Conservation Agriculture Technologies for Cropping Systems Sustainability and Food and Nutrition Security in Nepal

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Conservation Agriculture Technologies for Cropping Systems Sustainability and Food and Nutrition Security in Nepal

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Abstract

Recent global experiences on sustainable intensification of smallholder cropping systems show that improving food security and income with reduced production inputs and increased systems sustainability would be possible through the adoption of conservation agriculture (CA) technologies. CA-based sustainable intensification follows three principles in farming, viz. minimum soil disturbance, crop residue retention, and diversified and sustainable crop rotations. CA aims at improving productivity, reducing production costs, and increasing farmers' income through reduced use of labor, energy, and other farm inputs, and improving the sustainability of cropping systems. Resource-conserving technologies (RCTs) include at least one of the three principles of CA and aim at reducing the use of external inputs. This chapter reviews the application of CA and RCTs for improving the sustainability of cereal-based cropping systems mainly in the context of Nepal but with relevance to the Eastern Indo-Gangetic Plains. The review,

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complemented with the authors' own results from several on-station and on-farm experiments, demonstrated that the CA and RCTs practices viz. dry direct-seeded rice, unpuddled transplanted rice, and zero-tillage maize, wheat and legumes with the retention of crop residues can increase grain yields and profits and save labor and water use compared to conventional tillage practices. No or minimum tillage along with residue retention can also suppress weeds, increase opportunity for crop diversification, improve soil physico-chemical and micro-biological properties, enhance nutrient- and energy-use efficiencies, and reduce greenhouse gas emissions. CA practices encourage the use of land leveling, farm mechanization, and precision crop production. CA and RCTs have also the potential for reducing soil erosion in sloping hilly areas and undulating land with narrow terraces. Despite several advantages, these technologies have however not been fully mainstreamed in the national agricultural research and extension system of Nepal. Knowledge gaps among extension workers, farmers, and other citizens, unavailability of farm machinery, trade-offs in using crop residues for improving soil fertility and animal feed, land fragmentation, poor rural infrastructures, and inadequate policy support are the major adoption barriers of CA-based technologies. The review concludes that there is an urgent need to institutionalize the CA and RCTs to attain the sustainability of cropping systems and achieve food, nutrition, and livelihood security of the growing population.

Keywords

Terai · Hills · Multi-criteria assessment · Direct-seeded rice · Zero tillage · SWOT analysis

12.1 Introduction

Nepal and the large areas of Eastern Indo-Gangetic Plains (EIGP) of South Asia follow traditional agricultural practices, where farmers practice intensive soil tillage, low or negligible chemical (external) inputs, and subsistence farming (Adhikari et al. 2021; Timsina 2018). This system of agriculture although partially meets the daily household survival needs, offers low returns/income with less prospects for improving the livelihoods of the smallholder farmers (Adhikari et al. 2021). The increased population pressure, labor outmigration, high cost of production, and high energy inputs in farming in the EIGP demand for increased food and income using input-efficient technologies. Resource-saving conservation agriculture (CA)-based technologies/practices and appropriate mechanization are some examples of such input-efficient technologies (Aryal et al. 2021). Further, due to the increasing impact of climate change and rainfall variability in crop production, farmers in the region are more vulnerable to climate change-related stresses than ever before (Paudel et al. 2020a).

In Nepal, due to the low productivity of major staple cereals, for example, rice, wheat, maize, and millet yields of less than 2.47, 2.23, 1.40, and 1.14 t ha^{-1} respectively in hills and 3.49, 2.87, 2.94, and 1.07 t ha^{-1} respectively in the Terai region (MoAD 2019), achieving food security for the increasing population is a huge challenge (Gauchan et al. 2022; Rasali et al. 2020). Hence, the country is importing hefty amounts of cereal grains every year. The country imported 0.54, 0.14, and 0.35 million tons of rice, wheat, and maize grains worth 232, 38.4, and 90.8 million US$, respectively in 2017 (FAOSTAT 2020). Gauchan et al. (2022) estimated cereal demand for 2030, 2040, and 2050 and concluded that unless cereal productivity is sustainably increased with the use of improved and resource-saving technologies (RCTs), the country will continue to face a food deficit requiring import every year. Agronomic research has also shown the existence of huge yield gaps (>8 t ha^{-1} in rice, >6 t ha^{-1} in maize, and > 4 t ha^{-1} in wheat) between climatic potential and farmers' fields (Krupnik et al. 2021; Timsina et al. 1995, 2018, 2021), which can widen further due to the impact of prevailing global climate change. Such yield gaps suggest the need and opportunity to improve food security by increasing farmers' yields by reducing gaps. To reduce such yield gaps, climate-resilient agricultural practices are needed. CA-based RCTs can offer a range of promising adaptation and mitigation measures in EIGP including Nepal (Paudel et al. 2020a; Magar et al. 2022b). RCTs include at least one of the three principles of CA aiming at reducing the use of external inputs and hence would be equally useful for Nepal and the EIGP.

Maintaining and improving the sustainability of smallholder food production system is important for achieving Sustainable Development Goal (SDG) No. 1 (No poverty), No. 2 (End hunger, achieve food security and improve nutrition, and promote sustainable agriculture), No. 5 (Gender equality), No. 6 (Ensure availability and sustainable management of water and sanitation for all), No. 12 (Ensure sustainable consumption and production pattern), and No. 13 (Take urgent action to combat climate change and its impact) (UNDP 2017). To meet these SDGs and improve food and nutritional security in Nepal, agricultural productivity must increase substantially through sustainable intensification (SI). SI aims at producing more food with efficient use of production resources while reducing environmental footprint, building resilience, preserving natural capital, and improving the flow of environmental services (Pretty et al. 2006; Pretty and Bharucha 2014). Research in South Asia has demonstrated that CA or RCTs can provide a pathway for SI with ample opportunities for adopting such technologies in Nepal (Bhatt et al. 2021; Amgain et al. 2020; Dixon et al. 2020; Gathala et al. 2013; Hobbs et al. 2008; Hobbs and Gupta 2003; Islam et al. 2019; Jat et al. 2020; Kumar and Ladha 2011; Kukal et al. 2010; Kumar et al. 2016; Pretty et al. 2006; Timsina et al. 2010b). Thus, the objective of this chapter is to review and provide the current state of research and technology readiness on CA or RCTs for their adoption, and advice these technologies to the extension, research, and policymakers for their mainstreaming in all tiers of the Nepal government (Federal, Provincial, and Local) to meet the food and nutritional security of the increasing population. Wherever deemed necessary, the relevance of these technologies to the EIGP and South Asia is also discussed.

12.2 CA for Increasing Productivity and Sustainability: A Conceptual Framework

CA offers a set of improved crop production practices that aim to maximize the farm profits in the long run by optimizing agricultural production while conserving inputs, such as labor, fuel, seeds, fertilizer, pesticides, and water, and minimizing or mitigating impact on the natural resources (Amgain et al. 2019a; Dixon et al. 2020; Pretty et al. 2006). The wider areas and broadened practices of CA have resulted in a wide range of definitions. CA follows three principles, i.e., minimum soil tillage, crop residue retention on the soil surface, and sustainable crop diversification (FAO 2017; Hobbs et al. 2008; Friedrich et al. 2012, 2017; Kasam et al. 2018; Saharawat et al. 2010). CA is defined as a "resource-conserving agricultural production system to achieve acceptable profit together with high and sustained production levels by conserving natural resources and environment" (FAO 2007). It is also defined as "management of soil, water, and agricultural resources to achieve ecological, social, and economically sustainable agricultural production" (Jat et al. 2020), "resource-efficient or resource effective agriculture" (Hobbs et al. 2008). All definitions centered around the basic principles of CA. Further, a new terminology "conservation agriculture-based sustainable intensification" (CASI) has also been recently used in literature (Islam et al. 2019; Dixon et al. 2020). CASI technologies are synonymously being used as CA or RCTs in literature and RCTs contain at least one component of CA: we use all three terminologies synonymously in this review.

