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Mamta Phogat

Chaudhary Charan Singh
Haryana Agricultural
University, Hisar, Haryana,
India

Rita Dahiya

Chaudhary Charan Singh
Haryana Agricultural
University, Hisar, Haryana,
India

PS Sangwan

Chaudhary Charan Singh
Haryana Agricultural
University, Hisar, Haryana,
India

Vishal Goyal

Chaudhary Charan Singh
Haryana Agricultural
University, Hisar, Haryana,
India

Corresponding Author:**Mamta Phogat**

Chaudhary Charan Singh
Haryana Agricultural
University, Hisar, Haryana,
India

Zero tillage and water productivity: A review

Mamta Phogat, Rita Dahiya, PS Sangwan and Vishal Goyal

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Abstract

Nevertheless, zero tillage is the best choice because crop residues retained in zero tillage decreases evaporation, controls soil temperature, reduces erosion, reduces total cultivation costs, increases soil organic carbon stock, enhances water use efficiency and increases crop yield on sustainable crops. A range of resource management technologies are advocated to increase water productivity. In all agro-climatic conditions, the conservation of soil moisture is a crucial priority for improving soil and water productivity. Conserved soil moisture helps minimise water inputs without impacting grain yields, which further increases the output of water and crops. The best choice for efficient water usage and sustainable output could be zero tillage after maintaining sufficient residue load and with proper control of weeds. Keeping all of these under consideration, an attempt was made to come up with an efficient sustainable solution that could be used to implement the zero tillage successfully.

Keywords: Zero tillage, conventional tillage, water use efficiency, sustainable production

Introduction

Tillage has been used in agriculture to prepare the seed bed, integrate fertiliser, compost and residues into the soil, relieve compaction and control weeds (Phillips *et al.*, 1980; Leij *et al.*, 2002) [29, 37]. However, tilling the soil is harmful and can promote soil erosion, high moisture loss rates, degradation of the soil structure and depletion of soil nutrients and C stocks. Zero tillage decreases the harmful effects of tillage, preserves soil resources and may lead to the accrual during tillage of most of the soil C lost (Ogle *et al.*, 2003) [35]. Hobbs *et al.* (2008) [20] reported improvements in soil quality by improving soil structure, improving soil biological activities, nutrient cycling, soil water holding ability, soil infiltration rate, soil hydraulic conductivity and, ultimately, soil and water productivity. Long-term zero tillage practises in a nut shell can therefore improve the soil's all properties. Conservation tillage is now considered a promising alternative to conventional tillage practise (Teklu, 2011) [49]. Conservation tillage is a promising alternative to traditional tillage practise. The world population is expected to be about 9.8 billion by 2050 and 37 percent of them will live in China and India (UN, 2017), requiring an estimated 59-98 percent increase in food demand (Valin *et al.*, 2014), putting more strain on natural resources. Zero tillage is the most significant aspect of conservation farming. The world is facing a population boom today and there is an urgent need to sustainably increase agricultural productivity and overall food production without compromising the environment and natural resources. Technologies introduced in the country during the 1966-67 green revolution led to food security, intensive cropping, inadequate and imbalanced fertiliser usage, high yielding crop varieties, heavy machinery usage, excess tillage, etc., resulting in soil health and deterioration of quality. Five of the top ten problems facing humanity (i.e. food, water, the environment, energy and poverty) have been directly related to soil health and quality for the next 50 years. The introduction of conservation agriculture therefore involves a growing concern for food security through best practises in soil management. Conservation agriculture is a resource-saving mechanism for producing agricultural crops that aims to achieve equal benefits along with high and sustained production levels in this era of climate change while protecting the environment at the same time (FAO, 2010) [16]. Zero tillage refers to soil management systems that result in crop residues covering at least 30 percent of the soil surface, one of the aspects of conservation agriculture (Jarecki and Lal, 2003). As they save energy and provide optimal soil conditions for sustainable crop production and reduced cultivation costs, conservation tillage practises like zero tillage or

