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SPECIAL SECTION: NEAR-TERM PROBLEMS IN MEETING
WORLD FOOD DEMANDS AT REGIONAL LEVELS

Conservation agriculture for food security and climate resilience in Nepal

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Abstract

Achieving the sustainable development goals of the United Nations requires innovations in agriculture and development of climate-smart and economically feasible approaches for smallholder farmers in developing countries. Historical climate data of Nepal, which include 116 yr since 1901, has shown an increasing trend for average temperature by 0.016 °C yr⁻¹ whereas precipitation has shown a decreasing trend by 0.137 mm yr⁻¹. Such weather trends could enhance glacier melt associated flooding, and delayed monsoon rainfalls negatively impacting the agricultural production. The Nepalese government is promoting conservation agriculture (CA) through development of low-cost technologies that can be used effectively in difficult terrains. Such techniques include crop diversification, crop rotation, cover crops, and minimum tillage; all of which can reduce soil degradation. In addition, increasing crop residue retention can result in greater C sequestration and crop yield and reductions in greenhouse gas emissions. However, there is still lack of consensus on the merits of CA in the context of smallholder farming systems in Nepal. This paper reviews existing literature and provides an overview of farming practices in Nepal, highlights near-term challenges associated with climate change and food security, and discusses the role of CA as a climate-smart strategy to minimize soil degradation and improve food security.

1 | AN OVERVIEW OF THE NEPALESE FARMING SYSTEM

The agriculture sector of Nepal employs approximately 66% of the country's labor force, representing the main driver of economic growth and food security (Cosic et al., 2017). A typical farm has a limited land area, with the average household owning 0.68 ha of land (CBS, 2013). The country has three physiographic regions namely, Terai, Hills, and Mountains,

with several agroecological niches for crop and livestock production (Figure 1). The farming practices in different agroecological zones (Figure 2) vary based on resource availability, land-use systems, environment, farming activities, productivity, and access to utilities such as road and market networks.

The Terai plains lie at the lowest altitude (<1,000 m.a.s.l.) and support 20% of agricultural land (Paudel et al., 2009). The Köppen climate zone of this region is Tropical Savannah (Aw) (Karki et al., 2016) and is conducive to growing up to three crops, rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.)–rice, rice–wheat, rice–maize (*Zea mays* L.), a year if irrigation facilities are present (Table 1). This region receives 80% of

Abbreviations: CA, conservation agriculture; m a.s.l., meters above sea level; SOC, soil organic carbon.

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the annual rainfall during the summer monsoon season (June–September) whereas the winter season is dry. Due to fertile soils, favorable climatic conditions, easy access to irrigation and chemical fertilizers and pesticides, crop yields are greatest in the Terai than in any other region (MOAC, 2010; Shresth et al., 2011). For example in Peri-urban areas near the capital city of Kathmandu, use of the pesticides has increased by 30% in 2015 compared with 2014 especially for vegetable production, due to easy access and better infrastructure (Jeranyama et al., 2020). In the irrigated cropping systems in the Terai and lower hill valleys, rice and wheat are predominant as summer and winter cereal crops, respectively, whereas in the upland non-irrigated region, the main crop is maize.

Hills and Mountain terrains represent 80% of Nepal's agricultural area (Paudel et al., 2009). Based on the Köpen climate classification, the hill region is Cwa (temperate climate with dry winter and hot summer), Cwb (temperate climate with dry winter and warm summer) and Dwb (cold climate with dry winter and warm summer), whereas the high mountain regions have ET (Polar Tundra) and EF (Polar frost) climate. Crop yields in the hills and mountains are often low due to the small size of fields in the terraced land, rainfed agriculture, and difficulty accessing input supplies due to the lack of adequate roads and markets (Ghimire et al., 2020). In the hill region, maize is rotated with other cereal crops

Core Ideas

- According to historical data, temperature has increased and rainfall has decreased in Nepal.
- Proper management is needed to maintain fragile soils sustainability.
- Conservation agricultural techniques will maintain environmental and food security.
- Government policies should prioritize and promote conservation agriculture technologies.

