Agronomic and Environmental Aspects of Conservation Agriculture on Wheat Crop Production

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Abstract

Tillage-based soil management for intensive crop production generally leads to soil degradation and eventual loss of crop productivity. Moreover, farmers have been facing high costs for fuel, labor, agro-chemicals, and other production inputs required by intensive cropping. Intensive tillage causes a more significant loss of soil carbon and increases greenhouse gas emission, mainly carbon dioxide, which has a significant role in global warming. Recently, studies on conservation agriculture (CA) reported that it is a sustainable way to intensify crop production and sustain rural livelihoods in several countries including Nepal. This paper reviews the practice of CA as a viable system for sustainable wheat crop production and soil quality improvement. As compared to tillage-based agriculture, CA improved wheat yield, soil structure and stability, increased drainage and water-holding capacity, reduced risk of rainfall runoff and pollution of surface waters with pesticides and lower energy consumption and lower CO\textsubscript{2} emissions. Moreover, crop residues are more naturally left on the surface to protect the soil and to drive the carbon cycle towards the conversion of plant biomass carbon to soil organic matter and humus. There is no routine use of herbicides, pesticides and chemical fertilizers in the production of crops and animals in CA. There is always increase in species richness in conservation agriculture than in tillage-based systems. The practice of conservation agriculture requires long-term assessment of yield and soil quality, focus on other crops such as oilseed and legumes, crop diversity and CA, and the effect of climatic parameters on CA.

Keywords: Conservation agriculture; No-tillage; Soil erosion; Soil organic matter; wheat yield; mulching

Introduction

Conservation Agriculture (CA) is recommended to manage farmland for sustainable crop production that simultaneously preserves soil and water resources (Zheng et al., 2014). Conservation Agriculture as a system which is based on minimal soil disturbance (no-till, minimum tillage) and permanent soil cover (mulch, crop residue) combined with diversified rotations with legumes (FAO; CA website, 2004). Conservation agriculture involves durable soil cover through crop residues or cover crops, and crop rotations for achieving higher productivity. Moreover, CA is considered as a resource-saving agricultural production system that aims to make production intensification and high yields. Besides, it also enhances the natural resources (Bhan and Behera, 2014). With the increase in environmental hazard, CA practice has been

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applied worldwide due to its positive effects on soil and water conservation, environmental health, and economic viability (Gupta and Sayre, 2007). It depends on three major principles i.e. maintenance of a permanent vegetative cover or mulch on the soil surface, direct planting to minimize soil disturbance, diversified crop rotation and direct seeding to reach the objective of economically, ecologically and socially sustainable agricultural production (Zheng et al., 2014).

Varied crop rotation is also necessary to avoid disease and pest problems (Gustafson & Friedrich 2006). Conservation Agriculture also prevents the need for tillage when zero till agriculture is practiced over more extended periods. It has been proven that Conservation Agriculture maintains a permanent or semi-permanent organic soil cover. The organic soil cover might be a growing crop or dead mulch. The organic soil cover protects the soil physically from sun, rain, and wind and to feed soil biota. The soil micro-organisms and soil fauna play role in the tillage function and soil nutrient balancing. Mechanical tillage disturbs this process. Varied crop rotation is also necessary to avoid disease and pest problems (FAO, 2006). The benefits of tillage in agriculture are explored before introducing CA has been practiced in its many local adaptations for more than three decades and has spread widely (Hobbs et al., 2007). The practice of CA requires is unrecognizable, so it requires a deeper knowledge of its ecological underpinnings to manage its various components for sustainable intensification, where the aim is to optimize resource use and protect or enhance ecosystem processes in space and time over the long term.

Conservation tillage is a tillage system which increases plant residues on the soil surface which increases water infiltration and reduces erosion. It is a practice used in conventional agriculture to minimize the negative effects of tillage. However, it still depends on tillage as the structure forming element in the soil. Nevertheless, conservation tillage practices such as zero tillage practices can be transition steps towards Conservation Agriculture. According to Bhusari et al., (2015), conservation tillage as the method of seedbed preparation that includes the presence of residue mulch and an increase in surface roughness as the key criteria with potentiality to cultivate compact land with minimum soil disturbance which directs to a better soil environment and crop yield with environment friendly practices. Specifically at least 30% of the crop residue must remain in the soil surface after planting in CA in order to minimize soil erosion by water(Dickey et al., 1985). Conservation tillage is an ecological approach to soil surface management and seedbed preparation. Conservation Agriculture has many advantages it improves soil structure, increases soil organic carbon, minimizes soil erosion risks, conserves soil water, decreases fluctuations in soil temperature and enhances soil quality and its environmental regulatory capacity. Crop residue is an essential and renewable resource.

