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A review on long term effects of tillage on weed management

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Abstract
Tillage operations in various forms have been practiced from the very inception of growing plants. Primitive man used tools to disturb the soils for placing the seeds. The word tillage is derived from 'Anglo-Saxon' words *Tilian* and *Teolian*, meaning 'to plough and prepare soil for seed to sow, to cultivate and to raise crops'. Jethrotull, who is considered as father of tillage suggested that thorough ploughing is necessary so as to make the soil into fine particles. Tillage is the mechanical manipulation of soil with tools and implements for obtaining conditions ideal for seed germination, seedling establishment and growth of crops. Tilth is the physical condition of soil obtained out of tillage (or) it is the result of tillage.

Keywords: conservation tillage, zero tillage, tillage system, minimum tillage, row zone tillage, no tillage

Introduction
Tillage has long been an essential component of traditional agricultural system. Broadly defined, tillage is the mechanical manipulation of the soil and plant residues to prepare a seed bed for crop planting. The benefits of tillage are many: it loosens soil, enhances the release of nutrients from the soil for crop growth, killed weeds, and regulates the circulation of water and air within the soil (Reicosky and Allmaras, 2003) [24]. In some cases, however, intensive tillage has been found to adversely affect soil structure and cause excessive breakdown of aggregates, leading to soil erosion in high-rainfall areas. Intensive tillage can also have a negative impact on environmental quality by accelerating soil carbon loss and greenhouse gas emission (Reicosky and Allmaras, 2003) [25]. Further, tillage operations account for more than 25 percent of agricultural production costs (Carter, 1996) [4]. With recent increases in fuel prices, tillage now account for a higher proportion of production costs than harvesting does (Edwards and Smith, 2005) [7]. Such concerns have fueled interest in finding tillage systems that minimize negative impact to the environment while sustaining economic crop productivity.

Effect of tillage on soil environment
Chemical properties
a. Bulk density
Punia *et al.* (2016) [23] reported that bulk density of the soil did not vary much even after five years of experimentation. Bulk density of soil increased with soil depth but did not vary much even after ninth crop harvest. In Conventional tillage- conventional tillage, bulk density in 0-5 cm was around 1.37-1.39 g cm^3, whereas corresponding values for Zero tillage-Zero tillage were 1.38-1.42 g cm^3.

b. Soil temperature
Punia *et al.* (2016) [23] reported that the data on soil temperature (0-10 cm soil layer) recorded during first week of February and April (2004-08) in wheat indicated that soil temperature in early February was 0.7-1.7 ^{O}C higher under ZT/MT method compared to CT. This increase in temperature under ZT might have facilitated better crop growth by better uptake and utilization of nutrients and also by avoiding crop from possible cold injury. Whereas lower temperature (2.1-3.8 OC) under ZT or MT compared to CT in first week of April might be helpful in uniform crop maturity by avoiding crop from terminal heat which usually results in forced maturity leading to shriveled grains and lower yields. Similar findings have been reported earlier also in wheat under ZT method in rice-wheat cropping system (Yadav *et al*., 2002) [40].

c. Soil carbon

Punia et al. (2016) [23] reported that data on soil carbon recorded after 7th crop of wheat harvest in May, 2007 from different soil layers (0-5, 5-10, 10-15 and 15-20 cm) varied significantly in different soil layers. In general, it was maximum in treatments of ZT-ZT and MT-ZT method of planting and significantly more than CT- CT method at all soil depths. In 0-5 cm soil layer, soil organic carbon was maximum (1.01-1.03%) in ZT-ZT and MT-ZT method of planting as compared to 0.85% in CT-CT method. Similarly, the soil organic carbon content was reported more in soil that had been more under zero tillage/reduced tillage for longer periods (Franzluebebbers *et al.*, 1995). Mishra *et al.* (2010) [8, 16] reported that Variation in tillage did not influence the physico-chemical properties of soils, except organic carbon content, which was slightly improved in zero tillage as compared to conventional tillage.

d. Biological properties

Punia *et al.* (2016) [23] reported that microbial population after harvest of 6th crop (rice) in sequence, ranged from 219-242 mg/kg soil in treatments of zero tillage (MTZT and ZT-ZT) which was more than CT-CT treatment (168 mg/kg soil). Dehydrogenase activity in ZT-ZT treatment was 117 µg TPF/µg soil/24 as compared to CT-CT treatment whereas phosphate population in ZT-ZT method was 104 µg PNP/g dry soil/hr as compared to 80 µg PNP /g dry soil/hr in CTCT method. Results of experiments conducted at CCS HAU Hisar by Kumar (2003) [14] also have clearly reflected that microbial count, soil organic carbon and DHA were higher in ZT field followed by mould board plough and CT soil. The greater number of microorganisms and their activity closure to soil surface under zero till system could be associated primarily with some residues retained.