(Table 1). Upland rice, tea (*Camellia sinensis* L. Kuntze), cardamom (*Elettaria cardamomum* L. Maton), ginger (*Zingiber officinale* Roscoe), and coffee (*Coffea arabica* L.) are also cultivated in the areas where soil and climate are favorable. In the mountains, crops like buckwheat (*Fagopyrum esculentum* Moench) and naked barley (*Hordeum vulgare* L. ssp. vulgare) are cultivated in some areas. In addition, the pastoral system of livestock grazing is also combined with crop production in high mountain locations due to rough terrain and a short growing season.

The livestock sector contributes a major part to sustainable agriculture and the rural economy. Grain cultivation and

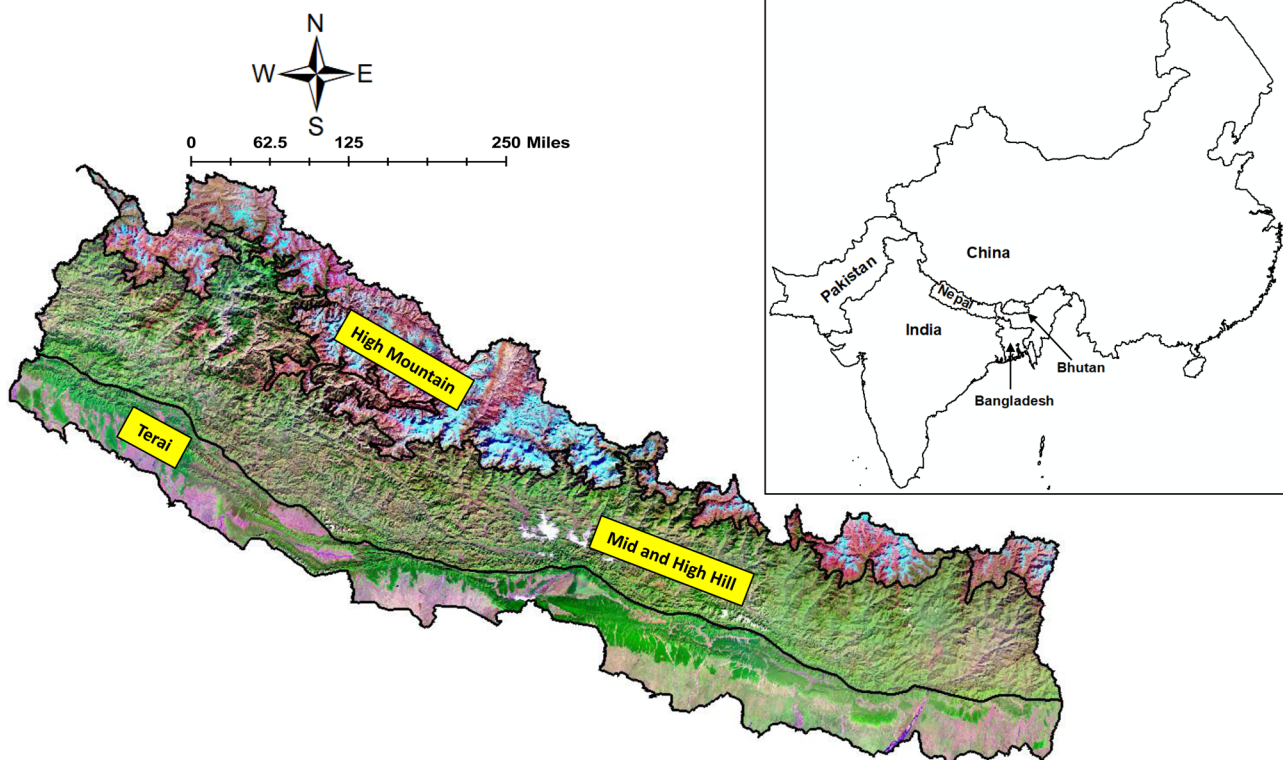


FIGURE 1 Terai, Hill, and Mountain Eco-Regions of Nepal
(Raw data source: MoALC, 2018; ESA, 2021)



FIGURE 2 Typical farming systems in (a) Terai, (b) Hill, and (c) Mountain regions of Nepal
(Source: Rajan Ghimire, Ecological Services Center, Nepal)

TABLE 1 Major cropping systems in different ecological zones of Nepal

Terai and lower mountain valley	Middle mountain	High mountains
<1,000 m.a.s.l.	1,000–2,000 m.a.s.l.	2,000–3,000 m.a.s.l.
Rice–wheat	Rice–wheat	Maize–finger millet (<i>Eleusine coracana</i> L. Gaertn.)
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: modified from Ghimire et al., 2020).

