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Conservation Agriculture in Maize-based Cropping System of Nepal: A Review

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ABSTRACT

Maize-based cropping system followed by intensive tillage and faulty practices often associated with many negative implications such as the decline of soil organic matter, increase soil erosion by wind/water, lower nutrient-use efficiency, field burning of crop residue, air pollution mainly attributed to the monoculture of intensive conventional production systems leading to global warming and decline in factor productivity. Conservation Agriculture (CA) underlying principles of minimal soil disturbance, soil cover and crop rotation are increasingly recognized as an essential for the sustainability of this cropping system. Therefore, a brief review was done to find out the results its constraints and the possible interventions under a maize-based system of Nepal. Very few works under CA is done so far under maize-based cropping system of Nepal, however, the results are encouraging. There are some constraints in CA technologies promotion, such as scale-neutral agri-machineries, crop residues competition between CA use and livestock feeding, skilled and scientific manpower availability and overcoming the bias or mindset about tillage. CA provide opportunities to reduce the cost of production, improve resource use efficiency, saves water and nutrients and increase yield. There is a need to develop and promote low-cost technologies of CA that can be used effectively in maize based system of hills and Terai.

Keywords: Crop rotation, maize-based system, tillage, residue retention

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INTRODUCTION

Maize (*Zea mays* L.*)* is the second most important staple food crop after rice in Nepal. The area and production of maize are in a declining trend annually, which could be due to the negative impact of climate change, poor soil nutrients and water availability to the plant (Pariyar et al 2019). The application of poor technologies, use of obsolete genotypes along with the higher cost of production, which has been exacerbated by the shortage of labor have further increased the problem (Joshi et al 2011). Maize-wheat is the second most important cropping system in Nepal after rice-wheat and the most prominent cropping system for food security in the mid-hills of Nepal. Soil conservation measures have not been initiated in such slopy lands leading to severe erosion each year. Declined soil fertility status of maize growing areas in the mid-hills is one of the major constraints for its sustainability (Gautam et al 2009).

In an intensive cropping system, input-use efficiency is low (Drechsel et al 2015). The major maize-based farming systems are less profitable. Farmers are adopting conventional agricultural practices, which are water-capital-energy-intensive, and thus a serious threat to the sustainability of the system (Bhatt et al 2016). Additionally, there is a lack of quality inputs, sites specific nutrient management and pest management options for mechanization and sustainable intensification (Panday et al 2018). Conventional agricultural practices such as crop residue removal and excessive tillage on farming land lead to loss of residual moisture and ultimately the fertile soil becomes prone to nutrient depletion and damage soil structure (Gupta, 2006). The organic matter content in the soil is low since there is very low use of farm-yard manure and also low residual nutrients on it. Nepalese farmers use 2.5–3 Mt ha^{-1} of FYM annually for soil fertility management (Panday et al 2018). The yield gap between potential and actual crop yield is huge as realized by the farmers and is mainly attributed to the lack of good agricultural management practices, poor nutrient content of chemical fertilizers and poor seed germination (Pokharel 2016). In addition, several climatic variations like high temperature and low rainfall have escalated the yield gap (Panday 2012). The area under cereal-based farming has been found to diminish due to several constraints. One of the major reasons includes intensive tillage practice for land preparation. The field needs to till at least 2-3 times, two intercultural operations for weeding and earthing up operation. These increase in the number of plowing and furrowing have accelerated soil erosion and nutrition loss leading to further degradation of agricultural land (Acharya et al 2007). With recent increases in fuel prices tillage now accounts for a higher proportion of production costs than harvesting doses. Fertilizer recommendations are entirely based on soil types and agro-ecological zones. Regardless of recommendations, farmers mostly use acid-forming nitrogenous fertilizers (Panday et al 2018).

