Does conservation agriculture work for rainfed farming in Nepal? A review

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Abstract
Intensive tillage-based agricultural practices severely affect the soil's physical, chemical and biological properties that eventually limit the crop yields in longer run. It is due to declining soil physical, chemical and biological properties. Several studies have been done to restore and improve the soil quality, however conservation agriculture (CA)-based practices of minimum tillage, crop residue retention and appropriate crop rotations has been observed to be promising across the globe. Studies on CA under Nepal's rainfed farming systems of Terai and hills of Nepal improved the soil quality, increased individual crop and system yields, reduced labor demand and was economically profitable. However, lack of adequate soil moisture during planting in initial seasons, inadequate tillage equipment and weed management options are the key constraints of rainfed farming to be transformed into CA in initial stages. In Nepal, the introduction of animal-drawn direct seeding equipment, management of residues or mulches, mechanical or herbicidal weed management options for small-scale rainfed hill farmers can be of paramount significance in scaling-out of the CA based practices in Nepal. For this, further on-station and on-farm verifications of CA based practices need to be carried out across the various cropping systems and agro-ecological regions of the country by Nepal Agricultural Research Council (NARC), Nepal in collaboration with international CG centers, universities, extension and development institutions.

Keywords: Conservation agriculture, economics, rainfed agriculture, soil water, yield

Introduction
Rain-fed agriculture, where crop production relies on seasonal precipitation, often shows a grim picture of a fragile environment due to water scarcity, drought, soil degradation, low rain (water) use efficiency, poor infrastructure and inappropriate policies. Rainfed agriculture covers 80% of the world's cultivated land, and contributes about 60% to the total crop production (UNESCO, 2009). Low productivity in many arid and semiarid rainfed agricultural systems is often due to degraded soil fertility and limited water and nutrients input. Though rain-fed agriculture is practiced in almost all hydro-climatic zones, it provides much of the food consumed by poor communities in developing countries. In Nepal, despite having ample fresh water resources, almost 67% of agriculture is based on rain-fed farming, the annual agricultural output in the dry season is highly dependent on weather conditions. In Nepal, more than 80% of total precipitation falls during the monsoon, from June to September (Malla, 2008). Therefore, the crop yields vary from year to year depending upon the weather conditions mainly precipitation. Studies on CA under rainfed agriculture in Nepal are meager. However, an attempt has been made to highlight the works done across the various cropping systems in Nepal.

Methodology
The methodology adopted to prepare this article is review of various works done on conservation agriculture (CA). As the CA in rain fed system is particularly less explored dimension in case of Nepal. Here we have tried to compare the empirical international studies on rain fed aspect of CA to the available research results done in the country to demonstrate the effectiveness of conservation agriculture in Nepalese context. The collected information are summarized and described in comprehensive way with the help of figures, pictures and tables wherever needed to give the clear picture of whether CA is useful or not in rain fed system of Nepal.

Results and Discussion

Water scarcity is the biggest threat to the food self-sufficiency, which seems to exert even stronger influence on rainfed agriculture in future (Hoff *et al.*, 2009). The scarcity of water for food production through agricultural droughts and dry spells will be a big challenge for water management (Rockstrom, 2003). Factors that influence the performance of rainfed farming systems include the ratio of precipitation to potential evapotranspiration, water availability, drought risk, temperature regimes, soil quality, external input use etc. There are many interrelationships among these factors (Harrington and Tow, 2011).

Broadly, agri-food systems under rainfed water scarcity is characterized by food and nutrition insecurity, unemployment and migration. Natural resources growth is hampered and more prone to losses of biodiversities and women are more vulnerable to these shocks. Therefore, the only option in these areas is to harvest, storage and utilize rainwater and the strategies for it has been shown in figure 1 below.