Effects of tillage on soil moisture

Mishra *et al*. (2010) [16] reported that irrespective of the depth, conventional tillage stored more soil moisture up to five days after first irrigation as compared to zero tillage. This might be due to more pore spaces available in soil due to tillage, which allowed more water storage in the soil. However, after 25 days of first irrigation, zero tillage retained more soil moisture (17.88%) as compared to conventional tillage (14.41%) indicating moisture conservation in zero tillage. Preceding crop residue cover in zero tillage provides shade that typically reduces the amount of solar radiation reaching the soil (Sauer *et al*., 1998) [27], and reduces evaporation rates causing the soil to warm more slowly (Shinners *et al*., 1994) [30].

Effects of tillage on crop growth

a. Weed density

Punia *et al.* (2016) [23] reported that weed density studies conducted at 30 DAT in rice revealed significantly higher density of grassy weeds as well as broad-leaf weeds in treatments of ZT and MT methods of rice transplanting as compared to CT (conventional puddled method of rice transplanting). *Echinochloa crusgalli*, *E. colona* and *Leptochloa chinensis* were major grassy weeds, while broad-leaf weed *Ammania baccifera* and sedges *Cyperus iria* and *C. rotundus*. During *Kharif*, 2007 (7th crop in sequence) total number of weeds were more when rice was transplanted by ZT and MT methods. Higher density of broad-leaf weeds in zero till rice was also reported by Lamid *et al.*, (2001) [15]. Density of *P. minor* was more in wheat planted by CT method but broad-leaf weeds such as *Chenopodium album, Melilotus indica* and *Rumex dentatus* dominated the weed flora planted by ZT method. Density of *R. dentatus* was significantly higher in plots of ZT-ZT and CT-ZT. After five years of continuous zero till wheat, weed flora changed in favour of broad-leaf weeds particularly *R. dentatus* and *C. album* during *Rabi* 2007. During first year, density of *P. minor* in field at 35 DAS was almost same in all tillage treatments and decreased in next two seasons but density of broad-leaf weeds particularly *C. album* increased every year and was more in wheat planted by ZT method.

Based on the comparison finding with zero tillage and conventional tillage, Mishra *et al.* (2010) [17] reported that the experimental field was infested with wild oats (*Avena sterillis* ssp. *ludoviciana*), burclover (*Medicago hispida* Gaertn.), littleseed canarygrass (*Phalaris minor* Retz.), common lambsquarters (*Chenopodium album* L.), common vetch (*Vicia sativa* L.) and lathyrus (*Lathyrus aphaca* L.). Initially (2001- 02), the population (No/m^2) of *P. minor* (162.5) and *C. album* (171.5) was higher (46.8 and 48.5%, respectively of the total population) as compared to *M. hispida* (6.78) and *A. ludoviciana* (9.75) (1.9 and 2.8%), but after four years (2004-05), the trend was completely reverse. Irrespective of the tillage, population of *P. minor* (4.77) and *C. album* (1.75) decreased drastically (1.0 and 0.33%, respectively, of the total population) and that of *A. ludoviciana* (409) and *M. hispida* (111.75) increased (77.6 and 21.2%). Because of increased density and vigorous growth of *A. ludoviciana*, it suppressed other weeds in general and *P. minor* and *C. album* in particular over time. Zero tillage reduced the population of *P. minor* and *C.album* but increased the population of *A. ludoviciana* as compared to conventional tillage. The population of *M. hispida;* however, did not show any definite trend in response to tillage. Tank mix application of isoproturon+2,4-D failed to control wild oats and resulted in increased population similar to that of weedy check. Application of clodinafop at 0.06 kg/ha *fb* 2,4- D at 0.50 kg/ha effectively controlled both grassy and broad-leaved weeds.

