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The Systems Productivity, Profitability and Soil Properties are Altered by Tillage Methods and Cropping Systems in the Mid-hills of Nepal.

Pankaj Gyawaly[1*], Renuka Shrestha[1], Tika Bahadur Karki[1], Reshama Neupane[1], Rajendra Kumar Bhattarai[1], Bhimsen Chaulagain[1], Sangita Kaduwal[1] and Soni Kumari Das[1]

[1]National Agronomy Research Centre, Khumaltar, Lalitpur, Nepal
[*]Corresponding author's email: pankajgyawaly@gmail.com,
ORCID: https://orcid.org/0000-0003-1236-4218

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ABSTRACT

With the aim of identifying appropriate crop establishment methods in cereals-cereals, cereals-legumes, legumes-cereals and legumes-legumes cropping patterns, an experiment was carried out during 2019/20 to 2020/21 in National Agronomy Research Centre, Khumaltar. The experiment was laid out in split plot design with 8 treatments and 3 replications. Main plot was for two tillage methods [Zero tillage (ZT) and conventional tillage (CT)] and sub-plots for 4 different cropping patterns (maize-wheat, maize-lentil, soybean-wheat and soybean-lentil). In zero tillage, the soil was disturbed only along the rows for making seeding furrows and the previous crop residues were left anchored. The rest of the crop management practices were adopted as per the recommended practices. The data were analyzed using GenStat software. The results revealed that tillage treatments did not influence the winter crop yields in 2019, but in 2020, ZT recorded a significantly higher yield of wheat (4.9 Mt ha^{-1}) compared to CT (3.4 Mt ha^{-1}). Similarly, irrespective of crop establishment methods, pooled system yields and benefit: cost ratios were significantly influenced by various cropping patterns. The significantly higher system yield was recorded with maize-wheat (9.0 Mt ha^{-1}) and the least with the soybean-lentil (5.2 Mt ha^{-1}) cropping systems. Improvements in the soil properties were observed as SOM was 14% higher in ZT compared to CT. Similarly, average soil moisture and soil temperature in ZT and CT were found to be 30.2%, 27.5 °C and 28.7%, 29.4 °C, respectively. It is suggested that CA could possibly be an alternative production system for the fragile agro-ecology in the mid-hills of Nepal.

Keywords: Conservation tillage, cropping pattern, economics, soil properties, system yields

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INTRODUCTION

The current high input farming system (conventional agriculture) has put serious exhaustion on the production potential of soil which is more directed towards deriving benefits rather than being synergistic to the production system. Conventional agriculture led to the degradation of natural resources, reduced total factor productivity, depletion of water resources and affected agricultural production (Kumar et al 2018). Apart from the challenges posed by conventional agriculture, the topographical setup is the major hindrance to agriculture in Nepal. More than 56% of the agricultural land in Nepal is fragile and sloppy. The decline in soil fertility has been the major problem in Terai, hills and mountainous regions in Nepal. However, it is more pronounced in the sloppy terraces, where annually 87 tons ha^{-1} of soil is lost (Maskey and Joshi 1991). Atreya et al (2006) observed that total annual soil loss from conventional and reduced till was 16.6 and 11.1 Mt ha^{-1}, respectively.

Conservation agriculture with minimum soil disturbance, residue retention and crop rotation has several benefits resulting compounding effect to enhance crops yield in the long run (Amgain et al 2020). The principles of conservation agriculture work well when these principles are applied simultaneously. The minimum soil disturbance provides the benefits of cost saving in land preparation and at the same time minimizes soil erosion, nutrient runoff, and increased infiltration and maintains soil physical properties (Marahatta et al 2014). The crop residue retention on the other hand serves as nutrient replenishment (Watson et al 2002) to soil as a greater portion of nutrient uptake by crops is retained in crop residues, helps soil carbon sequestration, mulch, smoother weeds, masks evaporation from the surface, reduces the direct impact of rain to the soil, reduces runoff, and buffer soil temperature. Careful crop rotation with legumes and alternately long and short-rooted crops helps nutrient uptake from different strata of soil for assured crop yields, nitrogen fixation and increased system yield. Thus, we can utilize the three principles of CA to solve the existing problems of conventional agriculture (Figure 1) and transform it into a sustainable and regenerative system which is economical, viable and environment friendly approach (Jat et al 2012).