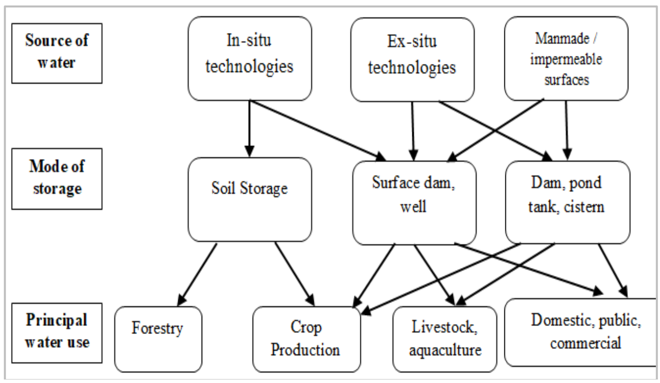

Fig.1: Rain water harvesting strategies

(Source: https://wocatpedia.net/wiki/File:Rainwater_harvesting_systems.jpg)

Categorically, it can be addressed by genetic resources, plant breeding and crop management. In this paper, an attempt has been made to highlight how crop management practices in particular conservation agriculture improve soil moisture regime under rainfed cropping systems. The emphasis will be primarily on *in-situ* water management under uplands.

In-situ water harvesting techniques

It is necessary to store the maximum amount of rainwater during the wet (monsoon) season for use at a later time. One of the methods frequently used in rainwater harvesting is the storage of rainwater *in-situ*. The *in-situ* technology consists of making storage available in areas where the water is going to be utilized. Rainwater harvesting for infiltration also known as in situ water harvesting is a practice in which rainwater uptake in soils is increased through the soil surface, rooting system and groundwater, hence influence the water availability and subsequent vegetative growth and crop yield (Manyatsi *et al.*, 2011). Soil effectively acts as the storage agent, which improves water holding capacity and fertility and reduces risks of soil loss and erosion. An attempt has been made in this paper on an alternative production system that could contribute to water harvesting, storage and efficient utilization *in-situ*.

Conservation agriculture

Conservation agriculture is a set of management practices including minimum tillage, crop residues (mulching) and crop rotation has demonstrated the potential to increase agricultural productivity and food security while preventing erosion and maximizing the ecological functions of the soil (Kassam *et al.*, 2009). It is often stated that the CA system can help agriculture adapt to increasing climate variability and the occurrence of extreme events (Williams *et al.*, 2018). The erosion protection, reduction in soil temperatures and improved infiltration rates can help deal with more intense rainstorms, and increased daily temperature ranges and frequency of drought (Kassam *et al.,* 2009). Summarizing available research, Dixon *et al.,* (2020) concluded that CA can improve food production, increase energy and water use efficiencies, while reducing greenhouse gas emissions.

Effects of CA practices on soil properties under rain-fed condition

Laborde and McDonald (2019) reported that after two years of conversion of conventional system to CA in maize-rapeseed and maize-wheat rotational systems, the mean weight diameter of dry aggregates (0-5 and 5-10 cm depths) was greater (by 45% and 24%, respectively), soil sorptivity slower, and bulk density (measured at the 0-15 cm depth) greater in CA than the conventional tillage (CT). These findings demonstrate that during the initial years of transition from conventional to a CA based crop management system, soil physical properties may improve but crop yield could either decrease or remain stable in the mid-hills of Nepal. As such, the benefits CA appear to be largely oriented towards improving environmental outcomes, and the efficiency and profitability of crop production. Additional management interventions are conversely likely to be needed to increase yield.

Conservation agriculture and soil moisture regime

One of the most notable distinctions of CA is that it requires spending little or no time on the physically demanding tasks of moving the soil (Haggblade *et al.,* 2011). In addition, reduced tillage can improve the physical, chemical and biological properties of the soil through increased soil organic matter. Mulching maintains moisture by covering the soil while rotation can help improve soil quality and reduce the incidence of crop diseases and pests. Summarizing available research, Dixon *et al.,* (2020) concluded that CA can improve food production, increase energy and water use efficiencies, while reducing greenhouse gas emissions. The major components of the conservation agriculture practice at the soil-atmosphere interface showing how tillage and mulch management affect infiltration, soil moisture availability, utilization and crop performance. Tillage alters soil structure and increase porosity of the upper layer and enhances the initial infiltration while mulch reduces raindrop impact on soil surface, increasing infiltration of rainwater and reducing evaporation.