Stancevicius *et al.*, (2002) [32] made investigations (1989–2000) at the same experimental site, in the SP, DC and SC plots and reported that the weed seeds and vegetative reproductive parts were distributed in the topsoil, which induced faster germination and regrowth as well as higher crop weediness. In 2002–2006, after modification of the experiment (NT was included), the SP, DC and SC soil tillage technologies slightly increased weed infestation in sugar beet crops. In the NT plots, there was a higher number of annual (32%) and total (29%) weeds in comparison with the CP (control treatment) (Romaneckas *et al.*, 2009). Colbach *et al.* (2014) [26, 5] investigated that, superficial tillage which left seeds closest to the soil surface resulted in the highest weed density. It was also found that, at the beginning of maize vegetation, the reduced soil tillage increased the weed stand density during 2010-2012. The number of perennial weeds varied more than did the number of annual weeds. On average, in the DC and SC plots there were 2 and 3 times more perennial weeds than in the control plots.

Shah *et al.* (2011) [29] reported that weed density was influenced by tillage significantly at 120 DAS only although higher weed density was observed in surface seeded plots at 35 and 70 DAS of wheat. Higher weed density in surface seeding plot was due to the presence of weed seeds on the upper part of soil surface whereas in conventional tillage most of the weed seeds were buried in deep layer, which could not emerge out. Similar results were also reported by Murphy *et al.* (2006). Singh *et al.* (1998) [21, 31] also reported that less weed density in conventional tillage due to the late emergence of weed and favorable environment for crop growth which have suppressive effect on weed. Significantly, lower weed density was observed in mulched plot at all the growth stages i.e. at 35, 70 and 120 DAS of wheat than non mulched plot due to the reduction of weed density and dry matter accumulation due to smothering effect of mulch on weeds. Woldetsadik *et al.* (2005) [36] also reported that mulch was effective enough to prevent excessive weed seed production, so there was less weed density in mulched plot. Significantly, higher weed density was observed in plots applied with half Nitrogen at CRI and half at 40 DAS at 70 and 120 DAS of wheat. The results of the experiment conducted at TNAU, Coimbatore during the year (2005 to 2010) revealed that the lower density of weeds recorded in conventional tillage (Murali Arthanari *et al*., 2012) [20].

Mishra and Singh, (2012) [18] report that population density of *A. ludoviciana* at 60 days after sowing in continuous zero tillage was significantly less than that of continuous tillage system during initial year. However in subsequent years, tillage systems did not have significant influence on its density. Tillage systems did not affect the population of *M. hispida* during first year of experimentation. However, at the completion of the experiment, rotational tillage and continuous tilling significantly reduced its population than ZT–ZT system, indicating that rotational tillage could be an alternative to continuous tillage system to control *M. hispida* population. Application of recommended herbicide (clodinafop propargyl fb 2,4-D) alone significantly reduced the population of *A. ludoviciana*, indicating that additional hand weeding at 35 DAS is not required to manage its population. Scursoni *et al.* (2011) [28] also reported effective control of wild oat in wheat with clodinafop in Argentina. However, application of herbicide alone or its integration with one hand weeding at 35 DAS did not control *M. hispida* during 2006–2007.