For the sustainability of the crop production system in Nepal and the EIGP, we conceptualized the CA with four pillars and each with relevant indicators, i.e., economic and human health

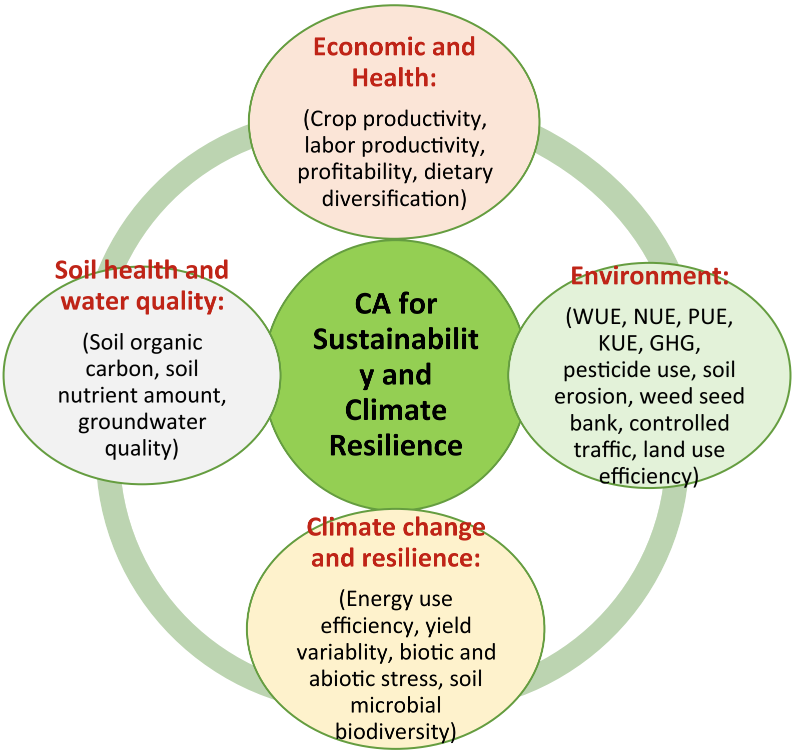

Fig. 12.1 Four sustainability pillars and indicators that CA improves: a conceptual framework. (*Source* Authors' conceptualization). WUE = water use efficiency; NUE = nitrogen use efficiency; PUE = phosphorus use efficiency; KUE = potassium use efficiency; GHG = greenhouse gas emission

condition, environment, soil health and water quality, and climate change and resilience (Fig. 12.1). A sustainable production system that uses CA is suggested to have all four pillars and their indicators strengthened/improved over conventional practices. To maintain food security and economic growth, gain in crop productivity should come from efficient use of all resources, including land, labor, water, energy, and chemicals, along with a lower environmental footprint and building resilience (Rockström et al. 2017).

12.3 Development and Scaling-Up of CA-Based Technologies in Nepal

12.3.1 Conservation Agriculture and RCTs: Past, Present, and Future

From the early 1980s, several initiatives and projects were launched in Nepal with the objectives of resource-saving using CA-based technologies especially in rice- and maize-based systems. To make the crop production system more productive, profitable, and resilient, these initiatives made a series of testing, development, and promotion of different CA-based technologies especially in the Terai region (Table 12.1).

12.3.1.1 Testing and Verification of CA-Based Technologies

Among the CA and RCTs evaluated in south Asia, zero tillage (ZT) especially in wheat (ZTW) is the most common RCT, first initiated in Indian and Pakistani Punjab in the 1980s for wheat planting (Pandey and Gurung 2017). Later, ZT and other RCTs were introduced in other regions of India, Pakistan, and Bangladesh in the 1990s (Friedrich et al. 2012, 2017). In Nepal, no-till wheat was grown by farmers at the bank of Ridhi Khola in Palpa and in Bhaktapur before the commencement of wheat research. Research on no-till wheat in Nepal was first started in Janakpur and Bhairahawa during 1970s with the objective of minimizing yield losses due to terminal heat stress caused by late planting

Table 12.1 Timeline on the progress of evaluation and scaling of CA-based technologies in Nepal

Year	Government initiatives and projects	CA/RCTs	Geographical coverage	References
1980	India government	Zero tillage wheat (ZTW)	Indian and Pakistani Punjab in South Asia	Pandey and Gurung (2017)
1980	Rice–wheat consortium via Nepal agriculture research council (NARC)—6 +5national wheat research program (NWRP)	ZTW, direct-seeded rice (DSR)	Rupandehi, Kapilvastu, Nawalparasi	Giri (2001)
2000–2001	NWRP, Bhairahawa	ZTW, DSR	Rupandehi, Kapilbastu	NARC/NWRP Report (2001)
2014–2015	National maize research program (NMRP/NARC) and CIMMYT–Nepal with different commodity programs	Zero tillage (ZT) and residue management in maize	Terai, Chitwan; Central hills (Gulmi)	Karki et al. (2014a), (2015a)
2014	CIMMYT, Nepal; NMRP and agriculture implements research station, Ranighat, Birgunj, Parsa	ZT and residue management in maize CT, ZT, and PRB with, residues management in rice–wheat system	Chitwan Parsa	Dahal et al. (2014), Karki et al. (2014b), Khatri et al. (2014b), Paudel et al. (2015), Sah et. al. (2014)
2015–2018	NMRP and CIMMYT, Nepal	ZT and planting geometry in maize	Chitwan	Karki et al. (2015b), Lamsal and Khadka (2019)
2013–2015	NMRP, regional agriculture research center (RARS), Parwanipur, NWRP, Bhairahawa, and CIMMYT, Nepal	ZT and residue in wheat; DSR	Bhairahawa and Parwanipur	Karki (2015), Tripathi (2015), Bhurer et al. (2013)
2009–2021	Cereal systems initiatives for South Asia (CSISA) [CIMMYT and IRRI Nepal managed project]	ZTW, DSR, CA-Rice, CA-Wheat, CA-Maize, laser land leveling, Brown manuring	Rupandehi, Chitwan, Nawalparasi, other Terai districts	https://csisa.org/about-csisa/overview/
2014–2021	The sustainable and resilient farming systems intensification (SRFSI) project, CIMMYT, Bangladesh	Crop diversification and rotations, reduced tillage using machinery, DSR, ZTW, ZT maize, ZT lentil, unpuddled transplanted rice, efficient water and residue management practices	Eastern Indo-Gangetic plains (Dhanusha and Sunsari)	https://aciar.gov.au/about-aciar, Islam et al. (2019), Brown et al. (2021), Magar et al. (2022a, b)

Source Authors' compilation

(Giri 2001). However, the area covered by CA or RCTs in Nepal is still quite low. On the other hand, adoption of CA or RCTs under rice–wheat (R–W) and rice–maize (R–M) cropping systems has increased remarkably in the recent decades in India (Alomia-Hinojosa et al. 2018; Farooq and Siddique 2014; Jat et al. 2009). Besides, the adoptions of raised bed planting and laser land leveling (LLL) are also increasing, mostly in the northwest IGP (Bhatt et al. 2021; Bhan and Behera 2014). Such positive development in India indicates these technologies might gain popularity among farming communities and youth service providers in Nepal too if precision machinery, herbicides and fertilizers, and favorable policy supports are provided to service providers and farmers. Most widely practiced CA/RCTs in Nepal include zero-till wheat (ZTW) and maize (ZTM) (Dahal et al. 2014; Karki et al. 2014a, 2015a; Khatri et al. 2014; Sharma et al. 2018; Paudel et al. 2015; Karki 2015, Tripathi 2015). Several CA-based technologies have been verified and tested by conducting a series of on-farm demonstrations and training events in different crops across the Terai region of Nepal (Table 12.2).

12.3.1.2 Comparative Advantages of CA/RCTs Over Conventional Practices in Hill and Terai Regions

Soil health indicators: Few studies comparing the effects of reduced tillage (RT) or ZT and conventional tillage (CT) on soil properties and crop yields were conducted for several crops in both mid-hills and Terai of Nepal. McDonald et al. (2006a, b) compared the effect of six tillage and crop establishment practices in R–W systems on soil physical properties and yield on a silt loam soil of Khumaltar, Kathmandu for two years. In rice season, the saturated hydraulic conductivity was higher in DSR than in puddled transplanted rice (PTR) plots, but bulk density (BD) was higher in the PTR than DSR plots. However, in the wheat season, there were no significant effects on BD, soil moisture retention characteristics, and root development patterns. Laborde and McDonald (2019) reported improvement in soil physical properties in the mid-hills after two years of conversion from conventional to CA-based maize–rapeseed and maize–wheat systems. They further reported that in hills and mountains, soil erosion rates and soil and nutrient losses from the terraced lands with intensive tillage could vary considerably and could be reduced through RT practices. Brown and Shrestha (2000) and Partap and Watson (1994) reported higher losses of SOM, N, P, and K up to 150–600, 7.5–30, 5–25, and 10–40 kg ha^{-1} yr^{-1}, respectively from terraced lands under CT than under RT. Tiwari et al. (2009) reported that RT with residue retention in a maize–cowpea rotation was more effective in maintaining soil fertility and increasing farm income compared to the conventional maize–millet rotation.