CA and soil erosion control

A major benefit of CA is the control of soil erosion due to maintenance of soil cover, greater infiltration and reduced run-off (Erenstein *et al.,* 2015). Tiwari *et al.,* (2009c) suggested that reduced tillage (RT) with residue retention in maize-cowpea rotation was more effective in maintaining soil fertility and increasing farm income compared to a maize-millet rotation. Atreya *et al.,* (2005) reported no differences in maize yield between different tillage treatments but total annual soil and nutrient losses in RT (11.1, 126 kg/ha SOC, 11.8 kg/ha N, <1 kg/ha P and 2.4 kg/ha K, respectively) were lower compared to CT (16.6 t/ha, 188 kg/ha SOC, 18.8 kg/ha N, <1 kg/ha P and 3.8 kg/ha K, respectively) in a central mid-hill location in the Kathmandu valley. Atreya *et al.,* (2008) reported significantly lower annual and pre-monsoon soil and nutrient losses with RT and rice straw mulching compared to CT, but both conservation approaches neither significantly reduced runoff nor increased maize yield compared to CT. Both studies suggest that RT could be a viable option for minimizing soil and nutrient losses without sacrificing crop yields in the mid-hills of Nepal, although efforts are needed to overcome perceptual hurdles to adoption among farmers.

CA and soil moisture holding capacity

Moisture holding capacity (MHC) can be an important determinant in crop productivity. High crop water demand under rainfed farming promotes rapid soil drying by evapotranspiration, which can lead to plant moisture stress. Improvements in soil moisture holding capacity through aggregation and enhanced organic matter content are commonly observed in reduced tillage systems. After 13 years, tillage was found to have a significant ($P < 0.01$) effect on MHC at the three moisture tensions tested. Conventional tillage (CT) produced lower moisture holding capacity (MHC)s at all tensions. With increasing tension from (−10) to (−100) kPa, CT retained an average 67.49% of the (−10) kPa MHC, while no tillage (NT) retained 70.72%, and reduced tillage (RT) 65.73%. (Williams *et al.*,2018). Tiwari *et al.*, (2008b) reported that RT decreased runoff 7-11% and soil loss by 18-28% compared to CT in a mid-hill watershed in the central region of Nepal. The author finds out that the effect of prolonged drought on maize during winter season of 2015 at Rampur, Chitwan, Nepal was evident and no tilled with residues for three years had less effect of drought than the conventionally tilled without residue plot. Similarly, from another experiment on various tillage methods and hybrids of maize during winter season of 2014, at Rampur, Chitwan, Nepal, carried out by the author, revealed that at physiological maturity stage of maize significantly lower soil moisture content of 11.9% in conventional tillage as compared to 14.32%. in NT.

Infiltration rate

Improved aggregate stability, combined with the residue retention in CA systems, is often observed to have a significant positive impact on soil water storage. These increases typically due to a combination of greater rates of infiltration and decreased soil water evaporation (*Li et al.*, 2019b). Increases in infiltration are commonly attributed to the improved aggregate stability in the surface of the profile (where improvements in SOC are highest) and the greater number and continuity of macropores available to rapidly transmit water into the soil profile in the absence of tillage (Li *et al*., 2019b). It should also lead to increased water infiltration from the creation of a larger number of root channels (Baudron *et al.*, 2012). The presence of crop residues can also help protect the surface of the soil from raindrop impact and prevent the formation of surface seals, which can decrease infiltration rates (McGarry et al 2000). Knot (2014) observed that cover crops (surface residues) increased infiltration and soil water content and decreased run-off and associated soil loss (Mchunu *et al.,* 2011). They also shade the soil and decrease wind speeds at the soil surface, decreasing water loss from evaporation (Nielsen *et al.*, 2005; Lampurlanés and Cantero-Martínez, 2006). In a study carried out by the author at Rampur, Chitwan, Nepal during 2010 to 2015 under maize based cropping system, increased infiltration rate in CA than conventional agriculture was recorded after the elapsing of time for 10 minutes. Up to 20 minutes both have cumulative infiltration of 25 mm but after that conservation agriculture exceeded with higher infiltration rate of 84 mm/ha in 20 minutes and 78 mm/ha in 30 minutes period (Figure 3). Zhang *et al.*, (2007) reported the increased infiltration rate by 3.7 times under zero tillage with residue retention after conducting experiment in Paleustalfin, Australia for 24 years. Conservation tillage (no or minimum tillage with crop residue) in rainfed environment is reported to avoid crusting and increase infiltration (Pansak *et al.,* 2008: Fuentes *et al.*, 2009). Jin *et al.*, (2009) and Pansak *et al.*, (2008) reported higher water conserved by conservation tillage, which is partly explained as the system, had crop residue which produces less evaporation and higher infiltration.