Limited soil disturbance and residue retention on the soil surface are becoming economically and ecologically viable options. Better root growth and productive use of water and nutrients can be encouraged by improved soil physical condition. Long-term zero tillage improves the status of soil organic carbon and modifies soil pore geometry, which eventually affects basic physical parameters such as bulk density, aggregate stability, water retention capability, etc. However, the effects of conservation tillage are highly variable across environment, soil type and depth, cropping system, and vary widely with the period of system adoption. Zero tillage (ZT) is an essential part of conservation agriculture that, compared to traditional tillage (CT), reduces soil disturbance, amplifies physical, chemical and biological properties of the soil, retains soil and water, and reduces the total cost of production (Baker *et al.*, 2007) [2]. Tillage practise, on the other hand, is associated with soil ploughing with certain weed monitoring tools and implements and provides a beneficial soil tilth for proper seed germination, seedling emergence, and plant development and growth (Ahn and Hintze, 1990) [1]. In the current mechanised agriculture scenario, tillage has been found to compact sub-surface soil, limiting root penetration and development, nutrient and water availability, and thus plant growth and yield. As the tillage is not used over the years, the artificial inversion of the soil does not take place, and hence the soil-plant system achieves a physical equilibrium. Furthermore, intensive tillage practises usually increase water evaporation, soil degradation, environmental pollution and soil depletion as a consequence of reduced soil organic matter (Srinivasan *et al.*, 2012) [46]. In order to reduce organic matter degradation, sub-surface compaction and improved soil condition for root penetration and proliferation, increased fertiliser and water availability resulting in enhanced plant growth and yield, several scientists have advocated the introduction of zero tillage with the advent of herbicides for weed control. A systematic technique for linking tillage operations to soil and water productivity is largely lacking. Study plays a vital role in dealing with the never-ending problems associated with human life. Through more and more experimenting, a greater understanding of the real world is achieved. Owing to the accumulated nature of science, hundreds or thousands of studies discuss the same subject from several perspectives (Shoemaker *et al.*, 2003) [43]. In addition, outcomes are often highly complex, and extremely difficult to comprehend, leading to widely scattered processes in different parts of the globe. Narrative reviews will detail the exceedingly varied scientific results to create a description. A study cumulates and summarises all the available literature on a given subject in order to quantitatively determine the outcome through similar primary studies and the source of variance between these findings (Gurevitch *et al.*, 2018) [18]. There is a need to improve the efficiency of water use, particularly in arid and semi-arid regions, to save water supplies. Adoption of zero tillage practises can boost the efficiency of water use by 25-40% (Hatfield *et al.*, 2001) [19].

Conventional and conservation tillage

Conventional tillage is the traditional cultivation method where a few inches of the upper soil is completely inverted with tractor-driven ploughs (primary tillage implements), followed by subsequent smoothing of the soil surface by secondary tillage implements. Two components, the inversion of soil and the burial or destruction or burning in situ of crop residue, are related to the conventional tillage process.

Restoration tillage, on the other hand, does not invert the soil, causing 'empty' or 'minimum' soil disturbance. According to the Conservation Technology Information Center (CTIC), conservation tillage is defined as any tillage and planting system that leaves at least 30 percent of the soil surface covered by residue after planting. Three principles are included in conservation agriculture: (1) direct planting of crops with minimal soil disturbance (no-till or minimal till), (2) permanent soil covering or covering crops with crop residues (at least 30% of soil surface area), and (3) crop rotation (rotational crops, inclusion of pulses / legumes) (FAO, 2011; Hobbs *et al.*, 2008) [16, 20]. The impact on soil physical characteristics of conventional and conservation tillage may differ significantly, as one might expect. However, the change varies widely with the tillage method's environment, land, agro-management and adoption period (Mondal *et al.*, 2018b) [33].

Impact of zero tillage on water productivity

The ratio of crop production to water consumed (Richards *et al.*, 1993) [39] is water productivity. The use of water by crops depends on many variables, such as soil, weather conditions, water application methods and agronomic practises. Based on the results of five years of experimentation on zero wheat tillage in the Haryana rice-wheat cropping system, zero tillage was found to result in higher upper soil surface moisture content compared to traditional tillage systems. Similarly, there was no tilled soil in the topsoil with a higher moisture content than the ploughed soil (McVay *et al.*, 2006) [32]. To improve the productivity of other crop inputs, optimum use of irrigation water is necessary. Bonfil *et al.* (1999) [10] concluded that by managing without tillage, crop yield and water use efficiency can be improved in arid zones with annual precipitation of less than 200 mm by using the wheat-fallow rotation method. Under zero and traditional tillage, Mahey *et al.* (2002) [31] recorded nearly similar water use efficiency. Saving of irrigation water was reported under zero tillage over traditional sowing at the first irrigation average of 27.7 percent. In zero tillage, Tahir *et al.* (2008) [48] reported water saving and higher efficiency of water usage compared to the traditional system. Consumptive use of water in wheat ranged from 468 to 513 mm under Hisar conditions when irrigation was applied at IW / CPE of 0.90 during the whole crop growth cycle under zero tillage. In the seedbed zone, soil moisture and soil temperature conditions may promote or delay germination of seeds and the emergence of plants (Schneider and Gupta, 1985) [42]. Under zero tillage, surface residue cover can influence soil temperature and availability of moisture by insulating the soil surface. Soils with residue control are cooler than those without mulch loads in tilled soils (Wilhelm *et al.*, 1989) [54]. In a study by Karlen *et al.* (1994) [26] recorded the impact of the zero tillage system on the conservation of soil moisture after 12 years of different tillage systems, in which the gravimetric soil moisture of the zero tillage (32.4 percent) was highest compared to chisel plough (25.5 percent) and mouldboard plough systems (23.1 percent). Kaspar *et al.* (1990) [27] concluded that the residue covering maize sown under zero tillage has the potential to reduce the number of days required for emergence by 2.5 days and increase the yield of maize grain by 310 kg ha⁻¹ since residue cover has a major impact on soil temperature and moisture content. Crop residues on the surface have been reported to reduce the fluctuation of diurnal and seasonal variation in soil temperature, as observed in bare soil by interrupting radiation exchange between the atmosphere and