The highest PD in the barley crop was observed for *Malva sp.* (14 no m±2) under the NT system and for *Sinapis arvensis* under the CT system (8.2 no m±2). In both cotton and barley, the most7significant differences in total PD amongst the tillage systems, in the sequence of CT > MT > NT was reported by Bilalis *et al*., (2001) [2]. Wozniak *et al.* (2015) [38] reported that the HT system was observed to increase the number of weeds per m^2 compared to CT and RT systems. Higher weed infestation occurred also in the RT than in the CT system as well as in the plot after wheat than in the plot after pea. The analysis of variance components (*F*-Value) showed that weed infestation of wheat was affected to a greater extent by tillage system than by previous crops. This was in accordance with results reported by Wozniak and Haliniarz (2012) [37]. Usually, it is believed that the reduced tillage system increases weed infestation of crops (Wozniak, 2012) [39], because the falling down seeds are accumulated in the topsoil, from where they germinate and thus increase the number of weeds (Cardina *et al*., 2002). The crop of wheat sown in CT system after pea was mainly infested by *Stellaria media* (L.) Vill., *Fallopia convolvulus* (L.) A. Löve, *Viola arvensis* Murr., and *Veronica persica* Poir.; whereas in the RT system the main weeds were *Papaver rhoeas* L., *Chenopodium album* L., *F. convolvulus* and *S. media*; and the HT system was mainly infested by *P. rhoeas*, *Avena fatua* L., *Matricaria inodora* L. and *C. album*. In the case of wheat sown after wheat, the crop from the CT system was predominated by *S. media*, *Amaranthus retoflexus* L., *F. convolvulus* and *Galium aparine* L.; that grown in the RT system by: *A. retoflexus*, *S. media*, *C. album* and *P. rhoeas*; and that grown in the HT system by: *C. album*, *A. retoflexus*, *S. media*. and *A. fatua*.

Wozniak and Kwiatkowski (2012) [37] reported that weed infestation of barley crop was evaluated twice. At the tillering stage (12-13 in Zadoks scale), there was a significantly higher number of weeds per m^{-2} in HT than a strong negative correlations between the number of weeds m^{-2} and the number of barley plants after tillering (r= -0.87). It means that the increase in weed number during barley emergence had a negative impact on the number of barley plants and, consequently, on the number of spikes per m^{-2} (r= -0.86). Also, the number of weeds susfersion per m^{-2} in the CT system was the lowest before harvest, compared to RT system.

A long-term study of crop rotation on weed density

Wheat

Tuesca *et al*. (2000) [34] observed that the weed flora was dominated by winter annual broad-leaved species and the differences caused by tillage did not change systematically with time in wheat crop. Most of the weeds in wheat were small-seeded annual species and were usually not associated with any tillage system. *Chenopodium album* L. was the only small-seeded annual species that was frequently less abundant in NT from the beginning of the experiment. A special group of annual broad-leaved weeds strongly associated with conservation tillage systems in this rotation were wind-disseminated. Total density of this group was higher in RT during the last 3 years. When present, *Sonchus oleraceus L.* and *Carduus acanthoides L.* were more abundant in RT as compared with CT. The only grassy annual present in wheat was *Lolium multiflorum* Lam. and the main perennial species were *Sorghum halepense* (L.) Pers and *Cyperus rotundus L.* Neither species was associated with a particular tillage system. Most of the weeds in wheat were small-seeded annual species and were usually not associated with any tillage system considered, which agrees with a previous report (Buhler & Oplinger, 1990). Weeds present in this crop were generally absent in soyabean. The exceptions were *C. album* and *D. ferox*. Plants of these species failed to produce seeds in wheat because of destruction by tillage or herbicides before or at soyabean planting; this has also been observed in other studies (Ogg & Dawson, 1984) [22].

Soyabean

Tuesca *et al*. (2000) [34] reported that annual broad-leaved weed density was higher in soyabean with CT than with NT. In both tillage systems, the dominant summer annual broad-leaved species was *Portulaca oleracea L.*, showing higher density in CT. *Datura ferox L.* was only present under CT from the beginning of the experiment, whereas *Physalis viscosa L.* was only observed in tilled plots in the last 2 years. *Chenopodium album* density was higher in CT than in NT in the last 4 years of the experiment, with residue levels higher than 2000 kg ha±1. Wind-disseminated species (*S. oleraceus* and *C. acanthoides*) had a higher density in NT.

Grassy annuals were only represented by *Digitaria sanguinalis (L.)* Scop, in densities higher than one plant per m^2 in the last year. *Sorghum halepense* and *C. rotundus* were the only perennial species observed with more than one plant per m^2. *Cyperus rotundus* was the main perennial weed and tillage increased its populations. In soyabean, the higher annual broad-leaved density in CT than with NT concurs with the general trend as found by Buhler (1995) [3]. Higher density of *P. oleracea* in CT could be caused by germination and establishment of this species being favoured by light and high temperatures (Vengris *et al.*, 1972) [35], conditions usually found in tilled areas.