In a similar study, Atreya et al. (2005) reported lower total annual soil and nutrient losses in RT compared to CT in Kathmandu valley. Atreya et al. (2008) also reported significantly lower annual and pre-monsoon soil and nutrient losses with RT and rice straw mulching compared to CT without mulching. Tiwari et al. (2008a) reported that RT decreased runoff by 7–11% and soil loss by 18–28% compared to CT in a mid-hill region in central Nepal. Tiwari et al. (2008b) demonstrated higher losses of SOC, total N, available P, and exchangeable K from the intensively cultivated vegetable fields than from the RT fields. RT had higher soil surface roughness due to the small ridges formed by intercultural operation and higher ground cover due to retention of crop residue, resulting in reduced runoff and increased infiltration compared to intensive vegetable production and farmers' practice with intensive tillage**.** These findings suggest that RT alone would not effectively reduce runoff and soil loss in the upland hill terraces and that RT with residue retention would be required to mitigate early rainstorm impact. Overall, these 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.

A few studies have also compared CA with CT in Terai region of Nepal. Ghimire et al. (2011) reported that soil under a R–W system sequestered a significantly higher amount of SOC in 0–50 cm soil depth (more pronounced effect at 0–15 cm) under ZT than CT. The addition of crop residues to the ZT plots had greater SOC sequestration but there was no effect on soil N. Their findings suggest that a R–W system under ZT with residue retention than under CT with or without residue retention sequestered more SOC in Terai. Paudel et al. (2014) also compared the carbon sequestration in CA and CT after five crop cycles in Chitwan, Central Terai. They observed that ZT with

Table 12.2 CA-based technologies tested and verified in Nepal

Operation	CA/RCTs	Crop	Geographical area tested/developed/scaled	References
Pre-crop land management	Laser land leveling	Rice, wheat, maize	Central Terai, Far-western Terai	CSISA (2013)
Crop establishment	System of rice intensification (SRI)	Rice	Eastern and Central Terai Nawalparasi, Western Nepal	Dahal et al. (2014) Sah and Bastakoti (2014)
	Brown manuring	Rice	Central Terai	Marahatta (2017a)
	Unpuddled rice transplanting	Rice	Central and eastern Terai including Dhanusha, Sunsari, Kapilvastu, and Rupandehi	Devkota et al. (2016), Magar et al. (2022a, b)
	Dry and wet-direct seeding	Rice	Terai	Bhurer et al. (2013), Bastola et al. (2020), Magar et al. (2022a, b)
	Zero tillage Zero tillage, bed planting, and conventional tillage	Wheat and maize Rice–wheat	Terai and hills Eastern and central Terai	Karki et al. (2014a), (2015a), Dahal et al. (2014), Khatri et al. (2014), Sharma et al. (2018), Paudel et al. (2015), Karki (2015), Tripathi (2015), Magar et al. (2022a, b), Sah et al. (2013), Magar et al. (2022a, b)
Weed management	Integrated weed management (IWM); weed management in DDSR	Rice, wheat, maize DDSR	Terai Terai	Bhurer et al. (2013), Shah et al. (2020)
Tillage and residues management	Organic carbon sequestration	Rice–wheat	Terai	Paudel et al. (2014), Karki and Shrestha (2014)
Fertilizer management	Site-specific (precision) fertilizer management	Rice, wheat, and maize	Kaski, Lamjung, and Chitwan	Amgain et al. (2019b), Marahatta (2017a), Timsina et al. (2021), (2022)
	Precision fertilizer application LCC-based N management	Rice, wheat Direct seeded rice	Western Terai districts (Rupandehi, Bardiya, Kailali, etc.) Terai	Park et al. (2018), Subedi et. al. (2018)
Pest management	Bio-control; dry and wet-direct seeding	Rice, R–W	Terai	Bhurer et al. (2013), Bastola et al. (2020)
	Bio-fertilizers for N-fixation	R–W and R–M	Terai	Karki et al. (2014a), (2015a), Dahal et al. (2014), Khatri et al. (2014), Sharma et al. (2018), Paudel et al. (2015), Karki (2015), Tripathi (2015)

(continued)

Table 12.2 (continued)

Operation	CA/RCTs	Crop	Geographical area tested/developed/scaled	References
Soil management	Crop residue anchored on soil surface	Rice and maize	Terai and hills	Karki et al. (2014a), (b), Dahal et al. (2014), Pandey and Kandel (2019), Bastola et al. (2020)
	Crop rotation, residue retention, and inter-cropping	Maize and wheat	Terai	Paudel et al. (2015), Khatri et al. (2014)

Source Authors' compilation

residue retained plot sequestered 0.91 g kg^{-1} yr^{-1} SOC which was 22.6% higher than conventionally tilled residue removed plots. Their research suggests that CA with residue retention sequesters more SOC than CT without residue retention.

Economic and environmental indicators: A recent simulation study in a central mid-hills district showed that the maize yields under CA were either similar to, or lower than, CT, while there were no effects on the subsequent rapeseed and wheat yields under the maize–rapeseed and maize–wheat systems (Laborde and McDonald 2019). Tiwari et al. (2009) reported that RT with residue retention in a maize–cowpea rotation increased farm income but not maize yield compared to the conventional maize–millet rotation in the Kathmandu valley. Atreya et al. (2005, 2008) and Acharya (2017), on the other hand, reported that maize yield in mid-hills performed inconsistently under RT and CT though production cost was consistently lower in RT than CT.

Devkota et al. (2016, 2019) conducted farmer-participatory on-farm trials with a CA-based R–W system during 2011–2017 in western Terai. Both DSR and ZTW produced similar or higher grain yields with lower production costs, higher water productivity, and higher net profit than the CTW. DSR followed by ZTW increased the R–W system productivity, reduced total production cost, increased net profit (by US$ 347–572 per ha), and reduced climatic risk of growing crops compared to CT. Their results demonstrated that in areas with low early rainfall, DSR permits the timely establishment and significantly boosts yield and maintains yield stability. Karki et al. (2014a, b) also concluded that, compared to CT, CA significantly reduced the production cost and increased income without any yield penalty in a maize–wheat system in central Terai.

Dixon et al. (2020) and Magar et al. (2022a, b) concluded that CASI can strengthen the food–water–energy nexus by increasing food productivity, increasing energy- and water-use efficiencies, reducing GHG emissions, improving household food security and income, reducing labor and production costs, providing substantial benefits to women, expanding social capital, and strengthening system resilience in the EIGP, including Sunsari and Dhanusha districts in Nepal Terai. These socio-economic benefits were important drivers of smallholder adoption of CASI, underpinning the prospects for widespread scaling (Magar et al. 2022a).

12.3.1.3 CA/RCT-Based Machineries Testing and Verification

During the process of testing and verification of CA/RCTs in Nepal, several types of machinery in cereals production value chain, e.g., computer-assisted laser leveling equipment, seed drills for two- and four-wheel tractors, mini-tillers, and pesticide and fertilizer applicators, which are useful from soil/land preparation and crop establishment to crop harvesting, were tested and verified (Brown et al. 2021) (Table 12.3). Considering the urgent need for farm mechanization especially to reduce the production cost, minimize youth migration, minimize fallow lands, save energy, water, and

Table 12.3 CA/RCT-based machineries tested and verified in different locations in Nepal