livestock production are complementary, and for the most part, households combine the production of subsistence crops with small numbers of livestock as mixed farming systems. Large ruminant animals such as buffalo (*Bubalus bubalis*) bulls and oxen (*Bos taurus*) provide farm power in most areas. Overall, the livestock sector contributes about 26% of the agricultural economy in the country (MOAD, 2017). On the other hand, using animal power for different agricultural operations, is time consuming and labor intensive. The introduction of mini-tillers and hand tractors for field operations under the

Prime Minister Agricultural Modernization project (a 10-yr project which began in 2016) has shifted the role of livestock from a major source of draught animal power and manure contributor to mostly a source of protein (milk and meat) and manure for crop production (PMAMP, 2021). It is reported that planting potato (*Solanum tuberosum* L.) on a katha (about 0.3 ha) of land by traditional means used to take a day, but using mechanized equipment takes about 20 min. This may potentially change agricultural practices for the Nepalese farmers.

2 | CHALLENGES FOR FOOD SECURITY IN NEPAL

The agriculture sector in Nepal faces challenges due to its unique topography and physiography of the country (Figure 2). About 60% of the farmers surveyed across the country reported they are not able to sustain their livelihood from agricultural production alone due to low crop productivity (CBS, 2011). Although the production trend has been increasing over the decades, it is not adequate to meet the demand of the increasing population (FAO, 2015). Mostly, the farmers in the hill regions of western Nepal face food deficit conditions due to the fragile landscape, lack of access to resources, and lack of inputs and training on improved farming practices (such as quality seed, adequate fertilization, crop rotation). The food shortage situation is increasing as a result of many environmental effects induced by conventional agriculture practices. For example, many studies report a significant amount of soil loss from conventional agricultural fields (Chalise et al., 2020; Kiboi et al., 2017; Koirala et al., 2019; Shao et al., 2016). The soil erosion rate is estimated at 1.7 mm (about 22 Mg ha⁻¹) of topsoil each year in Nepal (Chalise et al., 2019). In another study using Revised Universal Soil Loss Equation (RUSLE) model combined with a geospatial tool reported annual soil erosion of 35, 18, and 0.1 Mg ha⁻¹ in Mountain, Mid-Hills, and Terai, respectively (Koirala et al., 2019). Such soil losses from erosion reduce the organic matter, N, P, and K content of the land and ultimately affects the soil nutrient status and reduces the crop yield (Tiwari et al., 2010).

Climate change exhibits an additional threat to food security in Nepal. Warmer temperatures and lower rainfall results in less water in dams for irrigation which then reduces the potential to maintain food production and crop yields. From 1977 to 2009, there was a record average 0.06 °C increase in average annual temperature, which shows a warming trend over the years (Shrestha et al., 2011). The models developed to assess temperature rise over time in Nepal predict an increase of 1.2 °C by 2030 (WWF, 2005). The global circulation models (GCM) predict that the number of extremely hot days per annum will increase by 55% by the 2060s and by 70% in the 2090s (NCVST, 2009). Similarly, using the 116 yr of historical data for Nepal, temperature anomalies revealed inter-annual fluctuations and temperature change patterns have increased over the long term. The rate of change was determined from the slope of the linear regression model, which was 0.016 °C yr⁻¹ (Figure 3a). This increasing trend was even faster after 1975, with an annual increase rate of 0.035 °C yr⁻¹. In the case of precipitation, however, historical data showed a declining trend at the rate of -0.137 mm yr⁻¹ (Figure 3b). After 1975, the precipitation decline rate was -0.255 mm yr⁻¹. These results indicate the climate change

impacts have been more severe during the last 41 yr from 1975 to 2016.