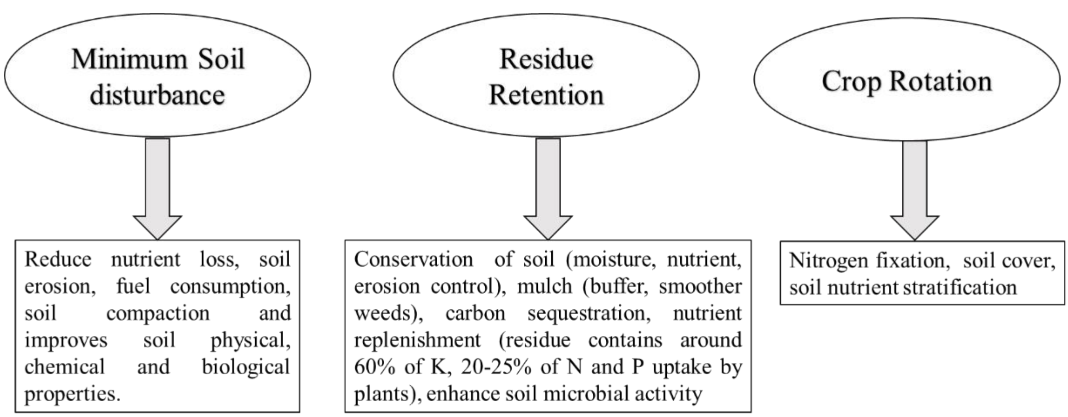

Figure 1. Flow of how three principles of conservation agriculture mitigate the problems posed by conventional agriculture.

Therefore, Conservation Agriculture (CA) has been found to be an alternative to the conventional agriculture system across the globe that reduces the cost of production (Karki et al

2014), enhances the soil quality (Gathala et al 2011), soil organic matter to mitigate GHG emissions, reduce the incidence of weeds (Malik et al 2005), improve system yields and economics (Amgain et al 2020; Karki et al 2014) and lower risk (Laborde et al 2019). Many works have been done on CA abroad and in Nepal's Terai, but very less has been done in the hilly regions of Nepal, hence information is meager in CA in the mid-hill ecologies. Considering the above facts, an experiment has been carried out at the research block of National Agronomy Research Centre, Khumaltar.

MATERIALS AND METHODS

The experiment was carried out in 2019 and 2020 in the Research Block-A of the National Agronomy Research Centre, Khumaltar (27°39' N, 85°10' E and 1360 masl) which represents mid-hill agro-ecology of Nepal. This experiment has been set up as a long-term experiment since 2014 and the treatments have been slightly modified in recent years. The experiment was laid out in a split-plot design with two tillage practices (viz. Convention tillage and Zero tillage) as the main factor and four cropping patterns/systems as sub factor viz. Maize-Wheat, Maize-Lentil, Soybean-Wheat and Soybean-Lentil were replicated three times. This paper deals with the performance of winter crops i.e wheat and lentil, system yield and the economics as affected by the tillage practices and cropping pattern. The details of the crop management practices followed in the consecutive years are presented in Tables 1 and 2, respectively. Other practices were followed as per recommendation. Minor variations were imposed in planting dates and harvested areas of each crop in 2020.