Operation	Machinery	Geographical Tested/Developed/Scaled	References
Pre-crop establishment	Laser land leveling	Bara, Parsa, Dhanusa, Sunsari	CSISA (2013). National Agricultural Engineering Research Center (2019), Agricultural Implement Research Centre (2018), Sustainable and Resilient Farming Systems Intensification (2018), Brown et al. (2021)
Tillage and ploughing	Minitiller (6.5 hp)	Mid-hills (Kavre, Sindhupalchowk)	National Agricultural Engineering Research Center (2019), Brown et al. (2021)
	Powertiller (12–18 hp)	Mid-hills	Prime Minister Agricultural Modernization Project (2020)
Seeding and crop establishment	Power-tiller operated bed planter	Parsa, Lalitpur	National Agricultural Engineering Research Center (2020)
	Raised bed planter/permanent bed planting	Parsa	National Agricultural Engineering Research Center (2017, 2018, 2019), Agricultural Implement Research Centre (2018)
	Power tiller operated seed drill	Rupandehi, Bara, Parsa	Various reports
	Multi-crop planter	Dhanusa, Sunsari, Bara, Parsa	Sustainable and Resilient Farming Systems Intensification (2018)
	Zero-till drill (paddy and wheat)	Banke, Rupandehi, Bara, Parsa, Sarlahi, Dhanusa, Sunsari,	National Agricultural Engineering Research Center (2017, 2018, 2019), Brown et al. (2022)
	Happy turbo seeder (wheat)	Parsa (AIRC and farmers' fields)	Agricultural Implement Research Centre (2018)
	9- and 11-row seed-cum-ferti-drill for Dry-DSR (paddy)	Bara, Parsa (AIRC and farmers' fields)	Agricultural Implement Research Centre (2018)
	Drum seeder for Wet-DSR (paddy)	Bara, Parsa, Udayapur	Agricultural Implement Research Centre (2018)
	Jab seeder (maize)	Kavre, Sindhupalchowk	National Agricultural Engineering Research Center (2018)
	Precision maize planter	Bara, Parsa, Dang Banke	Agricultural Implement Research Centre (2018), CSISA (2020)
Weed Management	Conoweeder (Paddy)	Parsa, Lalitpur, Kailali, Bardiya	CSISA (2020), National Agricultural Engineering Research Center (2019), Agricultural Implement Research Centre, Parsa (2018)
	Rotary weeder (Paddy, maize)	Parsa, Kavre, Lalitpur, Dang. Banke	CSISA (2020), National Agricultural Engineering Research Center (2017)
	Dryland weeder (vegetables)	Lalitpur, Jumla	National Agricultural Engineering Research Center (2020)
	Self-propelled weeder (sugarcane and maize)	Bara, Dang	Agricultural Implement Research Centre (2018)
	Modified tractor driven cultivator (maize, sugarcane)	Parsa, Chitwan	National Agricultural Engineering Research Center, Khumaltar (2019), Agricultural Implement Research Centre (2018)

(continued)

Table 12.3 (continued)

Operation	Machinery	Geographical Tested/Developed/Scaled	References
Herbicides Application	Mini-tiller driven sprayer	Dhankuta, Sindhuli	National Agricultural Engineering Research Center (2019)
	Boom sprayer	Parsa	National Agricultural Engineering Research Center (2017)
	Knapsack sprayer	Throughout the country	
Fertilizer Application	Urea applicator/fertilizer spreader	Western Terai, Lalitpur, Kailali, Bardiya	CSISA (2019, 2020); National Agricultural Engineering Research Center (2017); Brown et al. (2021)
Straw Management	Tractor driven round baler	Bara, Parsa Kanchanpur	Agricultural Implement Research Centre (2018); CSISA 2020

Source **Authors' work**

labor resources, and reduce drudgery, Nepal Government formulated Agricultural Mechanization Promotion Policy in 2014 (FAO, 2014) and implemented Prime Minister Agriculture Modernization Project (PMAMP) throughout the country (MoALMC 2018).

12.3.2 Performance of Key CA/RCTs

12.3.2.1 Direct-Seeded Rice

DSR is an alternative rice establishment method in which rice seeds are broadcast or directly seeded in the dry or wet tillage (puddled) field instead of transplanting the seedlings in the puddled field. Common DSR technologies in Nepal are:

(i) *Wet direct-seeded rice (WSR)*: This is an old method of rice establishment and is common in Jhapa and Morang districts in the eastern Terai region and high rainfall areas of other Terai districts. In this method, rice seeds are soaked for 24–72-h and then the sprouted seeds are broadcast or sown in lines using a drum seeder under wet tillage and puddled soil (Bedari et al. 2020). Despite being efficient in resource use, its adoption however is low, mainly due to non-uniform stand establishment with hand broadcasting and unavailability of herbicides for weed control (Dhakal et al. 2015). But with the availability of drum-seeders and selective herbicide molecules, this method might emerge as the potential alternative to puddled transplanted rice (PTR) in double rice cropping lowlands and high rainfall areas in the future.

(ii) *Dry direct-seeded rice (DSR)*: This is an ancient method of rice establishment in the hilly areas, especially in the western mid-hill districts of Gorkha, Lamjung, Tanahun, Parbat, Syangja, Palpa. It is known as *Ghaiya Dhan*, grown mostly in rainfed upland unbunded terraces with seeding in March–April. *Ghaiya* rice seeds are broadcast after 2–3 passes of dry tillage followed by hand weeding and 30–45-day old seedling transplanting in dry or moist (but unpuddled) soil. However, in recent years, due to labor shortage for manual seedling transplanting, intercultural operation and weeding, and due to labor becoming more expensive and lack of mechanization, the area under dry DSR (*Ghaiya Dhan*) is decreasing in hotspot hill districts.

However, with the development and import of 4-wheel tractor-drawn 9- and 11-rows seed-cum-fertilizer drills and 2-wheel tractor-drawn Chinese seed drills (with 4 and 6 row-seeders) for strip and full tillage, mechanized DSR is now taking momentum in the Terai region for the last few years. Using these seeders, rice seeds and fertilizer are drilled in line preferably in leveled field with Laser Land Leveler after dry tillage. Marahatta (2017b) conducted three on-farm trials (farmer as replication) to compare DSR and PTR in rice and CA and CT in maize for two years (2011 and 2012) in Sunuwal, Nawalparasi district in western Terai. The detailed methodology of these experiments has been reported in Marahatta (2017b). These results showed no yield difference between DSR and PTR (Table 12.4, Fig. 12.2), but due to the lower cost of cultivation, DSR was found profitable (Fig. 12.2). These results are consistent with several other studies in Bangladesh, Nepal, and India (Gathala et al. 2013; Sharma et al. 2004; Singh et al. 2001; Tripathi et al. 2005; Timsina et al. 2010a). As Nepal Terai receives almost sufficient rainwater (>1300 mm) during rice planting season (June–October), even under rainfed conditions and without supplementary irrigation, the performance of DSR can be good and this technology is now being adopted by farmers in high rainfall areas (Devkota et al. 2019).

Further, we conducted a series of on-farm experiments with paired treatments comparing different types of DSR with PTR in six central and western Terai districts (Chitwan, Nawalparasi, Rupandehi, Bara, Parsa, and Bardiya) for five years during 2011–2015. In these experiments, conventionally tilled DSR (CT-DSR) and zero tilled DSR (ZT-DSR) each with and without residue retention were compared with PTR without residue retention (Table 12.4). The results showed a non-significant difference in mean yield between DSR and PTR, though significantly higher rice yield was obtained under CT-DSR and ZT-DSR with residue retention compared to PTR (Table 12.4). DSR without residue retention (under both CT and ZT) had a lower yield than PTR. PTR had low weed pressure and better crop establishment. Similar results for DSR and PTR were obtained in a study in the EIGP in northwest Bangladesh (Timsina et al. 2010a; Hossain et al. 2020). CT-DSR had a similar grain yield but high cultivation cost to ZT-DSR after 4 years of cropping. Similarly, Gathala et al. (2011) observed 9–10% higher rice yield under ZT with residue mulch compared to CT or ZT without residue in northwest India. These results are due to better soil moisture (Singh et al. 2016) and higher nutrient availability (Yadvinder-Singh et al. 2004), and higher weed suppression through providing a physical barrier on the surface (Schuster et al. 2019). Incorporation of residues in these studies was, however, disadvantageous as it increased the short-term immobilization of inorganic N with plants showing N deficiency and resulting in lower yield under residue retention in CT-DSR. However, residue incorporation/retention exerts a beneficial effect as it increases soil organic carbon content and the immobilized N returns to the soil after residue decomposition. N rates need to be increased by 15% in the rice season under the R–W system to compensate the amount of N immobilized due to the incorporation of crop residues (Yadvinder-Singh et al. 2004).

The on-farm trials' paired comparison data (Fig. 12.2) showed that the optimal number of effective tillers ($\sim$200–300 m^{-2}), increased number of grains $panicle^{-1}$, reduced sterility percentage, and improved harvest index are needed to obtain a high yield from DSR. Compared to PTR, a yield penalty of 17% was observed in ZT-DSR without residue, but DSR yield increased by 5% with residue retention. ZT-DSR with residue retention had a higher thousand-grain weight and lower grain sterility with a reduced yield penalty. Saharawat et al. (2010) also reported that the number of effective tillers was 9% higher in DSR compared to PTR. Too high (>300 tillers m^{-2}) in DSR was not required as it created competition among the tillers resulting in decreased yield.