Maize-Soyabean rotation

Tuesca *et al*. (2000) [34] reported that for both crops in this sequence, tillage increased annual broad-leaved density, especially in the last years. *Chenopodium album* and *P. oleracea* were the most abundant annual BLW, and showed higher density in CT. *Datura ferox* density in soyabean and maize was higher in CT than in NT. Tillage had no effect on *Amaranthus hybridus* L. density. *Sonchus oleraceus* and *C. acanthoides* were wind-disseminated species, occasionally present in this rotation at low densities. As in W/S, this group of species was more abundant in NT. Annual grass weed density was greater in NT than in CT. *Digitaria sanguinalis* was the dominant summer annual grass weed species. Other annual grass weeds present in this rotation had very low densities and were not subjected to statistical analysis. Perennial weeds present with densities higher than one plant per m^2 were *S. halepense* and *Cyperus esculentus* L. and were not clearly associated with any tillage system. In late season counts for both rotations included in this study (data not presented), the weed density of annual broad-leaved species was low for all tillage systems. Weed density shifts over time for both rotations, significant regressions ($P<0.05$) between groups of species density and time. Negative values of the slopes indicate a decrease in density over time, whereas positive values indicate an increase over time. In the Wheat-Soybean rotation, in wheat, annual broad-leaved weeds decreased in both tillage systems. In soyabean, this group of species increased in CT and decreased in NT. Wind-disseminated species (*S. oleraceus* and *C. acanthoides*) were virtually absent at the beginning of the experiment, but increased in density in the last years in soyabean in NT. Perennials decreased over time in soyabean in CT and NT, and grassy annuals showed an inconsistent behaviour over time in both tillage systems and both crops of the rotation. In the Maize-Soybean rotation, annual broad-leaved weeds decreased over time in NT. Grassy annuals showed an increase during the course of the experiment in both tillage systems. The density of wind-disseminated species was very low, and no trends over time were observed. Perennials increased over time in both tillage systems in this rotation. The reduced establishment of annual broad-leaved weeds in NT in the M/S rotation could be caused by crop residue, as in the W/S rotation. The most common response of large-seeded species such as *D. ferox* to non-tillage systems is a decline in their populations (Buhler, 1995) [3].

Weed dry weight

Shah *et al*. (2011) [29] reported that weed dry weight and Weed dry matter was influenced by tillage significantly at 120 DAS only although higher weed dry matter was observed in surface seeded plots at 35 and 70 DAS of wheat. Higher dry matter of weed in surface seeded plot was due to the higher number of weed population. Tripathi (2006) [33] also reported higher dry wt. of weed in zero tillage as compared to normal tillage. Significantly lower weed dry matter was found in mulched plot at all the growth stages i.e. at 35, 70 and 120 DAS than non mulched plot due to the suppressive effect of mulch on weed. Yadav *et al*. (2007) [42] also reported reduced dry weight of weed due to mulch than no mulch. Significantly higher dry matter of weed was found in plots having half N at CRI and half at 40 DAS at 120 DAS of wheat.

Mishra *et al.* (2012) [18] reported that the total weed dry matter at harvest was significantly lower in continuous ZT during first year due to reduced population density of major weed *A. ludoviciana.* However, at the completion of the experiment, continuous CT significantly reduced the total weed dry matter. Application of recommended herbicide (clodinafop propargyl fb 2,4-D) alone significantly reduced the total weed dry matter than weedy check due to effective control of *A. ludoviciana*. Integration of hand weeding at 35 DAS with recommended herbicides was significant in 2007–2008 only.

Wozniak and Kwiatkowski (2012) [37] reported that changes in the air-dry weight of weeds were similar to the number of weeds per m^2. In CT system, air dry weight was lower than HT system by more than twofold, and threefold lower than in the RT system, similar to the results reported by Wozniak and Haliniarz (2012) [39] and Gruber *et al.* (2012) [9] reported that the no-till system increased weed infestation compared to tillage made with a mouldboard plow at a depth of 20-25 cm.