Table 1. Details on seed rates, spacing, fertilizers and sowing dates during 2019

Parameters	Maize	Soybean	Wheat	Lentil
Spacing (cm x cm)	60 x 25 (10 rows of 8 m long)	30 x 15 (20 rows)	20 cm continuous (30 rows)	25 continuous (24 rows)
Seed rate (kg ha^{-1})	25	60	120	40
Planting dates	13 May 2019	13 May 2019	4 Nov 2019	4 Nov 2019
Fertilizers ($N:P_2O_5:K_2O$ kg ha^{-1})	120:60:40	30:60:30	100:40:40	20:40:20
Harvest area (m^2)	38.4	38.4	15-42	48

Table 2. Details on seed rates, spacing, fertilizers and sowing dates during 2020

Parameters	Maize	Soybean	Wheat	Lentil
Spacing (cm x cm)	60 x 25 (10 rows of 8 m long)	30 x 15 (20 rows)	20 cm continuous (30 rows)	25 continuous (24 rows)
Seed rate (kg ha^{-1})	25	60	120	40
Planting dates	3 May 2020	3 May 2020	5 Nov 2020	15 Oct 2020
Fertilizers ($N:P_2O_5:K_2O$ kg ha^{-1})	120:60:40	30:60:30	100:40:40	20:40:20
Harvest area (m^2)	28.8	38.4	41.6	40

The meteorological data during the field experimentation are presented in Figure 2. Comparatively the year 2020/21 was lean year with records of 300 mm less rainfall (around 37 rainy days lesser than in 2019/20). The year 2020/21 observed the continuous spell of drought with no rainfall at all during four months of winter (October-January).

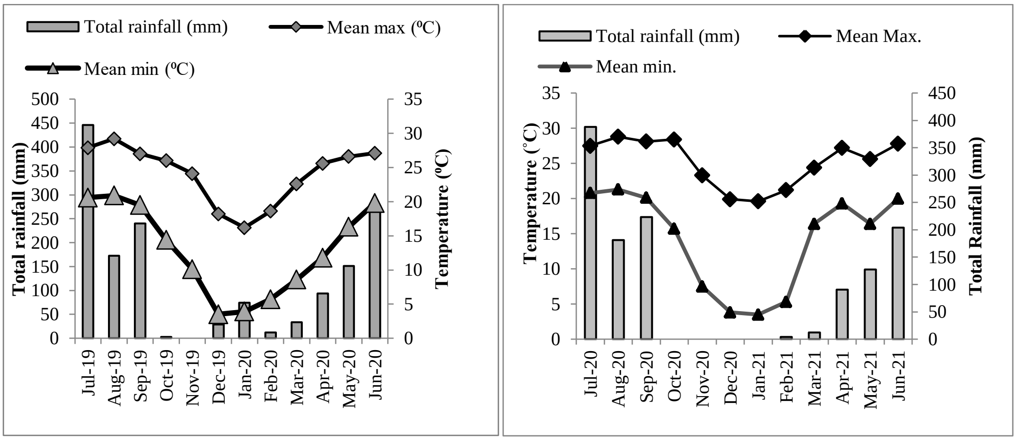

Figure 2. Mean maximum, mean minimum temperatures and total monthly rainfall recorded at Khumaltar during 2019/20 and 2020/21

System yield was calculated by converting the yield of maize, lentil and soybean into wheat equivalent yield.

$$\text{Wheat equivalent yield of crop X (Soybean)} = \frac{\text{Yield of crop X (soybean)} \times \text{Price of crop X (soybean)}}{\text{Price of wheat}}$$

The data obtained were analyzed using Microsoft Excel program and GenStat software. The mean comparison was done at 5% level of significance by DMRT. The figures were developed using MS Excel and Sigma Plot software.

RESULTS

Performance of winter crops during 2019-20

Flowering and physiological maturity in wheat was observed at 123 and 176 days respectively. The no. of grains and grain weight/spike was about 32 and 1.4 g, respectively (data not shown). Similarly, numbers of tillers and spike ranged from 6-7 plant^{-1} (data not presented). None of the parameters were affected by tillage except plant height and thousand seed weight (Table 3). Plant stand was less in ZT as compared to CT. Wheat in CT was taller than ZT and the seeds were bold in ZT wheat was bold seeded. In general, plant stand, grain yield and straw dry matter were higher in CT as compared to ZT. Though previous crops had no significant influence on yield and yield parameters, wheat followed by soybean gave slightly taller plants and greater straw biomass, while a slightly higher plant population was recorded in wheat followed by maize.