12.3.2.2 Zero Tillage in Wheat

The yield and economics data for the same districts (as for DSR above) in Fig. 12.3a, b revealed no difference in yields of ZTW (with residue) and CTW (without residue). ZTW sown after rice matured earlier by 10–12 days. As wheat is timely planted after ZT, yield reduction due to terminal heat stress is avoided as is

Table 12.4 Comparison of yield between different types of DSR and PTR across large numbers of on-farm trials in six Terai districts in Nepal during 2011–2015

Establishment methods	Grain yield (t ha^{-1})	Establishment methods	Grain yield (t ha^{-1})	Establishment methods	Grain yield (t ha^{-1})	Establishment methods	Grain yield (t ha^{-1})	Establishment methods	Grain yield (t ha^{-1})
DSR#	4.14	CT-DSR	3.97	CT-DSR + R	4.18	ZT-DSR	3.77	ZT-DSR + R	4.32
PTR	4.24	PTR	4.16	PTR	4.50	PTR	4.52	PTR	4.10
Mean diff	−0.10	–	−0.18	–	−0.32	–	−0.75	–	0.22
No. of paired trials	150	–	38	–	32	–	16	–	64
SEm (±)	0.08	–	0.20	–	0.14	–	0.23	–	0.11
T-value	−1.26	–	−0.94	–	−2.23	–	−3.25	–	1.95
P at 0.05	ns	–	ns	–	*	–	**	–	*

Source Authors' work

\# includes all types of DSR: CT-DSR, conventional tillage-direct seeded rice; PTR, puddled transplanted rice; + R, with residue; ZT-DSR, zero tillage direct-seeded rice; Mean diff., mean difference; SEm (±), standard error of the mean of the mean difference series. Ns, non-significant; * significant at 0.05; ** significant at 0.01

common for late-sown wheat after CT. Residue retention improved wheat yield with all N application rates (Fig. 12.3b).

12.3.2.3 Zero Tillage in Maize

The yield and profit comparison of maize under ZT and CT for the same six Terai districts showed significantly higher yield with ZT (8%) than CT (Fig. 12.4), whereas the yield variation was observed across N rates, varieties, and residue management. The results from the omission trials in ZT wheat showed a high N rate (150–210 kg ha^{-1}) producing significantly higher yield (by 44% and 20%) than low (60 kg ha^{-1}) and medium N rates (120–135 kg ha^{-1}), respectively. In maize, compared to CT, 4% higher yield was observed under ZT with residue retention. The yield advantage of 11% was recorded for the improved variety under ZT as compared to that under CT whereas the yield advantage was 16% for hybrids.

Karki et al. (2014a, b), from an on-station experiment with the maize–wheat system at Rampur, Chitwan, reported that ZT maize without residue retention was counter-productive while with residue retention it had 6% higher yield than under CT without residue retention, indicating that ZT can replace CT. ZT maize saved labor and the production costs related to field preparation and crop establishment and increased profits compared to CT maize. Similar results for maize have been noted in northwest Bangladesh (Islam et al. 2019; Rashid et al. 2019).

12.3.2.4 Surface Seeding in Wheat

In this system, no land preparation is needed and the sprouted wheat seeds are broadcast onto the saturated soil either in standing rice crop either before or after harvest (Hobbs 2001). In Nepal, surface seeding of wheat, lentil, and *Lathyrus* is mostly used in areas where long-duration rice varieties are cultivated and difficult to timely drain out water from the field to allow timely field preparation and seeding. This system offers advantages in terms of timely sowing, reduced risk of bird attacks, and decrease production cost. Tripathi (2010) reported that the benefits of

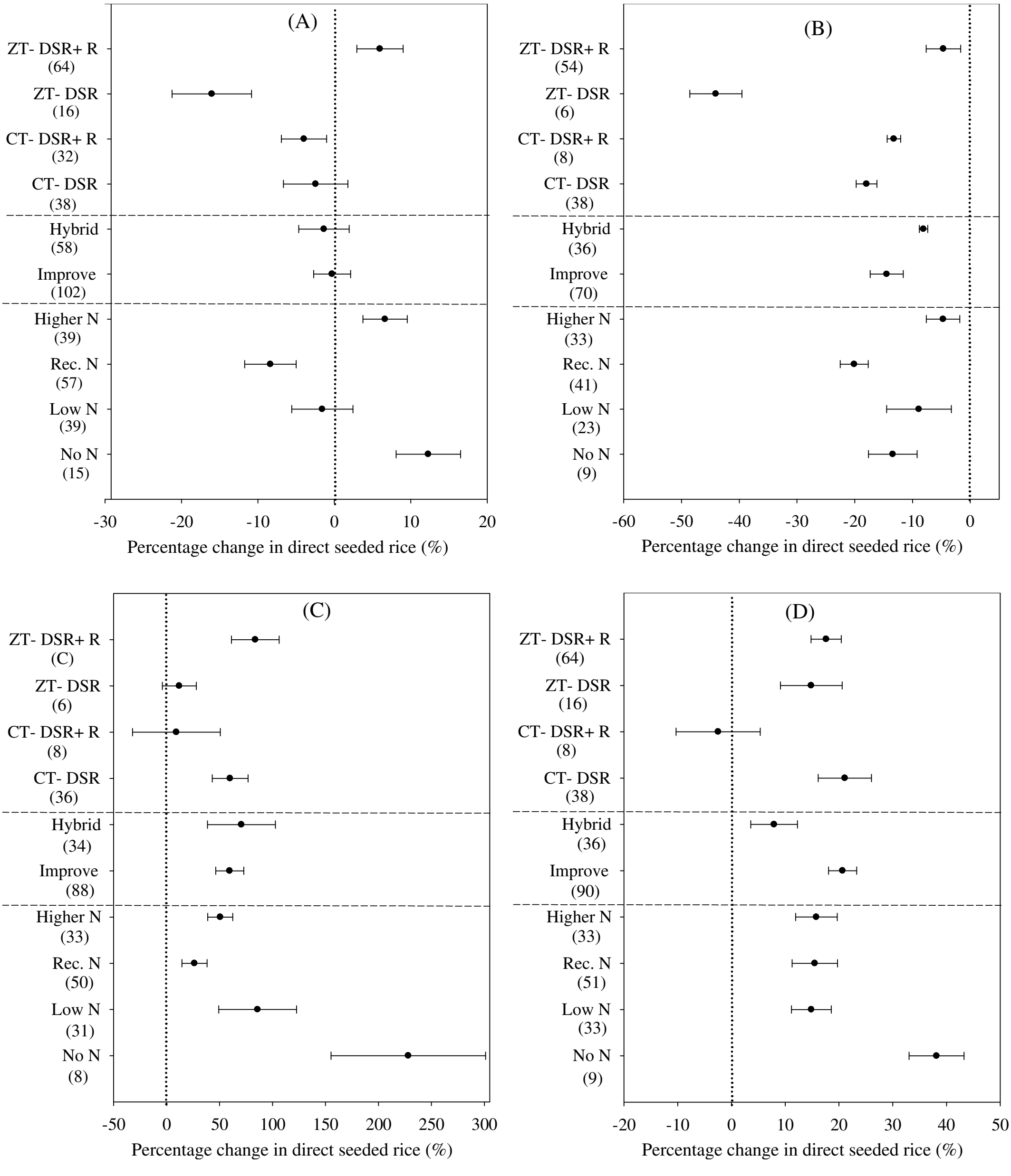

Fig. 12.2 Influence of different establishment methods and residues, varieties, and N input on the **a** yield change, **b** cost of cultivation, **c** net returns, and **d** B:C ratio of DSR relative to PTR. The number of paired observations included in each dataset is presented in parenthesis. *Source* Authors' unpublished data

surface seeding of wheat are even more pronounced in terms of cost savings and returns compared to when it is sown under ZT or RT after draining the saturated soil. The saving in cultivation cost with surface seeding of wheat under ZT was more than 150% compared to CT.