Yield

In a study conducted with tillage system for 3 years, Mishra *et al.* (2012) [18] reported that grain yield of rice and wheat varied significantly among treatments every year except *Rabi* 2003-04. During 2004-05, 2005-06 and 2007-08, maximum grain yield (4.98, 4.87 and 5.45 t/ha) of wheat was obtained under MT-ZT treatment which was significantly higher over CT-CT method during second and third years. More grain yield of wheat under ZT-ZT planting method as compared to other tillage treatments in long term trial in pearl millet – wheat cropping system has been reported by Yadav *et al*. (2005) [41]. Higher grain yield of rice under MT and ZT during *Kharif* 2004 could be due to quick growth of seedling transplanted in shallow position in ZT and MT due to good rains occurred at transplanting time. Adhikari *et al* (2003) [1] also reported grain yield of ZT rice at par with conventional transplanted rice.

Mishra *et al.* (2010) [16] reported that in general, tillage did not influence the grain yield of wheat over the years except in 2003-04, where zero tillage yielded significantly higher than conventional tillage. Weeds caused 59.8% reduction in grain yield of wheat as compared to clodinafop *fb* 2, 4-D. The highest mean grain yield (3230 kg) was recorded with application of clodinafop *fb* 2,4-D due to effective control of wild oats and other weeds, which was 77.8% higher than that of isoproturon+2,4-D (1817 kg). Lower grain yield in isoproturon+2, 4-D treated plots was due to poor control of wild oats. Significantly, higher total weed dry matter, total weed N uptake and grain yield was observed in surface seeded plot. Although higher weed dry matter and weed N uptake was in surface seeded plot, it produced higher grain yield due to the early sowing of surface seeded crop and having higher numbers of effective tillers $m^{-2.}$ In contrast, mulched plot produced significantly lower total weed dry matter and N uptake but higher grain yield of wheat due to its suppressive effect on weeds.

Wozniak and Kwiatkowski (2012) [37] reported that the studied cultivars of barley responded different to various tillage systems. The yield of Tocada *cv.* was higher in CT and RT tillage system, and lower in the HT. Yield difference between CT and HT systems was 8.8%, and between RT and HT systems it was 8.0%. Also, the yield of Rastik *cv.* was significantly higher in CT than in HT and RT systems. The difference in yields between CT and HT systems was 10.2%, and between CT and RT systems it was 14.6%. Irrespective of the tillage system, a higher yield was noted in the case of Tocada *cv.* than Rastic *cv.*, and the difference amounted to 22.3%. The higher grain yield was differentiated to a greater extent by cultivar (F= 422.81), and to a lower extent by tillage system (F= 24.73). It seemed that the response of the two cultivars to tillage systems was genetically determined. In studies by Jug *et al.* (2011) [12] and Małecka *et al.* (2012), cereals sown in the conventional tillage system had higher yield than those cultivated in different modifications of the no-tillage system. Also, Knight (2004) [13] reported lower yields of cereals in no-tillage systems than the conventional, whereas in dry and semi-desert areas, higher yields were obtained in the no-till than in plowing system (Guy and Cox, 2002) [10]. The reason for yield decline was poorer conditions of plants growth in the no-tillage systems. According to Morris *et al.* (2010) [19], the key objective of tillage is to provide optimal growth conditions for plants, but still the no-tillage systems sometimes fall short of expectations.

Wozniak *et al.* (2015) [38] reported that grain yield of spring wheat cultivated in CT and RT systems were significantly higher compared to the HT system. Higher yields were also achieved in the plot after pea than in the plot after wheat. The CT and RT systems facilitated better plant density and number of spikes per m^2 compared to the HT system. A higher number of plants (by 15.8-22.2%) at the sprouting stage (12-13 stage), and a higher number of spikes (by 3.9-7.3%) before harvest (at 90-91 stage) were determined in CT and RT than in HT plots. Also, a higher number of spikes were noted in the plot after pea than in the plot after wheat.

Rice

Mishra and Singh (2012) [18] reported that the various tillage sequence and weed control methods had a significant effect on rice yield during all the experimental period of 3 years. Initially (2006 and 2007) conventional tillage gave 23.3% and 18.6% higher rice yield than the zero tillage, whereas at the completion of the experiment (2008), zero tillage yielded 25.1% more than the conventional tillage regardless to weed control methods. Rice yields during 1st year were far below those accepted by producer, however, yields improved in subsequent years and continuous zero tillage produced the maximum.