The issue of food security has become a greater problem with the severe climate change impacts over the last few decades. According to the IPCC fifth assessment, climate change has negatively impacted crop production in many regions of the world (IPCC, 2014). Several studies have reported decreased yield with increased temperature in most crops (Challinor et al., 2014; Jiang et al., 2020; Lobell & Field, 2007; Sarker et al., 2014). The resultant risk of crop failure and volatility of food supply is much higher for subsistence farmers due to sole dependence on agriculture, poor production environment, and lack of knowledge and innovation for adaptive techniques to cope with extreme environmental conditions (Aryal et al., 2020; Hussain et al., 2016; Islam et al., 2016). Studies on the Hindukush Himalayan region, including Nepal and South Asian countries, have reported unprecedented trends in precipitation patterns and hydrological imbalances, increases in temperature and recurring floods, and the deterioration of forests, rangelands, and agricultural lands (Gawith et al., 2015; Gentle & Maraseni, 2012; Hussain et al., 2016). In a country where almost two-thirds of agricultural land is rainfed, crop production is more vulnerable to high temperatures and seasonal rainfall (Gentle & Maraseni, 2012).

The climate change impact in Nepalese agriculture has resulted in severe natural calamities such as frequent drought and floods, landslides, and diminishing productivity of agricultural crops (Malla, 2008). The effect of temperature rise is directly related to productivity loss as heat waves affect the physiology of plants (Rasul et al., 2011). Increased variability in temperature and more frequent occurrence of extreme weather events has increased the vulnerability of crops to biotic and abiotic stresses (Hansen et al., 2013) and altered the timing of agricultural operations, affecting crop production (Paudel, Acharya, et al., 2014). Increasing trend of temperature is expected to reduce the wheat and maize yields (Bhatt et al., 2014). Specifically, frequent droughts during winter are expected to reduce winter crop production. This leads to further depletion of water resources like rivers and dams which leads to immense challenges in irrigated agriculture production potential across the country.

3 | CONSERVATION AGRICULTURE IS A CLIMATE-SMART SOLUTION FOR FOOD SECURITY

Conservation agriculture (CA) practices (Figure 4) can improve food security, prevent land degradation, and improve the resilience of cropping systems against climate change in Nepal, irrespective of climatic zones and physiographic