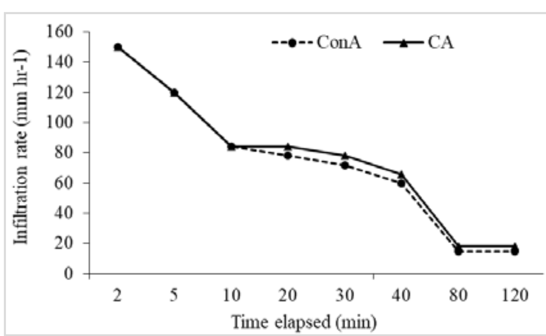

Fig. 2: Infiltration rate of soil as affected by crop establishment methods

CA and soil water evaporation

CA practices reduce the evapotranspiration (Grabowski and Kerr, 2015) and it might be due to the act of crop residues on the soil surface that not only improve aggregate stability, increase infiltration, reduce run-off but also significantly reduces the soil moisture evaporation (Singh *et al.,* 2018). Studies revealed that tillage methods affected the rate of soil evaporation and was also obvious on interaction effects of tillage and residues effect on evaporation. Residue limits the energy reaching the soil surface that limit the relative rate of evaporation in a simple logarithmic function (Steiner, 1989). At Kansas State University's Southwest Research and Extension Center, full-surface residue coverage with corn stover and wheat stubble has been shown to reduce evaporation by 50% to 65% compared to bare soil with no shading (Klocke *et al.,* 2009). Converting to no-tillage has also been shown to reduce irrigation water needs because soil water evaporation is reduced (Pryor, 2006). Mitchel *et al.,* (2012) with the application of wheat residue to a depth of 10 cm in corn (maize) field in California, USA revealed that residues reduced near-surface daily maximum soil temperatures at 1cm below the soil surface by up to 20°F relative to bare-soil conditions. They depicted that more water was retained in the soil under the residues than in the bare-soil plots. Coupling no-tillage with high-residue preservation practices could reduce soil water evaporative losses during the summer season by about 4 inches (10 cm), or 13%, assuming a seasonal evapotranspiration demand of 30 inches (Mitchel *et al.,* 2012). Similarly, from an experiment under maize based cropping system of Rampur, Chitwan during 2015 revealed that no tillage with plastic mulch plot had less evaporation loss compared to conventionally tilled plot.

CA and water-use efficiency

Plant-available water was higher under no-till (Taylor *et al.,* 2012 and Kidson, 2014). Water-use efficiency is also increased and save water by 15-50% through the adoption of CA technologies. It reduces water runoff, better water infiltration and more water in the soil profile throughout the crop growing period. It has potential to increase water application efficiency by over 50 % and irrigation efficiency by 60 % (Pokhrel *et al.,* 2018). In an experiment of crop establishment methods under maize (summer)-wheat (winter) cropping system for two years at Rampur, Chitwan, Nepal, author found that the soil water storage at anthesis stage of wheat was higher in NT with residues compared to CT without residues. The gap was wider at upper layers and was almost equal at lower depths (Figure 3). It might be due to the reduced losses of soil moisture due to evaporation from soil surface.

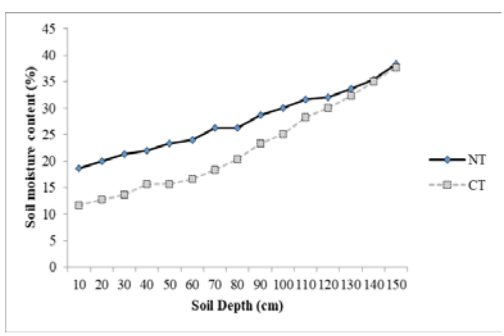

Fig. 3: Soil moisture content at 0-150 cm soil depth under NT and CT at anthesis stage of wheat in 2014 winter season at NMRP, Rampur, Chitwan.