Table 3. Wheat yield and yield components as affected by establishment methods and cropping patterns at Khumaltar during 2019/20

Treatment	FS (m^{-2})	PHT (cm)	SL (cm)	GY (kg ha^{-1})	TGW (g)	SDM (Mt ha^{-1})	HI
Tillage method (T)							
Zero tillage (ZT)	90	95	8.7	5275	48.5	12.49	0.55
Conventional Tillage (CT)	108	101	8.8	6542	47.6	13.64	0.55
LSD (<0.05)	-	6.15	-	-	0.841	-	-
Cropping pattern (CP)							
Maize-wheat	107	97	8.6	5967	48.1	12.80	0.54
Soybean-wheat	91	99	8.9	5850	48.0	13.33	0.56
LSD (<0.05)	-	-	-	-	-	-	-
Mean	**99**	**98**	**8.7**	**5909**	**48.1**	**13.07**	**0.55**
LSD (<0.05)T x CP	ns	ns	ns	ns	ns	ns	ns
CV (%)	14	2	4	13	0.8	7	6

Note: FS=Final stand, PHT=Plant height, SL=Spike length, GY=Grain yield, TGW=Thousand grain weight, SDM=Straw dry matter, HI=Harvest index

Lentil crop reached to 50% flowering and 90% maturity in about 99 and 144 days, respectively (data not presented). None of the parameters studied were affected by land establishment methods and cropping patterns (Table 4). However, lentils in CT showed taller plants with a greater number of primary branches, pods, seed pod^{-1}, grain yield and straw dry matter as compared to ZT. Similarly, slightly taller plants, bold seeds and a greater number of seeds per pod were found when the preceding crop was soybean.

Table 4. Lentil yield and yield components as affected by establishment methods at Khumaltar during 2019/20

Treatment	Fs	Pht	Bran	Pod	Upod	Seed	Gyld	Tswt	Sdm	HI
Tillage method (T)										
Zero tillage (ZT)	204	39	7	101	5	1.9	1963	16.4	3.18	0.55
Conventional Tillage (CT)	153	43	9	111	6	2.0	2117	16.6	4.28	0.47
LSD (<0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cropping pattern (CP)										
Maize-Lentil	192	40	8	110	6	1.9	1948	16.4	3.97	0.50
Soybean-Lentil	165	41	8	102	5	2.0	2133	16.7	3.49	0.52
LSD (<0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Mean	**179**	**41**	**8**	**106**	**6**	**1.9**	**2041**	**16.5**	**3.73**	**0.51**
LSD (<0.05) T x CP	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	24	9	6	13	36	3	9	4	20	24

Note: Fs = Final stand (m^{-2}), Pht = Plant height (cm), Bran = Branches $plant^{-1}$, Pod = No. of pods $plant^{-1}$, Upod = No. of unfilled pods $plant^{-1}$, Seed = No of seeds pod^{-1}, Gyld = Grain yield (kg ha^{-1}), Tswt = Thousand seed weight (g), Sdm = Straw dry matter (Mt ha^{-1}), HI = Harvest Index

Performance of winter crop during 2020/21

Wheat crop exhibited to 50% heading in 125 days and 181 days to physiological maturity (data not shown). None of the parameters were affected by tillage except plant height, grain yield and straw dry matter (Table 5). In ZT wheat, plant height, number of tillers m^{-2}, grains $spike^{-1,}$ grain yield and straw dry matter were higher than CT. Wheat in CT showed slightly higher spike length and thousand seed weight. Cropping patterns had non-significant influence on yield and yield parameters of wheat. Wheat followed by maize gave slightly taller plants, tillers m^{-2}, spike length, grains $spike^{-1}$, thousand seed weight and straw dry matter while slightly grain yield was recorded in wheat followed by soybean.