A novel management system needs to be promoted and adopted to address these issues. Furthermore, the Conservation agriculture (CA) production system has been demonstrated to be beneficial for sustainable agro-ecosystem management and intensification. CA system holds three principles: a) minimum soil disturbance b) permanent soil cover c) optimum crop rotation/intercropping (Dang 2019). Maize, rice, wheat in intensive care are exhaustive feeds and heavily deplete the soil nutrient. Inclusion of legumes in rotation or association with cereals under CA helps to break the continuous mono-cropping effects of cereals and plays important roles in adapting the production systems to climate change, suppressing weeds and fixing nitrogen (Snapp et al 2010). Crop residue retention and cover crops help reduce greenhouse gas emissions and increase C sequestration (Garcia Torres et al 2001). Crop residues act as a sink and source for plant nutrients. Different crop residues have different capacities to serve as sinks and sources of nutrients for crop yield depending largely on climatic conditions, soil properties, crop characteristics and tillage (Clay et al 2014).

Zero-tilled wheat and direct seeded rice area is increasing in terai whereas in hill major challenge is topography and little study on maize based cropping system has been carried out. Terai is being explored for CA to some extent whereas large areas in hills and mountains where crop ecologies are entirely different are not explored. The main body to develop, verify and disseminate CA technologies is Nepal Agricultural Research Council and Department of Agriculture in Nepal. Testing and promotion of CA under a maize based system have been carried out by IFAD, through CIMMYT in western Terai and adjoining hills of Nepal. Several machines have been tested and improved in Terai but are still not perfectly executed. In hills, no implements and equipment are tested for reduced and zero tillage and none of the tools are for zero till weeding and mowing (Karki and Shrestha 2014).

However, CA being a potential technology, little work has been undertaken in Nepal. The primary restriction to adoption of CA is the mindset that soil tillage is of utmost need for agriculture production other includes social, intellectual, environmental, technical and political characteristics. Furthermore, in mainstreaming CA system key restriction lies with the problem of up-scaling which is due to lack of knowledge, inputs (especially equipment and machinery), expertise, poor policy support, adequate financial resource and infrastructure (Friedrich et al 2009). Evaluations of CA systems have been rarely documented and have never been introduced on a larger scale. There is still a lack of consensus on the merits of CA in the context of smallholder farming systems in Nepal.

The major cropping system in different ecological zones of Nepal is given in Table 1.

Table 1. Major cropping systems in different ecological zones of Nepal

Terai and foot hills (<1000 masl)	**Mid hills (1000-2000 masl)**	**Mountain (2000-3000 masl)**
Rice-wheat	Rice-wheat	Maize-fingermillet
Rice –rice	Rice-winter legumes	Maize-wheat/barley
Rice-wheat-maize	Maize-wheat	Maize-buckwheat
Rice-vegetable	Maize-winter legumes	Buckwheat-fallow
Rice-wheat-vegetable	Maize-vegetables	Potato-fallow

Source: Ghimire et al 2020

Current status of CA in the world

Globally area under CA is 125 million ha out of which South America has the biggest area under CA i.e 55 million ha followed by North America, Australia, New Zealand Asia, Russia, Ukraine, Europe and Africa. Asia occupies 4 million ha i.e 4% area under CA. CA was adopted in 78 countries of the world (till 2015–16). Since 2009, the adoption of CA has increased by almost 10 million ha per year. Given strong and long-lasting work in these continents, limited results for non-tillage systems have been shown. The overall arable area under CA worldwide is still relatively small (approximately 9%) (Friedrich et al 2012). The region under CA is on the rise in Asia and vast areas of agricultural land are expected to migrate to CA in the coming decade, as is already the case in China, Kazakhstan and most likely India.

Current status of CA in Nepal

In Nepal, the adoption of CA technologies is in the primary stage, efforts to develop, refine and disseminate conservation based agricultural technologies started by the rice-wheat consortium in Terai in the 1990s. There are more payoffs than trade-offs for the adoption of CA. Nepal Agricultural Research Council (NARC) with CIMMYT and IRRI has been working on it under various ecologies. However, there are many bottlenecks in its promotion (Acharya and Karki

2021). In Nepal 800 ha area is under direct seeded rice and 500 ha is under zero tilled wheat (Saharawat et al 2021).