the soil (Bhatt and Khera, 2006) ^[6]. Residue cover seemed to be the primary factor in the soil temperature measurement (Beyaert *et al.*, 2002). Changes in the microclimate caused by soil surface residue cover result in reduced heat input into the soil, thus reducing the seed zone temperature. This could affect the emergence and growth of seedlings under no tillage in cold areas (Munawar *et al.*, 1990). Residue management such as the removal of residues from the middle of the planting row but retention in the inter-row space would increase the heat input into the soil surface, increase the temperature of the soil of the seed zone and increase the productivity in cold regions of no tillage system (Hares and Novak, 1992a;b). No tillage treatment with mulch on the soil favourably moderated the hydro-thermal regime, resulting in higher root growth, nutrient uptake and yields of maize and wheat grain (Sharma and Acharya, 1994). In the early stages, without tillage in maize and wheat, the mean soil temperature was lower, adversely affecting their initial growth (Fabrizzi *et al.*, 2005) ^[15]. The maximum soil temperature under limited tillage was higher than without tillage, but the minimum soil temperature for both tillage systems was comparable. Therefore, no tillage, compared to minimum tillage, led to a decrease in thermal amplitude (Sarkar and Singh, 2007) ^[41]. On fully covered plots in loamy soil in Michigan, USA, the soil temperature was lower by 20 °C at 2.5 cm depth (Dadoun, 1993) ^[12]. Soil temperature increased in the top 5 cm under strip tillage (1.2-1.40 °C) over no tillage and remained close to the soil temperature of the chisel plough (Bhatt and Khera, 2006) ^[6]. This increase in soil temperature has led to a shift in the plant emergence rate index under strip tillage compared to no tillage. Crop residues decrease water evaporation from the soil through shading, resulting in lower soil surface temperature and wind impact, and annual irrigation savings of up to 4 to 5 inches (van Donk *et al.*, 2010) ^[52]. It has been shown that soil surface residue covering with corn stover and wheat stubble decreases evaporation by 50 percent to 65 percent compared to bare soil without shading (Klocke *et al.*, 2009) ^[28]. Jalota, 2008 ^[21], showed that during wheat processing, mulch can suppress soil evaporation (Es) and soil evaporation can account for 30-60% of total evapotranspiration (ET) (Siddique *et al.*, 1990) ^[44]. This suggests that reducing Es can decrease ET and thus result in an increase of about 10-20 percent in water productivity based on ET. Crop residues may therefore be useful both in reducing the loss of water from groundwater and in reducing the need for irrigation (Li *et al.*, 2011). It has already been demonstrated that zero tillage sowing reduces the amount of irrigation water required for wheat (Erenstein *et al.*, 2008) ^[14]. Kumar *et al.* (2015) stated that the establishment of tillage crops has affected the infiltration of water into soil. The highest increase (28.2 percent) was observed after two years in narrow raised residue beds, followed by large raised residue beds (21.4 percent) and zero residue tillage (7.4 percent). Increased profitability was reported by Jalota *et al.* (2008) ^[21] due to 50 percent lower sowing costs and 23-39 percent higher cotton yield coupled with higher water productivity in zero tillage with mulch treatments. Retaining rice residue as a surface mulch could be beneficial for improving the status of soil water and moderating soil temperature, thereby increasing root growth, plant canopy, wheat yield and water productivity, as ZT plots recorded higher soil temperature and thus evaporation during the intervening periods (Bhatt and Kukal, 2016) ^[7]. Compared to traditional methods, zero tillage in wheat saved 8.8 percent of irrigation water (Sidhu *et al.*, 2007) ^[45]. By changing the

