and zero tillage was an S-shape time-dependent process, which reached a steady state after 25–30 years. West and Post (2002) concluded that a move from conventional tillage systems to zero tillage (both with residue retention) can sequester on average 48 ± 13 g C m⁻² yr⁻¹. West and Post (2002), for example, found that moving to zero tillage in wheat–fallow rotations showed no significant increase in SOC and, therefore, may not be a recommended practice for sequestering C. Likewise, Blancocanqui and Lal (2008) also found with some crops and crop rotations decreased SOC in zero tillage compared to conventional tillage. The mechanisms that govern the balance between increased or no sequestration after conversion to zero tillage are not clear. Although more research is needed, some factors that play a role can be distinguished. No-till farming also reduces the unnecessarily rapid oxidation of soil organic matter to CO₂ which is induced by tillage (Nelson et al., 2009). Baker et al. (2007b) found that crop rotation systems in CA accumulated about 11 t/ha of carbon after 9 years. The reduced use of tractors and other powered farm equipment results in lower emissions. Thomas et al. (2007) did not find a significant difference in SOC between zero and conventional tillage. Organic carbon levels were significantly higher with direct drilling, compared to conventional cultivation (Chan et al., 2002). Therefore, one would expect a substantial increase of TOC in soil under ZT compared to CT (Halvorson et al., 2002), especially in soils with relatively low initial organic matter content (Thomson et al., 2006). Crop residues provide a source of organic matter, so when returned to soil the residues increase the storage of organic C and N in soil, whereas their removal results in a substantial loss of organic C and N from the soil system (Malhi and Lemke 2007). Lower concentration of soil TOC over years in the zero-N treatments under CT compared to ZT was most likely due to a tillage effect, because tillage makes crop residues more accessible to soil microorganisms by incorporating them into soil, and subsequently results in faster oxidation/depomposition of organic matter. The effect of soil, crop residue and fertilizer
management practices on C sequestration in soil is additive. So, the total amount of organic C stored in the soil is the difference between C input (crop residues) and C output (C loss through gases from decomposition of crop residues, with few exceptions such as soil erosion). Therefore, one would expect a dramatic increase in organic C in soil from a combination of ZT, straw retention and proper/ balanced fertilization (Malhi et al., 2011a).

Hulugalle and Entwistle (1997) reported that pH was lower under minimal tillage as compared with conventional tillage, whereas Thomas et al. (2007) found no effect of tillage on pH. Govaerts et al. (2007) found a higher pH in permanent bed with all the residues retained than with part or all of the residues removed in a rainfall experiment in the highlands of Mexico. Duiker and Beegle (2006) did not observe significant tillage effects on the average pH of the 0–15 cm layer. Kettler et al. (2000) found that the main effect of ploughing on soil pH was more significant for 0–7.5 cm soil depth and both no-till and sub-till treatments, which leave plant residues at or near soil surface, were of lower pH than mould board ploughing treatments at all depths. Tillage and straw management usually had little or no effect on soil pH in any soil layer (Malhi et al., 2011b). The electrical conductivity was significantly higher in PB-straw burned than in PB where straw was not burned (Verhulst et al., 2011). Retention of crop residue on the soil (Sushant et al., 2004) reduced the bulk density, enhanced organic carbon and EC but reduced the pH of the soil.

Nutrient availability as well as losses from the soil was influenced to some extent by the tillage and crop establishment techniques. The increase of N in soil suggests that the N-supplying power of soil can be improved by returning straw to the soil and eliminating tillage (Malhi et al., 2011a). Gosai et al. (2009) reported that the total N varied significantly across the tillage types and study sites. Previous research under long-term no-tillage (NT) management has shown higher amounts of available P in the surface thin layer (0–5 cm or less) under NT than CT (Malhi et al., 2011b) due to P application and from decomposition of crop residues retained on the soil surface under ZT, as also suggested by Essington and Howard (2000). In Canda Malhi et al. (2011b) observed that the effects of tillage, crop residue management and N fertilization on these chemical properties were usually similar for both contrasting soil types (Gray Luvisol and Black Chernozem). Positive effect of returning crop residue in improving P fertility of soil and thus increasing potential for long-term sustainability of soil productivity was reported by Malhi et al. (2011b). Adoption of reduced tillage, fertilization and crop diversity can increase organic N and mineralizable N (Nmin) stored in the soil (Nyborg et al. 1995; Soon and Arshad, 1996; Malhi et al. 2009), thus improving soil fertility and nutrient supplying power of soil. Gosai et al. (2009) reported that available phosphorus of the soil varied remarkably along the crop’s growing duration, its depth and upon the tillage tool employed. Govaerts et al. (2007) observed a significantly higher total N under both zero tillage on the flat and permanent raised beds compared to conventional tillage in the highlands of Central Mexico No-till treatments higher P, K and organic carbon concentrations in the superficial 0–0.025 m soil layer and in runoff sediments than CT (Betrol et al., 2007).