Impact of CA in a maize-based cropping system

Carbon sequestration

Higher C stocks in CA systems have been reported due to favorable conditions for decomposition, i.e. high temperature and moisture, quicker drainage after heavy rains and CO_2 emission related to the heterotrophic microbial activity is greater in CA systems (Metay et al 2003). Soil organic carbon content was found to increase by 1% with stubble retention. Low bulk density in minimum tillage with straw cover is attributed to the increased soil organic carbon (Schultz 1988). Minimum tillage prevented the loss of organic carbon by atmospheric oxidation as the exposed surface area was less. CA increased the organic carbon (C) by 12 kg ha^{-1} over the conventionally tilled maize. Corn stover returned to soil organic carbon increase 14% in the top 15cm layer. No-tillage resulted in soil organic matter increasing up to 58% in the top 4cm of soil for no-till treatment (Clapp et al 2000). To find out the effects of CA on soil organic matter and nutrients, an experiment of tillage with two levels (NT: no-till planting of maize and direct seeding of rice and CT: Conventional tillage for both the crops) and residue management with two levels (RK: Residue Kept i.e. maize residue anchored at 40cm above the ground for rice planting and rice residue anchored at 30cm for maize planting and RR: Residue Removed) under the maize-rice system was carried out at Rampur, Chitwan, Nepal during 2010 to 2013. The effect of tillage and residue on the soil organic matter N, P_2O_5, and K_2O content was found to be significant. No-tillage and residue-kept plots had a higher amount of organic matter, N, P_2O_5 and K_2O compared to conventionally tilled and residue-removed plots (Karki and Shrestha 2014).

Greenhouse gases (GHGs) and global warming

In a meta-analysis of CA in South Asia, no-tillage with residue retention reduced greenhouse gas emissions by 12–33%, with more favorable responses on loamy soils in maize–wheat systems (Jat et al 2020). Tillage has a great influence on CO_2 emission which is directly related to the frequency of tractor passes across the farm field. The CA based practices such as laser land leveling, ZT with residue retention, direct-seeded rice, brown manuring with sesbania, unpuddled, raised bed planting, crop diversification and site-specific nutrient management provide opportunities for improving resource use efficiency and mitigating GHGs emission (Pathak et al 2012). In ZT wheat 5% lesser Global warming potential (GWP) than conventionally tilled (CT) wheat was observed. The net GWP was 1,327 kg CO_2 ha^{-1} $year^{-1}$ under CA, whereas 7,729 kg CO_2 ha^{-1} $year^{-1}$ under CT. Higher emission of N_2O–N in ZT than in CT plots is observed because the soils under ZT are usually moist with SOM more concentrated at the soil surface favoring greater N_2O production (Bhatia et al 2010). Residue retention instead of burning reduces CO_2 and other GHGs since burning of 1000 kg rice straw emits 280 kg CO_2–C, 3 kg CH_4–C and 0.07 kg N_2O–N, with a global warming potential of 1,118 kg CO_2 equivalents per hectare (Gupta et al 2002). CH_4 emission was more under continuous flooded transplanted puddled rice (56.4 kg CH_4 ha^{-1}) and lowest in direct seeded rice (3.8 kg CH_4 ha^{-1}) (Gupta et al 2015).

Water use efficiency

In a meta-analysis of CA practices in South Asia, no-tillage with residue retention increased crop yields by 5.8% and water use efficiency on loamy soils and in maize–wheat systems (Jat et al 2020). The improvement of soil infiltration in CA systems is due to increased roughness and complexity of the flow path which slows down the water flow rate across the soil surface and the improved topsoil porosity is mainly due to increased macrofauna activity and less soil crusting. Mulch limits the amount of solar energy reaching the soil surface thus decreasing the first stage evaporation of soil water by 10 to 50 % depending on the amount of mulch covered and moderating the temperature. As a result, water is stored more quickly in the soil profile which can act as a buffer against the effects of an eventual dry spell at the early stage of the crop cycle (Scopel et al 2004). Surface (0–30 cm) soil in a no-till system was shown to contain more moisture and to be cooler than a comparable plow tillage soil (Doran et al 1998). In CA-based maize–wheat system the plots under ZT permanent broad bed with residue could reduce 2 year mean irrigation water use by 14% and increase 2 year mean water productivity of maize crop by 57% over CT. Surface water runoff is generally reduced with CA systems, between 0 and 85% (Das et al 2020).