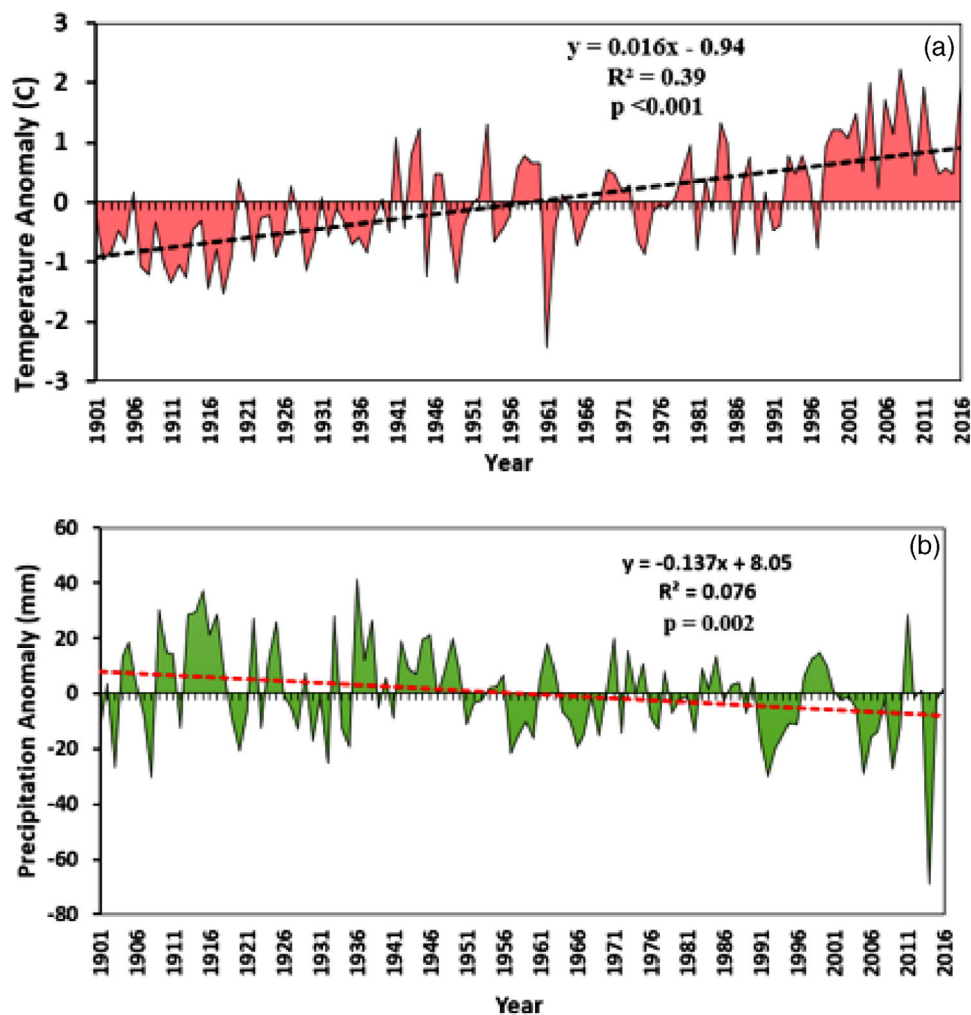


FIGURE 3 (a) Temperature and (b) precipitation change in Nepal from 1901 to 2016. Over the 116-yr period, while highly fluctuating, there are trends for higher annual temperature and lower precipitation. Graph area above zero indicate increases whereas areas below zero indicate decreasing trend. The average from 1901 to 2016 was used as a benchmark for representing change in this graph (Raw data source: World Bank Climate Change Knowledge Portal, 2021)

differences. Food production on degraded soils without adopting proper management practices does not necessarily decrease food security; instead, it increases environmental problems (Clay et al., 2014; Joshi et al., 2019). Nepalese agriculture consists of predominantly Mountain agriculture, with 56.8% agricultural land (Paudel et al., 2017) in sloping or terrace landscapes which have low fertility, coarse-textured soil, heavy cracking clays, or other problems (Shahid & Al-Shankiti, 2013). Sustainable food production in such land under the new realities of climate change can only be successful with holistic approaches that include all possible aspects of soil, water, and crop management. Sustainable agriculture and environment can be ensured in the mountainous landscapes by following the main principles of CA such as (a) ensure adequate living and residual biomass to improve soil and water conservation and control soil erosion, the preservation of permanent soil cover, and the promotion of minimal mechani-

cal disruption of soil through no-tillage systems; (b) support good, living soil by rotating crops, cover crops, and using integrated technologies for the management of pests; and (c) promote legume crops, agroforestry, and diversified cropping systems (Dumanski et al., 2006). Adoption of these principles in mountain farming could provide climate-smart solutions to improve food security through their positive effects on soil C sequestration, greenhouse gas mitigation, improved nutrient cycling, and agrobiodiversity (Figure 4).

Conservation agriculture minimizes soil disturbance, provides crop residue coverage, and diversifies and intensifies cropping systems, and minimizes soil degradation due to excessive chemical fertilizer application, low organic matter input, monoculture, and conventional tillage (García-Torres et al., 2001). In fragile sloping lands of hills and mountains, vegetation on field boundaries is practiced to reduce soil erosion (Brown & Shrestha, 2000; Dougill et al., 2001; Matthews