Conservation Agriculture has both agricultural and environmental benefits. It promotes soil health, productive capacity, and ecosystem services. CA is resource conserving technologies save water and nutrients, increase yields, increase crop diversification, improve efficient use of resources and ultimately reduces the cost of production. CA promotes soils bioactivity and biodiversity. It also improves soil structure and cohesion. Conservation Agriculture has a role in the reduction of soil erosion, soil agronomic inputs transport slightly reduced, while pesticide bio-degradation is enhanced. It protects surface and groundwater resources from pollution and mitigates adverse climate effects. Hence, CA provides excellent soil fertility and saves money, time and fossil-fuel. Mean (2015) reported that mulching minimizes soil degradation by controlling runoff and soil loss, reducing the weed invasion and stops the progressive water evaporation. Also, it facilitates for more retention of soil moisture and helps in control of temperature fluctuations, improves physical, chemical and biological properties of soil, as it adds nutrients to the soil and ultimately enhances the growth and yield of crops. Further, Devendra and Sevilla (2002) reported that mulching boosts the yield by 50-60 percent over no mulching under rain-fed sustainability of intensive production systems both under irrigated and rainfed conditions. Zero tillage prevents the disruption of soil structure. Mulching by weeds to crops improves soil structure owing to a five-fold higher mean population of earthworms underneath the mulch.

Zero tillage is another emerging practice of CA as a way of transition to Conservation agriculture. However, CA is still facing constraints on its promotion such as lack of appropriate seeders especially for small and medium scale farmers, competition of crop residues between CA use and livestock feeding, burning of crop residues, availability of skilled and scientific manpower and overcoming the bias or mindset of traditional agriculture (Derpsch et al., 2011). Further, it also presents the actual gaps or uncertainties concerning the scientists’ positions on these environmental aspects. Researchers have purposed different practices of CA for wheat crop production. However, adoption of this technology is still in the infant phase. To provide the latest updates of CA on wheat production and soil quality enhancement, we carried out this review. The search result of online database google scholar using keywords, “Conservation Agriculture,” ‘benefits of CA on wheat crop yield,’ and ‘role of CA on soil quality improvement’ was included. The first section of the paper will discuss the benefits of CA on wheat productivity. The second section of the paper will highlight the advantages of CA on soil quality improvement. Finally, a discussion will be made in the last section of the paper, which will provide some
critical research questions and therefore be helpful to researchers.

**Conservation Agriculture and Wheat Yield**
Conservation Agriculture has significant impacts on wheat crop production. Khorami et al. (2018) reported that conservation agriculture including tillage reductions, better agronomy, and improved varieties, showed encouraging results with an increase in wheat yield and maize biomass (Govaerts, 2009). However, Acharya et al., (1998) reported that Mulches resulted in 0.06–0.10 m³ higher moisture in the seed zone when wheat was sown compared with the conventional farmer practice of soil tillage after maize harvest. Mulch-conservation tillage treatments favorably moderated the hydro-thermal regime for growing a wheat crop. The mean root mass density under these treatments at wheat flowering is higher by 1.27–1.40 times over the conventional farmer practice during the 3-year study. Aggarwal (2006) reported that sowing of wheat on beds reduced mechanical impedance and increased root growth in the upper 30 cm of soil, which ultimately resulted in higher crop yield. Thierfelder (2009) reported that CA has the potential to increase the productivity of crops by reducing the moisture stress due to drought and therefore reduce the risk of crop failure. Interestingly, manual weeding for weed control found more effective in bed planting treatment than in conventional, as evident from the significantly lower weed population/m² in the former. A study reported that total water use by the crop is reduced nearly by 5 cm, whereas yield and water-use efficiency increased by 0.22 tonne/ha and 0.03 tonne/ha, respectively, under conservation agriculture. Higher yield and biomass of wheat and maize (Zea mays L.) was reported by Afzalinia et al., (2012) because of Conservation Agriculture. A recent meta-analysis by Zheng et al., (2014) on CA practice, reported the 2.9% increase in wheat yield with the No-tillage with straw retention as compared to Conventional Tillage; however, there were no significant effects of No-tillage only practices on the wheat crop yield.