Biodiversity and biological activity under Conservation Agriculture systems

Higher activities of glucosidase, acid phosphatase and arylsulfatase enzymes have been reported in the 0–10 cm layer with CA systems suggesting that these systems provide a more favorable habitat for microorganisms (Mendes et al 2003). Alkaline phosphatase activity was higher by 5% in Zero tillage (ZT) over CT and by 18% in residue–retention over residue removal treatment. Combined application of pigeon pea + wheat residue resulted in higher dehydrogenase, Beta–glucosidase, and acid phosphatase activities than no residue control at 0–5 cm soil under the permanent broad bed with residue than CT observed (Sepat et al 2015). A stable soil microbial community including beneficial bacterial and fungal species can be developed under CA, which can suppress pathogens. Dehydrogenase enzyme activity is considered the indicator of the oxidative activity of soil microorganisms while Beta–glucosidase is crucial to carbon (C) cycling. An increase in soil organic carbon (SOC) at a yearly rate of 0.2 kg under long term CA plots has been reported, which stimulates microbial biomass. An increase in the microbial biomass of 30 to 100 %, in the soil surface layers when plowing is suppressed. The use of deep-rooted cover crops and biological agents (e.g. earthworms) can help to relieve compaction under ZT (Piovanelli et al 2006).

Energy productivity and use efficiency

Land preparation and crop establishment in ZT are restricted to a single pass leading to the saving of 6-7 tractor hours and 35-36 L diesel per hectare over CT (Erenstein et al 2008). ZT could save 50–60 L ha^{-1} fuel amounting to ~3,000 MJ energy ha^{-1} (Sangar et al 2005). Raised bed planting in the maize-wheat-mungbean cropping system in ZT saved 91% energy in land preparation and 38% energy in irrigation, resulting in an 8% lower total energy requirement than that of CT flatbed planting (Saad et al 2016). An irrigated intensive 7 year-long maize based CA practice reduced the energy consumption by 49.7-51.5% in land preparation and 16.8-22.9% in irrigation leading to 14.8–18.9% higher net energy returns than CT (Parihar et al 2020).