Table 5. Wheat yield and yield components as affected by tillage methods and cropping pattern at Khumaltar during 2020/21

Treatment	PHT (cm)	Tillers m^{-2}	SL (cm)	Grains $Spike^{-1}$	GY (kg ha^{-1})	TGW (g)	SDM (Mt ha^{-1})
Tillage (T)							
Zero tillage (ZT)	95	466	9.5	42	4944	48.0	10.51
Conventional Tillage (CT)	86	381	10.0	37	3436	50.2	7.42
LSD (<0.05)	8.73	ns	ns	ns	534.5	ns	0.924
Cropping pattern (CP)							
Maize-Wheat	92	448	10.0	42	4099	49.2	9.66
Soybean-Wheat	90	399	9.5	37	4280	49.0	8.27
LSD (<0.05)	ns	ns	ns	ns	ns	ns	ns
Mean	**91**	**424**	**9.7**	**39.3**	**4190**	**49.1**	**8.97**
LSD (<0.05) T x CP	ns	ns	ns	ns	ns	ns	ns
CV (%)	4.9	17.1	5.2	9.6	8.4	3.0	21.9

Note: PHT=Plant height, SL=Spike length, GY=Grain yield, TGW=Thousand grain weight, SDM=Straw dry matter

Lentil reached to 50% flowering and 90% maturity at 84 and 166 days, respectively (data not presented). None of the parameters were affected by tillage methods and cropping patterns (Table 6). However, lentil in ZT recorded slightly higher plant stand, grain yield and straw dry matter as compared to CT. Lentil followed by soybean gave a greater number of pods and grain yield, while a slightly higher plant stand was recorded in lentil followed by maize.

Table 6. Lentil yield and yield components as affected by tillage methods and cropping pattern at Khumaltar during 2020/21

Treatment	Fs	Mat	Pht	Bran	Pod	Upod	Gyld	Tswt	Sdm
Tillage (T)									
Zero tillage (ZT)	140	168	34	5	73	3	1063	18.9	2.15
Conventional Tillage (CT)	132	165	34	7	89	4	829	18.5	1.77
LSD (<0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cropping pattern (CP)									
Maize-Lentil	138	166	34	6	78	3	896	18.6	1.98
Soybean-Lentil	133	167	34	5	84	4	996	18.7	1.95
LSD (<0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns
Mean	**136**	**166**	**34**	**6**	**81**	**3.52**	**946**	**18.7**	**1.96**
LSD (<0.05) T x CP	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	25.8	1.3	5.4	18.6	42.8	43.5	20.9	6.0	19.2

Note: Fs= Final stand (m^{-2}), Mat: Maturity days, Pht = Plant height (cm), Bran = Branches $plant^{-1}$, Pod = No. of pods $plant^{-1}$, Upod = No. of unfilled pods $plant^{-1}$, Gyld = Grain yield (kg ha^{-1}), Tswt = Thousand seed weight (g), Sdm = Straw dry matter (Mt ha^{-1})

Pooled analysis of the wheat and lentil yield in 2019/20 and 2020/21

The pooled analysis of two years showed that there were non-significant differences in the grain yield of lentil and wheat due to both tillage practices and cropping patterns (Table 7). However, the grain yields tend to be on the higher side in ZT compared to CT in both lentil and wheat. Also the pooled grain yield was slightly higher in cereals-legumes rotation rather than in cereal-cereal and legumes-legumes rotation.

Table 7. Pooled analysis of winter crops yield (lentil and wheat) yields as affected by tillage methods and cropping pattern at Khumaltar

Treatment	Lentil yield (kg ha^{-1})	Wheat yield (kg ha^{-1})
Tillage (T)		
Zero tillage (ZT)	1513	5109
Conventional Tillage (CT)	1473	4989
LSD (<0.05)	ns	ns
Cropping pattern (CP)		
Maize-Wheat		5033
Maize-Lentil	1514	
Soybean-Wheat		5065
Soybean-Lentil	1472	
LSD (<0.05)	ns	ns
Mean	**1492**	**5049**
CV (%)	14.6	13.0

System yield and economics

The pooled system yield (wheat equivalent), gross return, net return and BC ratio remained unaffected due to tillage practices, however cropping system significantly influenced all of these parameters (Table 8). Although, the pooled system yield was slightly lower in ZT compared to CT, gross return and net returns were higher in ZT which might be due to cost saving in ZT for land preparation. Cropping patterns significantly influenced system yield and economics parameters. Maize-wheat system recorded the significantly higher system yield followed by maize-lentil and soybean-wheat, which were statistically at par to each other. Soybean-lentil system had significantly the least system yield compared to other cropping patterns. Similar trend was also observed in gross returns, net returns and BC ratio.