Soil biological parameters as influenced by tillage and crop establishment techniques: Quality and degradation of soils is of particular concern in tropical regions where intensive management and year round warm temperatures can result in high rates of organic matter decomposition. Agricultural practices that improve soil quality and agricultural sustainability have been receiving more attention from researchers and farmers. Minimum tillage systems such as no-tillage (NT) or direct drill, with minimal soil disturbance, and diverse crop rotations that could maintain and improve soil quality. Conventional tillage (CT), which uses ploughing and disking to prepare the land, reduces soil organic matter, particularly in tropical/subtropical conditions. This can cause increased organic matter oxidation and reduction of soil structure by degrading soil aggregates. Similarly, manipulating the diversity of cropping sequences can also affect soils by affecting C levels, as can the chemical composition of organic residues that are added to soils. These effects on soil physical and chemical properties of management affect the microbial biomass and important processes such as decomposition of organic matter and mediation of nutrient availability to plants. The microbial biomass drives nutrient mineralization and is a small but labile source of major plant nutrients (C, N, P and S) (Jenkinson and Ladd 1981; Dick, 1992). Thus, microbial biomass can be used to determine the level of degradation of the soil (Smith and Paul, 1990; Brookes, 1995; Sparling, 1997). The NT system showed increases of 103 %, 54 %, 36 %, and 44 % for microbial biomass C, N, P, and Cmicotot/Corg percentage, respectively at the 0 to 5 cm depth than CT and this larger amount of C immobilized in microbial biomass suggests that soil organic matter under NT systems provides higher levels of more labile C than CT systems (Balota et al., 2003). The practice of crop residue retention and minimum tillage, in association with basal fertilizer application, increases the supply of C and N, which is reflected within one year in terms of increased microbial biomass, N-mineralization rates and available-N concentrations in the soil (Kushwaha and Singh, 2005). Studies conducted in Londrina, Brazil by Silva et al. (2010) reported that the microbial biomass carbon and nitrogen (MB-C and MB-N) values were consistently higher up to more than 100 % under NT in comparison to CT and were associated with higher grain yields.


Energy relations as influenced by tillage, crop establishment techniques and residue management:
Agriculture productivity is closely linked with the energy inputs. The measure of energy flow in crop production system provides a good indicator of the technological aspects of crop production system in agriculture. For sustainability in energy management the efforts have to be double pronged, firstly efficient use of commercial energies, and secondly harnessing renewable energy sources as supplementary and substituting commercial energy sources. Direct energy inputs to crop production systems are derived from power sources like human, draft animals, engines, tractors, power tillers, and electric motors, etc., required to perform various unit operations as well as indirect energy inputs are in the form of seeds, organic manures, fertilizers, pesticides, growth regulators, etc. Consumption of energy has been increasing at a steady rate to improve productivity in Indian agriculture. But the energy use efficiency is declining consistently (Sharma and Thakur, 1989). The adoption of high yielding varieties, expansion of irrigation facilities, mechanization and fertilizer, diesel electricity combination have pushed the demand for commercial energy to a new height. Among the field crops, legumes involve much less energy expenditure than cereals. In Germany, energy output: input ratios of rapeseed (Brassica campestris L.) were generally the highest at intermediate N rates. Since, N fertilizers are the major energy inputs, reducing their use and stabilizing yields using organic rather than mineral N would increase net energy yield (Hansen and Diepenbrock, 1994; Aggarwal, 1995). Kadleek and Cervinka, (2000) reported that indirect energy demands of wheat production systems made up 92-94 % of total consumption with most energy use associated with the use of fertilizers and agro-chemicals. More energy has been consumed in fertilizer treatments for soybean-chickpea crop sequence compared to control and increasing the levels of nutrients decreased the energy use efficiency and productivity (Joshi et al., 1998). Seedbed preparation by power tiller (rotator 2 passes + leveling) and tractor with improved implements (moldboard plough 1 pass + disc harrow 2 passes + leveling) gave higher profit and energy use efficiency than seedbed preparation by other methods. Sowing seeds by drilling in rows gave marked greater returns and energy output than broadcast sowing (Sharma and Thakur, 1989). Srivastava (2003) have reported that experiments during 1992-96 showed that tillage before planting which required about one-third (936 MJ/ha) of the total operational energy (2795 MJ/ha) could be saved without adversely affecting the yield of sugarcane (48.5 t/ha compared to 49.4 t/ha for zero and conventional tillage experiments, respectively). The largest contribution of conservation agriculture to reducing the CO₂ emissions associated with farming activities is made by the reduction of tillage operations (Govaerts et al., 2009b). Erenstein and Laxmi (2008) compared studies in rice–wheat systems in the Indo-Gangetic Plains and found seasonal savings in diesel for land preparation with zero tillage to be in the range of 15–60 l/ha, with an average of 36 l/ha or 81 % saving across the studies, equivalent to a reduction in CO₂ emission of 93 kg/ha in an year. West and Marland (2002) reported estimates for C emissions from agricultural machinery, averaged over corn, soybean, and wheat crops in the United States of 69.0, 42.2, and 23.3 kg C ha/yr for conventional tillage, reduced tillage, and zero tillage respectively. The reduced use of tillage for soybean and cotton crops has reduced energy consumption, left water-saving residue on the soil surface, and has led to reduced soil erosion and the associated benefits for water quality (Jerry Nelson, 2007).