12.3.2.5 Brown Manuring in DSR Field

Brown manuring is a technique of growing green manuring crops viz., *Sesbania* sp. or *Crotolaria juncea* @20–30 kg ha^{-1} together as an inter- or mixed-crop when DSR is sown. Brown manure crop is killed at 30 days after rice seeding (before

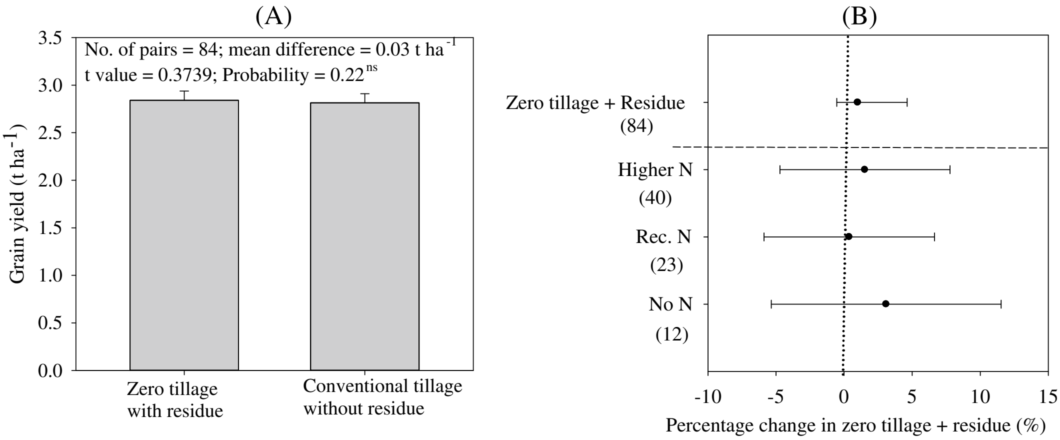

Fig. 12.3 Influence of ZT with residues and CT without residues on **a** grain yield of wheat and **b** grain yield of ZT wheat at varying N levels relative to CT wheat. The number of paired observations included in each dataset is presented in parenthesis. *Source* Authors' unpublished data

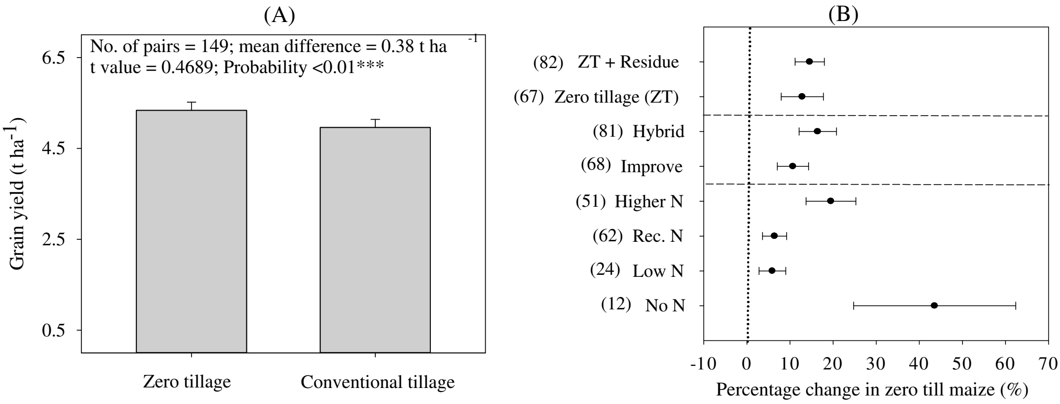

Fig. 12.4 Influence of ZT and CT on **a** grain yield of maize and **b** percentage change in grain yield of maize under ZT with or without residues, hybrid and improved varieties, and N levels relative to that in CT without residue. The number of paired observations included in each dataset is presented in parenthesis. *Source* Authors' unpublished data

mid-tillering stage) through the application of selective post-emergence herbicides for enriching the soil organic matter. Co-cultured *Sesbania or Crotolaria* sp. is knocked down and allowed to kill by spraying 2,4-D ethyl ester @0.5 kg a.i. ha^{-1} (Gaire et al. 2019). The dead leaves of green manure crops fall on the soil and decompose fast to supply N. This practice allows the green manure crops to decompose in the soil surface which minimizes weed pressure and increases soil fertility leading to an increase in DSR yield (CSISA 2020).

12.3.2.6 Inclusion of Mung Bean in Rice–wheat and Rice–maize Systems

R–W and R–M are the dominant cropping systems in Terai and lower elevation areas in mid-hills (Timsina and Connor 2001; Timsina et al. 2010b). Intensifying R–W or R–M systems with mung bean (during the fallow season) can increase yield and income from mung bean as well as from the annual cropping system. The inclusion of mung bean optimized the cropping system by reducing production costs, increasing income, and improving soil properties in Nepal (CSISA 2019, 2020). A study on the rice–maize–mung bean system in Bangladesh also showed that though there was no significant yield advantage from CA (permanent or fresh beds, strip tillage, and zero tillage with residue retention) in mung bean, there was a reduction in production cost and increase in farmer's income. There was however increase in total system productivity, decrease in total production cost, and increase in income from the cropping system (Rashid et al. 2019). Another study across eight districts in the EIGP, including two districts from Nepal Terai, also showed the benefits of including mung bean in the R–W or R–M systems in terms of increasing systems productivity, profitability, and water productivity (Islam et al. 2019; Dixon et al. 2020). These findings from the EIGP demonstrate the potential of mung bean in R–W and R–M systems for sustainable intensification.

12.3.2.7 Scaling-Out of Appropriate Machinery for Enhancing Mechanization

The increasing adoption of small-scale mechanization in Nepal is associated with an acute labor shortage due to out-migration. The use of small-scale mechanization ("mini-tillers"; 6–8 hp with 90–130 kg weight) for rice cultivation in mid-hills increased rice yield by 1.1 t ha^{-1} (Paudel et al. 2019a, b). Mini-tillers are replacing traditional bullock-driven agriculture, especially in the hilly region. These tillers can be used for row-cropped weeding in maize and sugarcane, for pumping water from groundwater, and for connecting reapers for rice and wheat harvesting (CSISA 2020; Brown et al. 2021).

Another small-holder farmer-friendly successful tool is "Seed and Fertilizer Spreader" (Brown et al. 2021). Park et al. (2018) analyzed the benefits of such a low-cost chest-mounted spreader as a small-holder mechanization option for wheat in Nepal. Using the spreader for spreading seed and fertilizer increased crop stand uniformity, yield stability, labor efficiency (by 52%), and profitability compared with the hand broadcast application of fertilizers (CSISA 2019, 2020). Another scale-appropriate machinery for all sizes of farmers is "laser land leveling" (LLL), which is getting momentum in South Asia. Despite its numerous benefits, its adoption, however, is taking place at a slower rate than anticipated. In the northwest IGP, however, the adoption intensity of LLL was more likely to be higher among large farmers though there was a negative association between land holdings and the proportion of laser-leveled lands (Aryal et al. 2018).

Mechanical harvesting by 2-wheel tractor (15–22 hp) operated and self-propelled "reaper" is highly flourishing in Nepal's R–W systems (Brown et al. 2021). For farmers living in the flat areas in hilly regions (where 2-WT can work) and those with the fragmented lands in Terai (where combines are not operational) who keep rice and wheat straw to feed livestock, it is possible to harvest rice using a reaper. Until September 2020, an estimated number of more than 4100 reapers have been sold by the machinery importers in Nepal which are estimated to cover around 17,000 ha of rice and wheat (CSISA 2020). With rotavators, farmers lose about 284–309 kg of wheat and US$ 93–101 of profit ha^{-1} season^{-1} despite US$ 11–15 ha^{-1} cost savings for land preparation. Wheat yield reduction in rotovator used field was due to soil pulverization, which caused water stagnation during irrigation, soil structural damage, and hardpan formation at 15–20 cm soil depth which impaired wheat root growth. So, new policy and extension efforts are required that discourage rotavator use and favor more sustainable tillage practices (Paudel et al. 2020b).

12.4 Multi-Criteria Assessment of CA/RCTs

Multi-criteria assessments of CA become useful to understand and analyze the tradeoffs among input use, yield, profits, and environmental consequences of the technologies and provide a sound basis for food security assessments and planning. Such assessments for CA/RCTs have been conducted in the EIGP but are lacking in

Nepal. Here we present such assessments from two initial studies from Nepal: one comparing DSR and PTR in the western Terai and another comparing four alternative tillage and crop establishment practices for a R–W system in the eastern Terai.

12.4.1 Trade-Offs Among Inputs Use, Yield, and Net Profit in DSR and PTR

A trade-off analysis was conducted using data from on-farm trials mentioned above in Nawalparasi in the western Terai (Marahatta 2017b). Due to the high seed cost of hybrid compared to the improved DSR variety, the latter was slightly better in terms of profitability. The percent benefit with N omission compared to N application was also higher for DSR than PTR; however, the gross and net returns in DSR were 22 and 43% higher for N application compared to N omission (Fig. 12.5). Despite the yield loss under DSR, the cost of cultivation was drastically reduced, and more profit was obtained (Fig. 12.2). PTR had the lowest B:C ratio. Though the highest yield loss occurred for ZT-DSR without residue retention, the highest reduction in cultivation cost made net profit and B:C ratio from it comparable with CT-DSR with residue retention. ZT-DSR with residue retention compensated the cost of the residue by yield improvement and was best in terms of profits.