Table 8. System yield and economics as affected by tillage methods and cropping pattern at Khumaltar

Treatment	Pooled System yield (kg ha^{-1})	Gross return NRS (,000)	Net Return NRS (,000)	BC ratio
Tillage (T)				
Zero tillage (ZT)	6979	238.97	90.47	1.59
Conventional Tillage (CT)	7362	224.03	86.03	1.60
LSD (<0.05)	ns	ns	ns	ns
Cropping pattern (CP)				
Maize-Wheat	8994a	315.50a	162.00a	2.05a
Maize-Lentil	7488b	230.43b	88.93b	1.63b
Soybean-Wheat	6965b	226.51b	80.01b	1.54b
Soybean-Lentil	5236c	153.57c	22.07c	1.16c
LSD (<0.05)	713.3	314.26	31.42	0.23
Mean	**7171**	**231.50**	**88.25**	**1.59**
T x CP (<0.05)	1126	242.01	56.42	ns
CV (%)	12.2	10.8	28.3	11.5

Conservation agriculture (ZT with residue) treatment also showed direct benefits to soil properties. Soil temperature, moisture and organic matter monitored during the crop maturity stage of winter crop during 2022 revealed these parameters were well off in ZT compared to CT (Table 9).

Table 9. Soil moisture (%), temperature (°C) and organic matter (OM %) at winter crop maturity as influenced by tillage practices during 2022

Treatments	Soil moisture content (%)	Soil temperature (°C)	Soil OM (%)
Tillage (T)			
Zero tillage (ZT)	30.2	27.5	3.2
Conventional Tillage (CT)	28.7	29.4	2.8

DISCUSSION

Crop performance

Winter crops yield were affected by yearly variations in the weather parameters. In 2019/20, over all crop yield was more compared to 2020/21. Generally, winters are drier compared to summer in Nepal where more than 80% of the total annual rainfall is consolidated during the summer (June to August). Similarly, in 2020/21 soil moisture was limiting factor for production as it exhibited the dry spell of drought for consecutive four months after planting of winter crops (Figure 2). It was also observed that tillage practices did not influence the winter crop yields in 2019/20, however, in 2020/21 wheat yield was significantly higher in CA compared to CT, but lentil yield remained unaffected (Table 3 and 4). Although the combined yield is slightly higher in ZT, it is reflected that crops yields are not stable where the yields are on the lower side in ZT system in 2019/20 and again in 2020/21 wheat and lentil performed better in ZT than in CT (Figure 3 and 4). To be more precise it is imperative to dig out the causes of differential yield performances or yearly variance in the yields. Although various works has been done in the aspect of CA in the country, either they fail to justify in terms of soil, crop growth and weather perspective or there seems to be crop management related issues that is not fully followed in line to CA system.

While shifting from CT to CA, we are lagging behind the best management practice (BMP) that need to be addressed in terms of residue retention, proper seed placement for assured plant stand and the nutrient management strategies that comply with CA. Generally, when it tends to be stressful year, CA stands out well as crops are less prone to stress environment in CA compared to CT. This is more comparative evident in the year 2020/21, despite the drought stress where life saving irrigations were provided to crops, both the winter crops, wheat and lentil, performed better in CA than in CT. This is mainly due to the crop residue and built up of organic matter which might have conserved the soil moisture denying evaporation from surface in dry season.