**Conservation Agriculture and Soil Properties**
Conservation Agriculture has positive impacts on soil quality and structure. Thierfelder (2009) reported that one of the immediate benefits of CA in dryland agriculture is improved rainfall-use efficiency through increased water infiltration and decreased evaporation from the soil surface. Also, CA decreases soil runoff and erosion. Acharya et al. (1998) reported that CA recycles available organic materials and enrich the soil environment in the long-term. Arshad et al. (1999) reported the greater soil water under No-Tillage (NT) over Conventional Tillage without dramatically altering bulk density due to redistribution of pore size classes into more small pores and less large pores. Khorami et al. (2018) study on Conservation Agriculture showed that No-Tillage had higher soil bulk density at surface soil, thereby lower cumulative water infiltration. Moreover, the lowest soil organic carbon and total nitrogen were obtained under Conventional Tillage (CT) that led to the highest C: N ratio. Application of maximum irrigation water under CT has negative impacts on water productivity. Afzalinia et al. (2012) on Conservation Agriculture showed that it significantly increased the soil moisture retention and slightly increased the soil bulk density compared to the Conventional Tillage method. Conservation Tillage also reduced the soil surface temperature and wheat and corn yield comparing to the Conventional Tillage method. Water-stable aggregation improved under NT compared with CT, perhaps because more soil organic C was sequestered within macro aggregates under NT compared with CT that helped to stabilize these aggregates. Steady-state water infiltration is greater under NT than under CT because of soil structural improvements associated with surface residue accumulation and lack of soil disturbance.

Soil organic carbon (SOC) is greater under NT than under CT nearest the soil surface. Kern and Johnson (1993) reported an increase of 21 to 36 Tg of soil organic carbon in CA over conventional farming. However, minimum tillage conserved current levels of SOC but did not consistently increase SOC above levels of conventional tillage. A study on CA showed that significantly higher water infiltration was on CA fields compared to conventionally plowed maize and wheat fields (De Vita et al., 2007).

Islam et al., (2000) reported that conservation management most consistently and markedly influenced soil quality indicator properties by increasing total and active microbial biomass carbon, increasing the ratio of active microbial biomass carbon to total organic carbon, increasing aggregation and decreasing the rate of basal respiration per unit of microbial biomass carbon. More stable aggregates in the upper surface of soil have been associated with no-till soils than tilled soils, and this correspondingly results in high total porosity under NT plots. Jacobs et al. (2009) found that minimum tillage (MT), compared with CT, did not only improve aggregate stability but also increased the concentrations of Soil organic carbon and Nitrogen within the aggregates in the upper 5–8 cm soil depth after 37–40 years of tillage treatments. Generally, straw retention improves aggregate stability, reduces soil erosion, and increases the infiltration and conservation of soil water, thus enhancing soil productivity. Additionally, straw retention directly increases the input of organic matter and nutrients into the soil, in turn improving soil nutrient availability for crop growth.

**Future Directions in Conservation Agriculture**
Most of the research has focused on CA to increase crop yield, soil fertility, and soil quality. However, the contribution of CA to the economy of the farmer is not clear. There is still a contradiction about the CA that whether the weed population crop field is more due to lack of use of herbicides or less due to suppression of growth by mulches.

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There is no research at developing countries where conservation agriculture is practiced by a small group of farmers at the subsistence level. Therefore, a study on the economics of CA and pesticides use might be the future area of study. No significant effect of NT on crop yield was found in China. Rusinamhodzi et al. (2011) found that NT had no significant effect on maize yield under rainfed conditions. According to Jacob et al. (2009), density fractionation of the surface soils revealed that tillage system affected neither the yields of free particulate organic matter (POM) nor occluded POM nor their organic carbon and N concentrations. The effect of CA on carbon and Nitrogen storage after long term practice of CA is further the area of study. Zheng et al., (2014) study reported the introduction of NT in Europe may indeed have exerted adverse effects and had reduced crop yield by an average of 8.5%. Moreover, Continuous NT decreased crop yield in North China, probably owing to the high precipitation (Zheng et al., 2014). The increased crop yield and soil properties because of conservation agriculture in the present studies are based on short-term results, but it is vital to evaluate medium and long-term effects on soil properties, crop yields and water use in future.