12.4.2 Trade-Offs Among Yield, Inputs Use, Energy-Use Efficiency, Water Productivity and Global Warming Potential in R–W Systems

A series of on-farm trials, conducted across three CASI and one CT treatments in the R–W systems in Dhanusha (rainfed) and Sunsari (irrigated) districts during 2014–2017, compared grain yield, inputs use (labor, N, P, and K fertilizers, irrigation, herbicide, etc.), energy-use efficiency (EUE), and total global warming potential (TGWP) (Magar et al. 2022a, b). For both crops and locations, there was a significant trade-off among yield, energy inputs and EUE, and TGWP

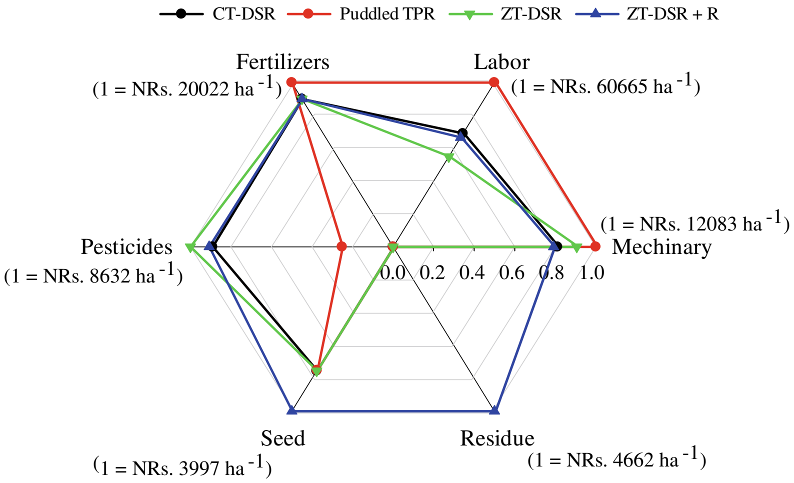

Fig. 12.5 Cost (NRs ha^{-1}) of different input categories for different rice establishment methods (Variable means are normalized on a 0–1 scale, with 1 representing the highest absolute value of that variable. The highest absolute value is also shown for each parameter. The cost is estimated for the year 2018/19, based on the consumer price index and services (Exchange rate NRs to USD = 105). *Source* Calculated and drawn from Marahatta (2017b)

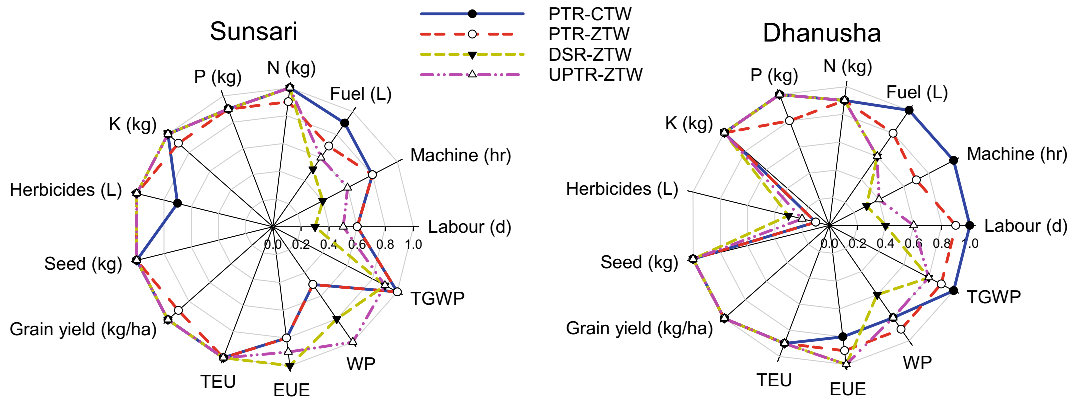

Fig. 12.6 Trade-offs among different inputs use, grain yield, total energy use (TEU), energy use efficiency (EUE), water productivity (WP), and total global warming potential (TGWP) in CT compared with three CASI practices in R–W system in Sunsari (irrigated) and Dhanusha (rainfed) districts. N = Nitrogen; P = Phosphorus; K = Potassium; PTR-CTW = puddled transplanted rice fb. conventional tillage wheat; PTR-ZTW = puddled transplanted rice fb. zero tillage wheat; DSR-ZTW = dry-direct seeded rice fb. zero tillage wheat; UPTR-ZTW = Unpuddled transplanted rice fb. zero tillage wheat. (Adapted from Magar et al. 2022b)

(Fig. 12.6). In both crops, the conventional method (PTR-CTW) recorded the highest energy use in labor, machinery, and fuel leading to the highest TGWP. Despite the higher amount of herbicide used in DSR-ZTW (a CASI treatment), the TGWP was low indicating the trade-off due to low energy use through other inputs. In the R–W system under irrigation, machinery, and fuel were contributing to the highest TGWP, while under rainfed, the highest energy input in labor, machinery and fuel in PTR-CTW contributed to the highest TGWP and the lowest energy use in the alternative CASI practices contributed to the lowest TGWP.

12.5 SWOT Analysis of CA/RCT-Based Technologies

Strengths, weaknesses, opportunities, and threats of the CA and RCT's were analyzed in 2020 involving multiple stakeholders after field visits of the on-farm experimentations in Terai regions of Nepal after reviewing the various research findings on CA in Nepal and the EIGP. The major SWOT of CA and RCTs is summarized in Box 12.1. There are several strengths and opportunities of the CA and RCTs despite some weaknesses and threats.

12.6 Constraints and Challenges for Adoption of CA/RCTs in Nepal

Despite numerous advantages in terms of economics, environment, human health, resilience to climate change, and soil health, CA is still one of the least adopted technologies by farmers in Nepal. Adoption of at least one of the three CA principles accounts for about 4.1% of the total cropland in Asia, 1.5 million ha in India (Kassam et al. 2019), and a few thousand ha in Nepal (exact data not available) as CA currently has several adoption barriers (Magar et al. 2022a, b). Appropriate machineries can facilitate the adoption of zero or minimum tillage and residue retention. Brown et al. (2021) studied the binary rates of adoption of nine type of machines (including those used for zero or minimum tillage) across Nepal Terai and found adoption rate varying from 0.9% (laser land leveler) to 30.7% (4-WT seed drill), with 1.8% for 2-WT seed drill. Of these, 4-WT seed drill and 2-WT seed drill are used for zero or minimum tillage. Devkota et al. (2019) stressed that coordinated efforts among government, private sector, and research and extension organizations are required to overcome the bottlenecks for the adoption of CA and

Box 12.1 SWOT analysis to identify opportunities and adoption barrier of CA and RCTs in Nepal

Strengths (S)	Weaknesses (W)
• Evidence-based scientific knowledge generated to solve the multiple complex problems • Availability of RCT-based farm machinery (LLL, ZT seed and fertilizer drills, bailing machines) • Availability of herbicides and weed control tools • International collaborations (CG centers CASI Platform, CSISA, etc.) • Curriculum on CA and RCTs in academic institutions • Critical manpower for CA& RCTs R&D • Creation of some production hotspots for RCTs (e.g., DSR in Chitwan, Rupandehi/Nawalparasi, Bardiya/Kalilali) spontaneously after project interventions	• The intensive tillage-based mindset among the farmers, agricultural technicians, and policymakers • No data on the actual area under various CA and RCT-based practices and responsible agency to estimate them • Knowledge gap among the stakeholders • Inadequate scale-neutral equipment and machinery • Inadequate knowledge-intensive Ca and RCT-based package of practices • Weed infestation in DSR and ZT and herbicide resistance • Changes in pest dynamics • Government policies not favorable for CA or RCTs • Land fragmentation and problem for land consolidation and commercialization • Poor market and storage infrastructures • Inadequate research thrusts on CA or RCTs in research institutions • Extensive areas under sloping hill agriculture with poor accessibility • The existing unfair custom duty tax provision for CA and RCT-based machinery spare parts
Opportunities (O)	**Threats (T)**
• Nepal has now three levels of government (Federal, Provincial and Local); the Federal government develops the policy, provincial governments monitor, and the local governments plan and execute as per their own needs • People are accepting that residue burning and repeated tillage are harmful to the farm, community and regional level • CA and RCTs-based farm-machineries are now being available in the Nepalese markets • Academic courses on CA and RCTs in graduate and post-graduate programs of AFU, TU and FWU in Nepal started since 2012 • International collaborations (CG centers CASI Platform, CSISA, etc.) • Curriculum on RCTs in academic institutions • Critical manpower for CA& RCTs R&D • Creation of some production hotspots for RCTs (e.g., DSR in Chitwan, Rupandehi/Nawalparasi, Bardiya/Kalilali) spontaneously after project interventions	• Adopting CA or RCTs may, in the short term, involve costs and risks. Switching to CA or RCTs quickly may appear too risky • Crop might fail to produce the yield at par with conventional agriculture in initial years/seasons • Many non-conventional biotic factors like soil-borne pathogens might emerge due to infected stubbles kept as residue • Weather and climatic conditions and heavy flooding after rainfall might not be favorable for DSR

Source (Authors' own work)

RCTs. From the stakeholders' perception analysis conducted with the multi-stakeholders (same for SWOT analysis), we found the following major issues that are limiting the adoption (adoption barrier) of CA and RCTs in the cereal-based cropping systems of Nepal.