Similarly, soil moisture conservation in NT systems relative to plough tillage (PT) systems has been reported in other studies (Bonfil *et al.,* 1999). While there were no significant differences in volumetric moisture content (VMC) measured at all dates in 2017, there was significant impact of tillage treatments on VMC measured in two out of the five measurement dates in 2018. It is possible that the residue cover in the NT treatment reduced soil water evaporation relative to the PT and strip tollage (ST) treatments, especially in 2018 due to higher mean seasonal temperatures compared to 2017, leading to significantly higher VMC in NT at these two measurement dates in 2018. CA based on no tillage system alters the partitioning of the water balance, decreasing soil evaporation and increasing infiltration and deep percolation, leading to increased yields and water use efficiency (Wang *et al.,* 2012). Water use efficiency is increased and save water by 15-50% through the adoption of CA technologies. It reduces water runoff, better water infiltration and more water in the soil profile throughout the crop growing period. It has potential to increase water application efficiency by over 50 % (Karki and Shrestha, 2015).

CA and crop yields under rainfed condition

In a study carried-out by Karki *et al.*, (2014) under rainfed maize-tori (rapeseed) system of Western hills of Nepal, grain yield of maize and tori was significantly higher over conventional agriculture. Similarly, Karki *et al.*, (2014) also carried out an experiment under maize based rainfed ecosystem of central terai, Nepal during 2013 and 2014. System yield was significantly the highest (11.29 t/ha) in NT with residue kept and intercropping of maize with soybean during summer and wheat during winter was followed. Obviously, the least system yield was observed in no tilled, residue removed and sole crop of maize followed by winter fallow (7.59 t/ha). In an experiment of tillage and crop rotation under rainfed condition, there was an increase in yield in no-tillage with rotation over no-tillage without rotation (Rusinamhodzi *et al.*, 2011). Reduced tillage practices combined with crop residue retention on the soil surface can increase moisture infiltration (Shaver *et al.*, 2007), reduce erosion and increase water use efficiency (Johnston *et al.,* 2002). Crop residues accumulating on the soil surface form a barrier to water loss by evaporation, decrease soil temperatures. The removal of stover in marginally dry years showed a tendency to result in lower grain yields (Linden *et al.*, 2000). Rusinamhodzi *et al.*, (2011) reported that overall effect on maize yield while reduced tillage (with or without mulch) and continuous maize from 5 years experimentation had negative effect on yield compared with the control.

CA and economics

Where CA leads to similar or greater yields, profitability is generally improved due to reduced costs of land preparation and labor, and reduced water requirements (Kumar *et al.*, 2018 and Devkota *et al.*, 2019). Many studies on CA based practices have been carried out under maize based rainfed ecosystems of Nepal and their findings were in agreement with each other and have been depicted in table below. Benefit cost ratio is the ratio of gross returns to cost of cultivation which can also be expressed as return per rupee invested.

Table 1. The economics of various studies carried out by various authors in Nepal

References	Economic analysis (benefit cost ratio)		Remarks
	Conventional tillage without residue	No tillage with residue	
Karki *et al.*, (2014)	1.7	2.5	Hills (maize-wheat/tori)
Paudel *et al.*, (2015)	2.3	2.5	Terai (maize+soybean-wheat)
Khatri and Karki (2015)	2.42	2.53	Terai: (maize+soybean-wheat)
Karki *et al.*, (2015)	2.43	3.3	Terai (maize-maize)
Karki *et al.*, (2015)	1.18	1.36	Hill (maize-wheat/tori)

Constraints of CA under rainfed agriculture

Lack of appropriate seeders and planters under limited soil moisture content on soil, trade-offs among various options for crop residue (as a soil cover/mulch for CA and livestock feeding and burning of residues, fuel etc.), inadequate package of practices for soil moisture management, weeding and intercultural practices and nutrient management, unavailability of skilled manpower are the key constraints of adoption of CA in Nepal. Conventional tillage-based mindset of the policy makers, technicians and farmers is another constraint to promote the CA based practices under rainfed agriculture in Nepal.

Conclusion
CA provides resilience to changing patterns of rainfall, builds and maintains the soil fertility by adding organic matter, moisture and minimize soil loss by erosion. By increasing or stable yields, CA can increase food security and add extra income for the rainfed farmers. In order to promote the CA based practices under rainfed farming in Nepal, there should be an appropriate farm machineries/tools, adequate biomass as residues and integrated crop management technologies. NARC in close collaboration with international and national organizations should have a long-term policy to promote CA based practices under rainfed condition in Nepal.

Acknowledgements
A large number of farmers and experts have been involved in testing, developing and promoting the various CA based practices and they all are highly acknowledged. The authors are also thankful to NARC management, NMRP, Rampur, CIMMYT and IRRI, Nepal.

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