Weed infestation and management

Species richness was higher in ZT than in CT indicating higher weed species diversity in ZT as compared to CT (Pratibha et al 2021). Weed seed bank about 60– 90% is accumulated in the top 5 cm of the soil in ZT resulting in their even germination and effective control through various techniques. Surface lying weed seeds in CA are subjected to decay, predation and desiccation by harsh weather resulting in the loss of viability (Nichols et al 2015). Herbicide effectiveness decreases with the amount of crop and weed debris on the soil surface. This debris not only ties up herbicides but also presents a physical barrier in uniform distribution of herbicides in the soil for residual activity. Thus application method and selection of herbicide rate is critical. Residue cover provides suppression against many weed species. In addition, there is generally less incidence of large seeded weeds in continuous no-tillage systems (Karki et al 2014). Stale seed bed for weed management in CA, here annual and perennial weeds of cereal and legumes can be controlled by either paraquat or glyphosate @ 1 kg a.i ha^{-1}. A tank mixture of glyphosate and 2,4-D is also effective for troublesome weeds like Cyperus rotundus (Marahattha et al 2014) Pre-sowing herbicides-glyphosate (@1 kg a.i ha^{-1}, glucofosinate, or dicamba and Paraquat (@ 0.5 kg a.i ha^{-1} or 0.5% by volume) are the most widely applicable herbicides for cereal-based farming (Karki et al 2014). Pre-emergence herbicide, pendimethalin reduces grassy and broadleaves in maize, wheat, and legumes. Moreover, in the first season experiment of tillage and weed management methods on spring maize at Rampur, results revealed that the weed index and weed control efficiency vary due to weed management methods where herbicide atrazine @ 0.8 kg a.i. ha^{-1} + glyphosate @ 2.5 mL L^{-1} of water as a pre-emergence spray with tank mixture was effective in weed control efficiencies and weed index (Shrivasta et al 2014). Post-emergence herbicide-atrazine @ 1 kg a.i. ha^{-1} at 20-30 DAS reduced grassy weed population in maize. Post-emergence herbicides, the mixture of tembotrione + atrazine was more effective in controlling all classes of weed flora at 40 and 60 DAS. Atrazine as pre-emergence followed by tembotrione + atrazine as post-emergence was found to be the best combination and this combination reduced the dry matter of weeds to the tune of 98.7 and 97.9% at 40 and 60 DAS, respectively resulting in significantly higher grain yields (11.57 Mt ha^{-1}) with maximum net returns (Mitra et al 2019). Application of metribuzin @ 1.4 g L^{-1} as pre or post-emergence within 20-30 DAS has been found effective for weed control in wheat and legume and sulfsufron @ 2.0 g L^{-1} was found effective in controlling broad leaf weeds in wheat (NAgRC 2020).

Tillage and cropping system effect on soil quality

Bulk Density (BD)

Increasing the years of practicing CA improves the BD of the soil within the optimum range (Ajayi 2015). The value of BD in all tillage-based cropping systems is found to be above the optimum range (Brady and Weil 2002). Lower bulk density values with minimum tillage than moldboard plow in the 0-5cm and 20-30cm soil layer observed as organic matter content at 0-5cm was greater under minimum tillage (Yang and Wander 1999). In minimum tillage plots that had been uncropped and received 3 levels of wheat straw mulch (0,8, 16 Mg ha^{-1} yr^{-1}), bulk density under higher mulch treatment was 58% lower and that under the low mulch treatment was 19% lower than the bulk density under the unmulched treatment for 0-3cm depth (Blanco and Lal 2007). The use of conventional tillage practice for 3 year increased the BD by 11.3% over the continued use of the CA-based maize legume cropping system. The reduction of BD at CA practices is due to the continuous incorporation of enough crop residues and the absence of soil disturbance resulting in an increase in organic matter and improvement in soil structure (Abebe et al 2020).

Soil pH

pH and cation exchange capacity of the soil were increased in crop rotation and intercropping systems in combination with CA due to the addition of soil organic C (Zerihun et al 2014). This is because crop residue returned to the soil under no-till increased the OM of the soil, thereby, increase in the pH of the soil. Long-term research on CT and CA based cereal–legume cropping systems found lower pH when continuously produced under conventional tillage practice (Zerihun et al 2014). pH in CA-maize+bean, CA maize +cowpea intercropping was found to be in the optimum range. Thus, CA based cropping systems are effective to stabilize the pH of the soil (FAO 1990).

Available nitrogen (N)

N mineralization could increase by 2 kg of N ha^{-1} $year^{-1}$ in the CA system due to the improvement in soil organic C and N stocks (Maltas et al 2007). The amount and dynamics of residue derived N mineralization depend on the type of crop, its productivity and the C:N ratio of its residues. Reduce tillage and surface residues increased soil N content in the surface 2.5 cm layer. Minimum tillage had a greater effect on mineralizable nitrogen than total nitrogen. Total nitrogen to 10 cm depth under no-tillage was 21% higher than for traditional tillage rain-fed maize/wheat systems (Thomas et al 2007). Various cover crops contribute to a more regular mineralization process, residue and crop litter fall have the potential to rapidly decompose and increase soil OM and further enhance the availability of N and other nutrients because legumes can fix N from the atmosphere, enabling diversified redox (Eh) niches and consequently diversified microbial communities. Reduced total available nitrogen under CT may be due to the removal of crop residue, higher decomposition rate and rapid leaching of the nutrients (Giller 2001).