mechanical impedance of root penetration, hydraulic conductivity and water holding capacity, tillage plays a vital role in improving the soil condition. Bulk density increases typically result in significant decreases in the flow of water through the soil (Bhatt and Arora, 2015) ^[4]. Naresh *et al.* (2013) ^[34] stated that maintaining crop residues with zero tillage on the soil surface would improve the rate of infiltration and decrease evapotranspiration. Bhatt (2015) ^[4] reported that at both field capacity and permanent wilting point, bulk density and moisture content would not differ significantly even after 2 years of zero tillage, suggesting that resource management technologies took a certain amount of time to demonstrate their significant impact on soil resources. Kahlon (2014) ^[25] reported that the lowest soil bulk density (1.55 Mg m⁻³) was reported at zero tillage for 0-15 cm soil depth. Under zero tillage, soil porosity was 41.2 percent in sandy loam soil 0-15 cm thick. The percentage of water stable aggregates (WSA percent) observed by Bhattacharyya *et al.* (2008) ^[9] was higher at zero tillage (57 percent) compared to traditional tillage (52 percent). Bornoux *et al.* (2006) ^[11] recorded higher rates of carbon accumulation under zero tilled conditions (around 0.4-1.7 t C ha⁻¹ year⁻¹) relative to tilled conditions. Subbulakshmi *et al.* (2009) ^[47] stressed that, under clay loam soils, soil organic matter status was not substantially enhanced by tillage methods. In addition, Jat *et al.* (2012) ^[23] stated that the accumulation of soil organic matter is longer than the period of the adoption of zero tillage. Bhatt *et al.* (2013) ^[8] and Bhatt and Arora (2015) ^[4] addressed the effect on soil-biochemical properties, water storage and productivity in soils of the rainfed areas of resource management techniques, including tillage. Plant-available water, aggregate stability, soil fertility, and soil biological properties and declining evaporation, runoff, and soil erosion zero tillage require adequate quantities of residues on the soil surface to enhance critical functions, including improving infiltration (Palm *et al.*, 2013) ^[36]. In general, under stressed conditions, zero tillage performs better compared to traditional tillage, delineating the merit of zero tillage, *viz.* improved water use efficiency when residues are maintained (Pittelkow *et al.*, 2015) ^[38]. Zero tillage raises the proportion of micro-pores in the soil, boosts the capacity to retain water, and decreases soil surface evaporation (Jemai *et al.*, 2012) ^[24]. In certain agro-ecosystems where rainfall is inadequate, these advantages are more advantageous. Crop residues retained on soil surface offers soil moisture benefits with increasing benefits from crop production (Rusinamhodzi *et al.*, 2011) ^[40]. These advantages are due to reduced water loss due to soil evaporation (Es), reduced runoff, weed suppression, increased organic C in the soil, and improved soil structure (Yadvinder-Singh *et al.*, 2005) ^[53]. Under zero tillage, crop residues stored on the soil surface decreased temperature and helped prolong the previous moisture for a longer period of time and thus increased the span between two irrigations (Bhatt, 2015) ^[4]. One irrigation saving in zero tilled plots with crop residues was observed during the second year of their experiment, which clearly showed that water efficiency was higher under zero tillage. Due to the decrease in soil evaporation, crop residues decreased the average amount of irrigation (Bhatt, 2015) ^[4]. The decreased amount of irrigation with crop residues retained on the surface of the soil led to marginally higher efficiency of water (Balwinder-Singh *et al.* 2016) ^[3]. Similarly, a six-year conservation agriculture experiment study found that zero residue tillage systems decreased the demand for irrigation water by 40-65 ha-mm compared to traditional systems, resulting in improved water production

under zero tillage by 19.4 percent. The zero tillage system's water productivity was 24 percent higher compared to conventional tillage systems (Das *et al.*, 2014)^[13].

Conclusion

The 1960s Green Revolution enhanced food production, but strong confrontational impacts on the environment, including depletion of SOC stock, increased chances of soil erosion and salinization degradation, and deterioration of physical properties of the soil, were due to industrial agriculture, heavy field machinery, excessive irrigation usage, and indiscriminate use of fertilisers and pesticides. The number of food-insecure individuals will increase because of the unparalleled increase in the world population and rapid economic growth. Furthermore, the per capita cropland area is also decreasing due to increased popularity, soil erosion, urbanisation, and other competitive uses. Therefore, the strategic goal is to balance the need for food production with the need for soil regeneration and the reduction of the environmental footprint of agroecosystems, and this can be accomplished by using sustainable methods such as zero tillage. The plan is to improve the quality of the soil by restoring SOC stocks, improving the productivity of inputs for use, reducing the yield gap and increasing the productivity of water for sustainable agroecosystems. The objective is to generate more from less land, less water use, less input of fertilisers and pesticides and less use of energy. The much needed paradigm change would also include identifying and implementing successful policies in order to turn empirical knowledge into reality. Properly implemented, zero tillage is one of the best strategies with the potential to optimise all of the land's physical resources, conserve soil and water, and maintain efficiency. It is possible to extend its usage by developing site-specific packages and educating the farming community and the general public about the merits of zero tillage and soil resource stewardship. Finally, we concluded in a nut shell that long-term zero tillage practises had the ability to improve the physical, chemical, biological properties of the soil and improve the water productivity and conserve soil and water resources for sustainable development.

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