Water productivity and WUE due to tillage and crop establishment techniques: In rice–wheat systems in the Indo-Gangetic Plains, zero tillage is reported to save irrigation water in the range of 20–35 % in the wheat crop compared to conventional tillage, reducing water usage by approximately one million l/ha (Gupta et al., 2002). The savings arise because with zero tillage wheat can be sown just after the rice harvest, making use of the residual moisture for wheat germination, potentially saving a pre-sowing irrigation, and because irrigation water advances faster in untilled soil than in tilled soil (Erenstein and Laxmi, 2008). The pre-planting tillage was unnecessary in addition, high residue rates under NT were not converted into higher water use by wheat (Mrabet, 2002). Zero tillage (ZT) combined with crop residue retention on the soil surface greatly reduce erosion and enhance water use efficiency (Johnston et al., 2002) compared to conventional tillage (CT). A study conducted at PAU, Ludhiana by Ram et al. (2010) reported that the permanent bed treatment in wheat recorded significantly higher water use efficiency (WUE) than all CT and NT treatments.

Root growth and development as influenced by tillage and crop establishment techniques: Tillage-induced differences in the soil nutrient status may also have a significant impact on root growth. No-tillage often results in the stratification of soil nutrients, especially of immobile elements such as P (Logan et al., 199; Crozier et al., 1999), thus inducing a higher RLD in the topmost layer under NT (Gregory, 1994). The roots in the NT system accumulated to a greater extent from 0 to 5 cm compared with the roots in the CT system (Chan and Mead, 1992) the opposite was true in lower layers (Chan and Mead, 1992). The root diameter may be indicative of the effects of soil strength on root growth and affects the utilization of nutrients in the soil. Sidiras et al. (2001) reported thicker barley roots under CT than under NT, in contrast to Braim et al. (1992). Soil strength is another factor that varies among tillage systems and affects root distribution (Baker et al., 2007a). Dwyer et al. (1996) found that, despite the fact that total root mass was not significantly different among tillage treatments, rooting was generally shallower in zero tillage than in conventional tillage.
Economics as influenced by tillage and crop establishment techniques: Low labour, animal or equipment requirement is a major advantage of conservation tillage because it allows elimination of several operations, depending on the conservation tillage systems used. Maximum reduction in operations occurs with no-tillage system, but this system generally involves the use of herbicides to control weeds. Zero tillage technology proved to be a wise choice as it was reported to be economical as well as ecologically viable as compared with conventional tillage due to savings in labour, fuel, repair and machinery overhead charges and less emission of greenhouse gases (Singh et al., 2001a; Zentner et al., 2002). Malik et al. (2004) reported that there was i) reduction in tillage cost from 2000 to 650/ha, ii) early sowing by 7-10 days in moist soil, iii) less Phalaris minor problem, iv) proper placement of seed. The development and rapid adoption of direct drilling of wheat into rice stubble has been a major advance in reducing production costs, increasing yields and reducing greenhouse gas emissions (no burning of diesel for tillage) (Hobbs and Gupta, 2003).

CONCLUSION
Overall it can be concluded that soybean and wheat either as a sole or in sequence can be successfully grown in continuous zero tillage without any yield penalty in comparison to continuous CT. Even in sequential tillage, where the tillage was skipped either in kharif to soybean or in rabi to wheat, yields and system productivity were similar. Therefore, ZT-flat/bed along with crop residue recycling need to be popularized in SW system among farmers of northwest IGP as a diversification measure in agriculture to replace RW for improving productivity, energy use efficiency, profitability.

REFERENCE