12.6.1 Complexity of the Farming Systems

Complexity within the farming systems like the fragmentation of agricultural lands poses a serious problem for the adoption of CA- or

RCT-based machinery. Likewise, landscape-driven irregular bunding of the field plots is also a hindrance in operationalizing the CA or RCTs. Lack of crop residue, lack of biomass valorization technologies, and competing use of residues for crop and livestock are other challenges in adoption of ZT with residue retention.

12.6.2 Unavailability of Right Machinery and Other Inputs

As stated by Brown et al. (2021), though recently there is some level of adoption of CA-friendly machineries, both machinery production and supply value chains are at the incipient stage in Nepal. Currently, it is almost fully import-based, and manufacturing, repair, and after-sales services are not well established. The availability of appropriate machinery has also been handicapped by limited resources among domestic manufacturers in both public and private sectors.

12.6.3 Inaccessibility of Financial Credits

The poor economic status of farmers results in low investment capacity for the adoption of new technologies. The agricultural credit facility is much less than required. The ever-changing interest rates together with complex rules and regulations of financial institutions make farmers hesitate to take loans to purchase the inputs such as machinery and herbicides required for the practice of CA or RCTs.

12.6.4 Disrupted Agricultural Extension Systems and Technical Know-How of the Citizens

Extension systems in Nepal have not been regularly promoting CT practices although the benefits and suitability of CA or RCTs are well known to most agriculture extensionists. Also, there is a huge gap in implementing need-based technology interventions in the current extension systems as a proper linkage among three levels of government has not been well established yet (Dahal et al. 2020). Further, the technical knowledge of such “Citizen Science” is low in the ground-level extensionists, development workers, other stakeholders, and the citizens.

12.7 Policy Issues and Implications

Nepal has produced a series of policy documents in recent decades broadly for agriculture modernization and commercialization. The third objective of the Agriculture Mechanization Promotion Policy 2014 (MoALMC 2018) vows to promote the RCTs. Also, National Climate Change Policy (2019) has prioritized the adoption of low carbon-emitting and energy-efficient technologies and crop diversification options but has not specified RCTs or CA. Following policy initiatives are suggested that provide insights into policy issues for promoting CA or RCTs in Nepal which can also have relevance to other countries in South Asia and particularly in the EIGP.

12.7.1 Priorities of Support Initiatives

Separate policy documents or guidelines should be formulated by the Directorate of Agriculture and institutionalize CA and RCTs in the government’s regular activities and ongoing and upcoming projects and programs. The priority for agricultural mechanization technologies for Nepal has advocated addressing labor shortage and drudgery reduction (Biggs and Justice 2015). These include scale-appropriate harvesting machinery such as reapers, mini-combine harvesters, threshers, and seeding and crop establishment machineries such as seed drills for RT, ZT and DSR, and rice transplanters under puddled and unpuddled conditions.

12.7.2 Strengthening Machinery Value Chain

Access to information, availability of machinery technologies and skills development for their use at the local level, and assurance of finance are the keys to strengthen the machinery value chain among the citizens are required. CA or RCTs need the approaches of "Citizen Science" for greater impact. Takeshima (2017) highlighted the need for policy-related research in mitigating the accessibility of tractor custom hiring services and identifying appropriate regulatory policies for mechanization. Assuming machinery availability as a major bottleneck for the adoption of DSR or ZT, a study suggested that the availability of custom hiring centers and service providers for the communities at the local level could potentially increase the service provisioning of seed drills for DSR and ZT in wheat or maize (CSISA 2020). Paudel et al. (2019b) suggested developing targeted cost-sharing programs and bolstering machinery service provisioning to reach multiple farms thereby increasing mini-tiller adoption considering the lower willingness to pay at present. Another area of potential policy intervention is ensuring spare parts availability of RCT-based machines by lowering custom duties and facilitating in-country production.

12.7.3 Gender Dimension

Female-headed households are reported to have a lower probability of mini-tiller adoption in the mid-hills of Nepal with a larger gap in food-insecure households (Paudel et al. 2020c). This indicates that the agricultural extension department of the government needs to prioritize female-targeted and food-insecure households inclined mechanization policies to reduce the adoption gap of mini-tillers and other RCT-based machines. Concrete policies and action plans are to be formulated for equitable access to agriculture machinery for both men and women (Silwal and Khanal 2021).

12.7.4 Scaling-Up of CA/RCTs

Resource conserving technologies like DSR, ZT or RT, and mechanization technologies are complex systems compared to CT practices like manual transplanting of rice seedlings and broadcasting seeds of wheat, maize, and other crops. A potential idea to scale-up those technologies could be developed through social networking and the establishment of for example, "Farmers Platform" so that they can act as influencers (Skaalsveen et al. 2020; Snow et al. 2021). In the context of less efficient machinery service business, it is mandatory to expand the network of "seed drill service providers" as most capital-constrained small and medium farmers cannot purchase seed drills for their own use (Keil et al. 2016, 2019). Hence, scaling up initiatives for CA or RCTs needs to strengthen the service provision model (Kafle and Paudel 2018; Keil et al. 2017; Taylor et al. 2011). Additional approaches or ideas to augment scaling initiatives strategically are establishing innovation platforms for selected technologies, utilizing location intelligence, and grabbing the benefits of remotely sensed images for preparing spatial suitability maps of CA or RCTs. The government programs like Prime Minister Agriculture Modernization Project (PMAMP) and Smart Krishi Village should embrace these approaches in their plans to scale out CA or RCTs aiming at increasing production sustainably.

12.8 Conclusions and Recommendations

Even though CA and RCTs have been moderately to fully mainstreamed in other South Asian countries, they have not been mainstreamed in the national agricultural research system of Nepal. The major reasons for that are knowledge gaps among researchers, extension workers, and farmers, inadequate farm machinery and tools, trade-offs in using crop residue for soil fertility improvement and animal feed, prevalence of smallholder farmers lacking finances to purchase machinery, poor rural infrastructures, and inadequate policy support. The undulating and sloping lands with narrow terraces further restrict the use of farm machinery in the hills and mountains of Nepal. This chapter suggests that there is an urgent need to test, verify, and scale-out various CA and RCTs across the mid-hills and Terai regions of Nepal to increase productivity, profitability, and sustainability cropping systems and to achieve food and nutrition security in the country. To meet this goal, the following key recommendations are suggested. Those recommendations can also be applied to other countries in South Asia, particularly in the EIGPs.

1. To achieve SDGs 1 (No poverty) and 2 (Zero hunger), CA needs to be mainstreamed in different departments under the agriculture ministry's planning and implementation activities.
2. To achieve SDG 13 (climate action), climate change mitigation and adaptation technologies like DSR and ZT are to be mainstreamed in the climate change-related policies, planning, and management mechanisms.
3. To achieve SDG 5 (gender equality), women-friendly technologies should be promoted in smallholder farming communities as women are increasingly involved in managing household activities in addition to farming activities due to male outmigration. Future plans and policies should be oriented toward empowering farm women by designing gender-friendly programs and activities aiming at reducing the gender gap.
4. RCTs heavily rely on mechanization. The country should have short-, medium- and long-term plans to promote and strengthen the machinery value chain along with the proper supply of other agricultural inputs like seeds and fertilizers. A concrete plan to initiate/establish machinery production units/industries in Nepal should be devised and implemented. To know the key drivers of success and adoption of machinery at both individual farmer and community levels through custom hiring-based service providers, a detailed research study utilizing both quantitative and qualitative approaches needs to be carried out.
5. The federal and provincial line ministries and associated research and extension bodies should develop a joint plan of action to scale-out the CA and RCTs making the local government a prime implementer of the plan. Regular brainstorming workshops among multiple stakeholders including GOs, NGOs, private sectors, and experienced international experts are required to get feedback on the ongoing and past activities on CA and RCTs.

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