Studies reported several benefits of conservation tillage over conventional tillage (CT) concerning soil health, plant growth, and the environment. There are no clear and consistent points on the effect of CA on different agro-ecological zones. Research on Conservation agriculture mainly focused on some combination of reduced tillage, increased crop residue return, improved soil fertility and/or increased application of organic amendments but not on increased crop diversity. Also, there is no plenty of quantitative data on the effect of CA. Thus, a study on the impact of CA on crop diversity might be the area of research for agronomist.

The yield, compatibility, and profitability of wheat with the leguminous crop is calculated meanwhile pulses crops are the core of agricultural sustainability, enhancing both soil health and consuming low nutrient, but there are not enough studies on CA practices and its impacts on pulses and oilseed crop yield. Thus, future research should emphasize the effects of CA on pulses and oilseed crop yield and productivity. The potentiality of CA as a source to conserve biological diversity and preserve ecosystem services cannot be denied, but there are very few researches on a specific climatic parameter that plays a crucial role in reducing wheat yield and then CA practices helpful to a farming system to alleviate and acclimatize those climatic parameters. Thus, future studies should direct the effect of climatic parameters on CA and wheat yield too.

In our study, we reported the positive effects of CA on wheat yield. However, recent studies showed that impacts CA could have both positive and negative effects on crop yield. For example, the positive effects of CA on crop yield were observed in the U.S., Australia, India, and Canada. However, adverse effects were observed in Europe (Zheng et al., 2014). Among the CA methods applied in China, straw retention showed a significant positive impact on crop yield. But there was no significant effect for reduced tillage without straw retention (Zheng et al., 2014). Also, there was a positive impact of CA on rice and maize whereas negative impacts of CA practices on wheat yield. The result also found that CA increased crop yield by 6.4% and 5.5% compared to CT in Northwest and South China, respectively, whereas no significant effects were observed in the North China and Northeast China regions, so the impact of CA on various climatic region, crop types and CA practices is further matter of research. Farooq et al., (2011) also reported that there were significant variations in CA effects on crop yield between cropping regions in the U.S. and Canada. To avoid negative impacts of CA on crop productivity, specific CA practices should be used in the specific areas and crops.

De Vita et al., (2007), who reported significantly higher wheat yield under straw retention than under CT only in dry years. Besides, straw retention may depress crop growth by nutrient immobilization in soil microbes and increases in residue-borne diseases. Thus, future studies should be more focused on CA practices such as straw retention about wheat yield. Rusinamhodzi (2011) found that 92% of the data show that mulch cover in high rainfall areas leads to lower yields due to waterlogging, 73% of the data show that conservation agriculture practices require high inputs especially N for improved yield, 56% of the data show that reduced tillage with no mulch cover leads to lower yields in semi-arid areas. There is both positive and negative effect of CA practices. To recommend specific CA practices on that particular biophysical condition, CA practices is further a matter of research on the target area.

**Conclusion**

Conservation Agriculture (CA) is a resource-conserving environment-friendly practice for sustainable crop production. Conservation Agriculture has positive impacts on wheat crop production and soil productivity. However, future research should direction the contribution of CA to the economic portion of the farmer by analysing the cost benefits of CA. CA showed a significant positive effect on crop yield on a short-term basis, but research should focus on the economics of smallholder farmers practicing CA in the long run.

Mulching is one of the CA technologies that results in 0.06–0.10 m³ higher moisture in the seed-zone when wheat was sown compared with the conventional farmer practice of soil tillage after maize harvest (Acharya et al., 1998). Research has emphasized the effects of CA mostly on wheat and maize, but it should focus on pulses and oilseed crop yield and productivity too. Mostly the details of climatic parameters on effects of wheat yield are given on a
qualitative basis. To understand a clear view on the impact of CA on wheat yield, research should focus on providing climatic parameters data on a quantitative basis.

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