Maize yield in response to CA based cropping system

In the interaction between tillage and cropping system, maize-wheat, maize+soybean-wheat, soybean-wheat; soybean-wheat cropping system had significantly higher grain yield irrespective of tillage but conventionally tilled plot with soybean–wheat was found to have significantly lower grain yield. Higher yield in soybean–wheat cropping system was observed in comparison to maize–wheat cropping system because of the higher C:N ratio in maize residue. Higher C:N ratio residue makes slow decomposition of maize stubble. This effect immobilizes a relevant amount of N reducing its availability for wheat crops ultimately resulting in yield loss. The reduction of wheat yield in maize-wheat cropping system could also be due to interferences during seeding. Soybean being an antecessor crop there could be more available nitrogen and this could also be the reason for significantly higher yield of wheat in soybean–wheat cropping system. In the interaction between residue managed and cropping system plot retained with residues and following soybean-maize interaction had significantly higher grain yield than other plots. A significantly higher difference in grain yield was observed within the plot with either of the residue management system but with a different cropping system (Thapa et al 2018). In one of the experiment conducted in Nepal in western hills in its 4th year under the maize-rapeseed system, grain yield was affected significantly by tillage methods where a yield of 5.21 Mt ha^{-1} was produced under no till as against CT with 4.75 Mt ha^{-1}. In this experiment highest test weight (1000 grain weight) of maize was recorded in NT 263.9 g as compared to CT 262.5 g (Karki et al 2014). A meta-analysis across South Asia in a variety of cropping systems recorded a 5.8% higher mean yield with CA component ZT with residue retention than conventional agricultural practices (Jat et al 2020).

Production effeciency of the cropping system

In Nepal, most of the studies have shown that the individual crop and system yields increased due to CA-based practices. A two years study carried out under a maize-based system in the hills revealed that the effect of no-tillage and residue retention was evident in farmers' practice of conventional tillage without crop residues for crop yields of maize (Karki et al 2014). Similarly, in Terai, an experiment was carried out under a rice-maize system, the system yield of maize during the first year was not obvious, however, was varied significantly in the second year and was higher in CA over conventional tillage (CT).

Table 2. System yield of maize (kg ha^{-1}) as influenced by establishment methods, at Rampur, Chitwan, Nepal during 2010/11 and 2011/12

Treatments	System yield (kg ha^{1})	
	2010/11	**2011/12**
CT	6234	3943
CA	6234	5026
SEM (±)	73.3	73.3
LSD	ns	103.6

Higher system productivity from the inclusion of pulses in cereal based cropping systems has been achieved compared with continuous conventional practice. Relative Production Efficiency (RPE) was recorded from all CA based cropping systems in which maximum RPE was recorded from CA maize–bean rotation (145%). This indicates the superiority and desirability over the existing system (conventional tillage-maize). Moreover, it has been reported that positive figures of >20% relative production efficiency are considered worth recommending for an extension. A positive RPE value higher than 20% was recorded in all CA-based cropping systems (Dinesh et al 2014). Intensification through the inclusion of leguminous crops increased the relative production and land use efficiency of the production system (Sharma et al 2004). Legume may have advantages well beyond the N addition, fetches higher price over cereals, breaking pest (weed, insect pest, and diseases) cycles, and minimize harmful allelopathic effects which in turn improve system productivity, production efficiency of the production system (Reddy and Sudhakara 2003)