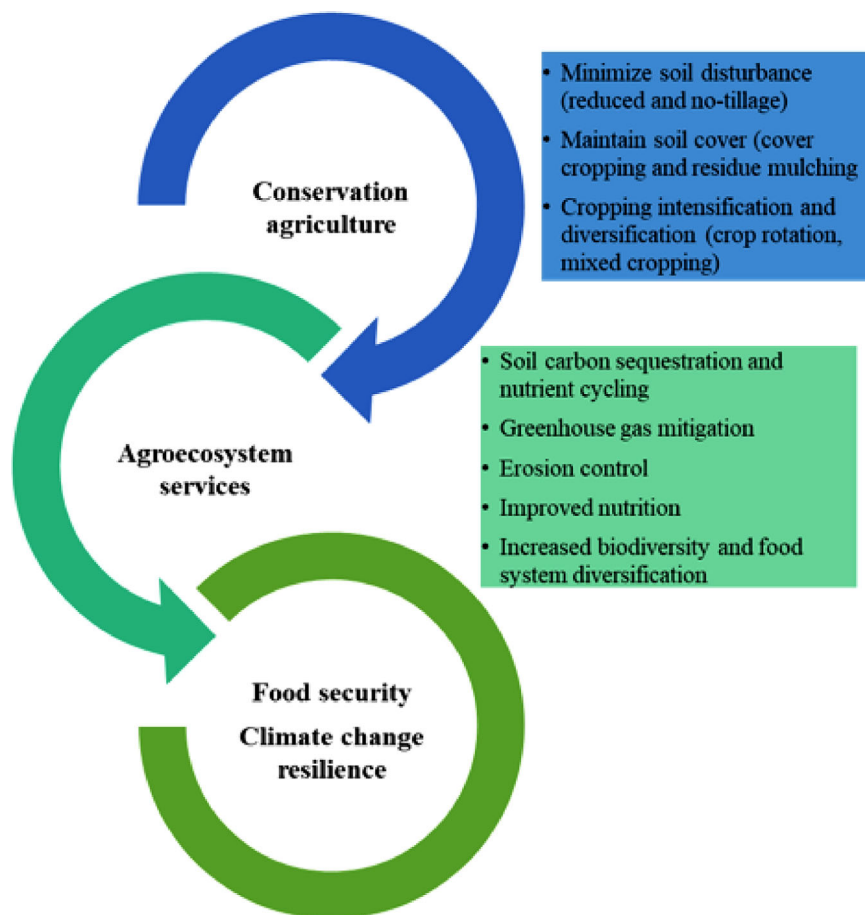


FIGURE 4 A conceptual model for increasing food security and climate resilience in agriculture through conservation agriculture

& Pilbeam, 2005). The benefits of CA practices have been documented in the Terai rice–wheat systems and integrated farming in Mid Hill region of Nepal (Table 2). For example, no-tillage alone could sequester 140 kg soil organic carbon (SOC) $\text{ha}^{-1} \text{yr}^{-1}$, while no-tillage with residue addition could increase SOC by up to 480 kg $\text{ha}^{-1} \text{yr}^{-1}$ (Ghimire et al., 2012). No-till management has increased crop production in an environmentally and socially sustainable manner, and cover crops can reduce greenhouse gas emissions (Reicks et al., 2021) and increase the C sequestration on agricultural land (Jat et al., 2020; Schwab et al., 2015). In a meta analysis of CA practices in South Asia, no-tillage with residue retention increased crop yields by 5.8%, water use efficiency by 12.6%, net economic return by 25.9%, and reduced greenhouse gas emissions by 12–33%, with more-favorable responses on loamy soils and in maize–wheat systems (Jat et al., 2020).

The CA techniques of no-till and use of mulch and cover cropping can reduce soil erosion (Clay et al., 2014; Seitz et al., 2018), improve soil aggregate structure, support microbial growth, increase soil organic matter, and reduce soil erosion (Ghabbour et al., 2017; Mikha & Rice, 2004; Six et al., 2000). Through the integrated management of soil, water, and biological resources, CA reduces external inputs and improves farmers' independence (Figure 3). Maintaining a permanent or semi-permanent soil cover, whether a live crop or dead

litter, which protects the soil from the sun, rain, and wind, and supports biological activities (Joshi et al., 2020), is the primary and, indeed, the central tenet of CA. Adopting conservation buffer systems in the mountains and hills of Nepal has reduced soil erosion and improved overall farming system performance (Schwab et al., 2015). Studies find higher microbial biomass with residue retention than with removal (Palm et al., 2014), with no-tillage rather than conventional tillage, and with crop rotation compared to monocropping (Clay et al., 2014).

Despite all the benefits of CA on the environment and sustainability, yield benefits are not universal. Laborde et al. (2019), Pittelkow et al. (2015), and Rusinamhodzi et al. (2011) reported that CA had less yield benefit as compared to the conventional system. Some studies report no change or little change in the yields, especially in the early years of the CA system's implementation (Ghimire & Bista, 2016; Laborde et al., 2019), while many other studies show considerably higher yields with CA than the conventional system (Kodzwa et al., 2020; TerAvest et al., 2019). More studies in the hills and mountains of Nepal will reveal the benefits of CA on region-specific farming systems, but overall positive effects of CA have been documented for South Asia. In a meta analysis evaluating various combinations of CA practices in South Asia, Jat et al. (2020) reported significant positive effects of

TABLE 2 Effects of alternative management on soil organic carbon (SOC) under various crops and cropping systems in Terai and Mid Hill region of Nepal