Wheat

Mishra and Singh (2012) [18] reported that in 2006–2007, wheat grown in zero tillage (either continuous or rotated with conventional) yielded significantly higher than conventional tillage. During 2007–2008, tillage sequences had no effect on wheat yield. However, at the completion of the experiment, continuous zero tillage gave 15.4% higher yields than continuous conventional tillage. Rotational tillage system was at par with CT but significantly lower than ZT. Application of recommended herbicides (clodinafop 60 g fb 2,4-D at 0.50 kg ha) alone or integration with one hand weeding at 35 DAS significantly increased the wheat yields than that of the weedy check.

Grain Quality

Wozniak *et al.* (2015) [38] reported that Contents of total protein and wet gluten in grain were differentiated only by the previous crops and were significantly higher on the plot after pea than on the plot after wheat. Test weight of wheat grain depended on both the tillage system and previous crop. In the CT and RT system its values were significantly higher than in the HT system. Higher grain volume weight (kg hL^{-1}) was also achieved on the plot after pea than on the plot after wheat. The *F*-Value analysis demonstrated that the test weight of grain was more dependent on the tillage system than on the previous crop. Total ash content in wheat grain was significantly higher in HT than in RT and CT plots. Higher ash content was also determined in the grain harvested from RT than from CT plot. Grain harvested after wheat as the previous crop contained more ash than the grain sown after pea. Analysis of *F*-Value showed that the content of ash in grain was influenced to a greater extent by tillage systems than by previous crops. Wozniak and Makarski (2012) [39] demonstrated that reduced tillage increased ash content in the grain and, simultaneously, decreased its grain volume weight. In addition, they showed that ash content of the grain was also affected by the previous crop and nitrogen fertilization. Wheat sown after soybean contained more ash, K, and Mn than that sown after pea. In turn, wheat sown after pea was characterized by significantly higher contents of Ca as well as Fe and Zn.

3. Effect of tillage on economics and energy efficiency

Mishra and Singh, (2012) [18] the economic and energy parameters for rice–wheat cropping system were calculated. The total cost of cultivation was more (US $ 583.9 ha) in CT–CT system than other systems due to higher costs involved in field preparations in both rice and wheat. The highest net returns and benefit: cost ratio was accrued with cultivating rice and wheat under zero-till system and managing weeds with herbicides + 1 hand weeding. Among the rotational tillage systems, ZT–CT was more economical. Weedy check produced the lowest net returns and benefit: cost (B: C) ratios, irrespective of the tillage systems. The continuous CT–CT system required maximum energy (38,187 MJ ha) due to higher energy required for field preparation in both rice and wheat followed by rotational tillage (35,979 MJ ha) and ZT–ZT systems (33,906 MJ ha). The output energy (108,672 MJ ha) and energy output: input ratios (3.18) were maximum in ZT–ZT system due to higher system productivity. The lowest output energy (84,961 MJ ha) and output: input ratio (2.35) was observed from CT–ZT tillage rotation.

Weed seed bank studies

Punia *et al.* (2016) [23] reported that grow out tests of soil samples collected from different soil depths in permanent tillage trial before *Kharif* 2007 (after 4 years of completion of trial) showed that in rice *E. colona, L. chinensis, E. crusgalli, C. difformis, A. baccifera* and *Dactyloctenium aegyptium* were the major weeds emerged from soil at different soil depths. Number of weed seeds emerged were more in ZT-ZT and MT-ZT treatments as compared to CT-CT. Weed density was maximum in upper 0-5 cm soil layer in all treatments. Grow out test of soil samples collected during *Rabi* 2007-08 (after 5 years of trial) from different soil depths under different treatments before wheat sowing, revealed pre-dominance of *P. minor, C. album* and *M. indica* in all treatments. Density of weeds was maximum in CT-CT treatment and it was distributed in all soil depths being more in 0-5 and 5- 10 cm soil depths.

Conclusions

- Continuous usage of conventional tillage found to reduce the weed density and improve crop yield in Rice, Maize-Sunflower and Spring Barley
- This paper concludes that conventional tillage system can be replaced by more economical reduced tillage options with proper recommended weed management strategies, however, some long term research is needed to determine medium-term positive or negative effects of reduced tillage on sustaining yields.

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