CA and Economics

The highest benefit-cost ratio (2.4) in the plot having no-tillage with residue was recorded followed by no-tilled with no residue (2.4) in Chitwan, Nepal (Bk and Shrestha 2014). In an experiment conducted on the effects of two tillage methods (zero tillage and conventional tillage), two residue managements (residue kept and residue removed) and two levels of cropping system (maize + soybean and sole maize) over 3 years (2015-2017) at Horticultural Research Station, Dailekh, Nepal, a relatively higher benefit-cost ratio resulted from zero tillage (2.3) as compared to conventional tillage (2.2) (Pariyar et al 2019). The higher gross and net return of the maize-soybean system might be due to higher land, soil and resource use, the higher total yield of maize and soybean and the higher marketing price of soybean. Higher net income is obtained in all intercropping systems in comparison to pure or sole cropping. Net benefit was higher in conservation agriculture (CA) ranged from NRs. 49.0 thousand per ha in 2015 and NRs. 31.4 thousand in 2016 with the total mean value of NRs. 40.2 compared to conventional agriculture. Relatively higher B:C ratio resulted from zero tillage (2.3) as compared to conventional tillage (2.2). This inferred that ZT is more profitable than CT and the profitability of ZT is mainly due to the less cost of production and higher gross income (Prasai et al 2018).

Bottlenecks/constraints for adoption of CA

Machines dependence and unavailability at the farmer's level

The utmost priority for CA is to scale appropriate seeder, tractor and other equipment. Crop specific ZT seeder/ bed planter, residue load specific turbo/ happy seeder, combine with straw management system (SMS) are required for seed and fertilizer placement, handle crop residues, seed/soil compaction and furrow closing. Small scale farmers especially in hills and mountain areas need lightweight direct drill seeder machines for animal, manual, or small–tractor power sources with low affordable cost. The increase in operational cost over time may result in lower economic benefits in machinery intensive CA systems.

Residue unavailability and competitive role

In smallholder farming system crop residues have alternate competitive uses such as of fodder, feed and fuelwood especially in mixed crop+livestock system and under rainfed agro-ecologies where copping is restricted to a single season and therefore fodder often is in critically short supply and further enhanced due to less production of biomass from different crops, residue allelopathy on crops, weeds and soil biota.

Heavy weed pressure and herbicidal dependence

In the adoption of CA sole dependence on herbicide and higher weed problem in the initial years is another limitation. Repeated application of the same herbicide and higher herbicide usage may expedite the development of resistance in weeds. Pre-emergence herbicides are less effective under residue laden conditions and for many crops selective post-emergence herbicides are lacking. Selective post-emergence herbicides that are available are hardly effective against perennial weeds.

Yield decline under zero tillage practice in the initial years

Yield reduction upto 5.1% in the first few years under ZT was recorded under meta-analysis across South Asia. The reduction of yield under CA particularly during the conversion phase was mainly due to nutrient immobilization, high weed pressure, higher insect, pest and disease attack, poor crop stands due to low germination, waterlogging in poorly drained soils, lack of knowledge and skills among farmers during initial years etc (Jat et al 2012).

Lack of technical knowledge and management skills

CA requires different operational skills and is management intensive. Improper crop husbandries and lack of knowledge in weed management, timing of irrigation and fertilizer, inadequate pest and disease management may lead to yield penalties under CA systems.

CONCLUSIONS

The study confirms that CA based practices can be a viable option for the maize-based farmers of hills and Terai however there are some bottlenecks for its adoption in Nepal. Therefore, to cope with the above mentioned constraints, research and development must work together. The first and foremost important thrust must be in creating awareness among the farmers and policymakers by its visible and tangible beneficial aspects through large plot demonstrations across the maize-based cropping systems of the country. The other areas of intervention must be in developing scale-neutral agri-machineries suitable for CA practices in both Terai and hills.

Collaboration with CGIAR centres and related agencies must be in place, since it needs relentless efforts and initiatives.

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AUTHORS' CONTRIBUTION

Sangita Kaduwal: Conceptualization, visualization, review collection, compilation and writing the draft

Tika Bahadhur Karki: Guidance

Reshama Neupane, Rajendra Kumar Bhattarai, Bhimsen Chaulagain, Prakash Ghimire: Sharing ideas.

Pankaj Gyawaly: Sharing ideas and editing

CONFLICTS OF INTEREST

The authors have no any conflict of interest to disclose.

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