Region	Soil type	Cropping system	Depth cm	Year	Typical practice	CA tools	Percentage SOC increase %	Reference
Mid Hill	Sandy loam	Integrated farming	15	3	Traditional FYM management	SSM of FYM	13.55	Bishwakarma et al., 2015
Terai	Sandy loam	R-W	20	2	CT	NT, crop residue	16.83	Paudel, Sah, et al., 2014
Terai	Sandy clay loam	R-W	50	3.5	CT	NT	9.89	Ghimire et al., 2012
Terai	Silty loam	R-R-W	12	20	N fertilizer	N + FYM	12.98	Regmi et al., 2002
Terai	Sandy	R-W	20	20	NF	FYM, crop residue	62	Gami et al., 2001

Note. CA, conservation agriculture; SSM, sustainable soil management; FYM, farmyard manure; R-W, rice-wheat; CT, conventional tillage; NT, No-till; R-R-W, rice-rice-wheat; NF, no fertilizer.

no-tillage and residue retention on crop yields and economic return. Their findings of 20–41% higher economic return and 12–33% reduction in global warming potential with the adoption of CA practices show significant positive effects of CA on food security and climate change mitigation.

4 | POLICY RECOMMENDATIONS

Despite the country's effort on agricultural modernization by implementing various agricultural plans and policies such as Agriculture Perspective Plan (1995), the National Agriculture Policy (2004) and Three Year Interim Plan (2007/2008–2009/2010), agricultural transformation, and food security status in Nepal has lagged behind many other countries. Sustainable intensification is a major challenge in mountain agriculture across the world since mountain ecosystems are largely associated with lower soil fertility, increased soil erosion, and reduced biodiversity (Schwab et al., 2015). Different policies and programs are required to encourage the use of CA methods. For example, more investment on rural road building, specifically in hills and mountain, may assist farmers in moving machinery and equipment. Also by improving farmers' mechanization capacity, and providing irrigation facilities to rainfed areas, adoption of CA could be increased. Furthermore, there is a lack of farm-level access to technology and information in rural areas. As a result, strong extension and research ties through government agencies may assist farmers to become more aware of the benefits of CA. More investment in research, outreach, and technology development in hills and mountain regions could boost agricultural production in these areas and enhance food security status of the country. The government sector has recently taken a number of steps. For instance, in the 2016 10-yr initiative, the Prime Minister Agricultural Modernization Project of the federal government, the Climate-Smart Village program of the Provincial governments and other sustainable agriculture programs have begun to address climate change and other challenges in agriculture through integrated approaches in crop and livestock management. Agricultural mechanization, region-specific commodity crop production, cooperative farming, and identification of niche markets are prioritized under this program to increase agricultural production and support the smallholder-farm economy (PMAMP, 2021).

5 | CONCLUSION

The CA involves a combination of production technologies to attain high yield on existing land to meet the domestic and global food demands with minimal environmental impacts. Evaluation of various aspects of CA revealed benefits by minimizing soil disturbance, soil erosion, and pest pressure, and by

increasing soil organic matter and aggregate stability. These effects are more pronounced in degraded soils. The benefits of CA documented from Nepal has shown promise especially in the mountain agroecosystem which faces sustainability challenges due to steep and fragile topography and rapid climate change. Implementing region-specific CA adaptation strategies and working closely with farmers to identify a suitable conservation tools will minimize climate change-associated risk and uncertainties in food production. Some model assessment suggests an increased yield of selected crops with a moderate rise in temperature and increased precipitation. Identifying those crops and developing a conservation management strategy will address both challenges, food security and climate change.

Even with all the advantages, there are still many challenges to CA adoption in Nepal, where the majority of farmers lack financial capital, and continue to practice traditional subsistence farming on small field parcels. Resource-poor farmers cannot easily cope with associated yield loss during the early years of transition to CA practice (Rapsomanikis, 2015). Thus, governmental policies are needed to support farmers and provide economic incentives through crop insurance or subsidies in the agricultural inputs, at least during the initial years of the CA practicing. The government needs to prioritize and promote low-cost technologies that can be used effectively in difficult terrains.

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AUTHOR CONTRIBUTIONS

Deepak R. Joshi: Conceptualization; Formal analysis; Writing-original draft; Writing-review & editing. Rajan Ghimire: Conceptualization; Visualization; Writing-original draft; Writing-review & editing. Tulsi Kharel: Conceptualization; Resources; Writing-original draft; Writing-review & editing. Umakant Mishra: Conceptualization; Writing-review & editing. Sharon A. Clay: Conceptualization; Investigation; Resources; Supervision; Validation; Writing-review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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