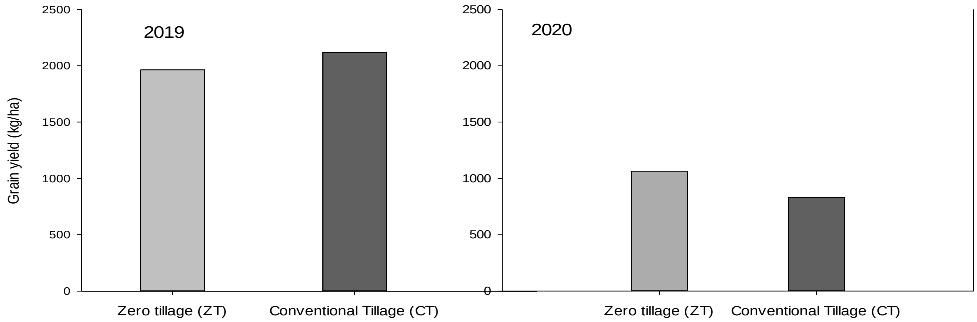

Figure 3. Grain yield of lentil as influenced by tillage practices in 2019/20 and 2020/21

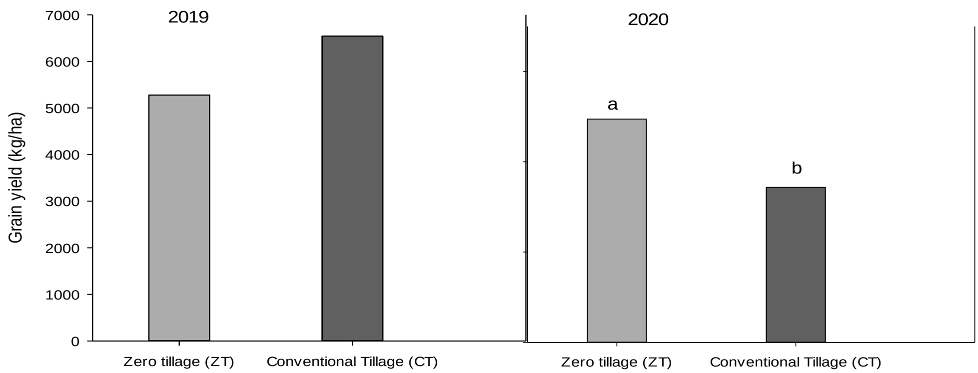

Figure 4. Grain yield of wheat as influenced by tillage practices in 2019/20 and 2020/21

The pooled analysis of the data of two years showed a non-significant influence of tillage practice on the wheat equivalent system yield (Table 8). In the present scenario, the performance of the CA system is under severe scrutiny to prove its efficiency over CT. One of the major reasons behind the below-average performance of ZT over CT in the system yield is the difficulty to maintain the plant population of crops, especially in summer. Similar observations were drawn by Laborde et al (2019) in maize-based cropping system of mid-hills in Nepal. The plant population in CA largely depends upon the precision sowing of crops close to soil alongside crop residue and the soil moisture availability for its germination, especially during summer, however, it is easier for winter crops to establish under residual moisture of summer monsoon in presence of residues. Tripathi (2010) reported that the benefits of 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.

Apart from this, CA needs precision nutrient management different to the CT practice. Although the fertilizer and water use efficiencies are higher in the CA compared to CT in drier seasons, but in summer when it is very hot, humid and precipitation is mostly concentrated, fertilizer management is challenging.

CA offers a set of improved crop production practices that aim to maximize 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 the impact on the natural resources (Amgain et al 2019; Dixon et al 2020).

Economics

CA has been advocated as cost saving practice of farming with avenues of deriving benefits either from reduced cost of labor, land preparation, water requirement or from increased yields or both (Kumar et al 2018; Devkota et al 2019). From system perspective, where crop intensification and diversification can be followed, the major profitable cropping system is cereals based system. Adjusting planting times to incorporate short growing legumes or other cover crops during the window period after winter crop harvest could derive better system yields.

Soil properties

Improvements in the soil properties have been noticed in the clay loam soils of mid-hills due to CA based cropping practice (Figure 5). Soil moisture, soil temperature and soil organic carbon were monitored during the maturity of winter crops (around 150 days of planting). The plots were continuously under CT and ZT in the respective treatments for 7 years, clear reciprocal relation between soil temperature and soil moisture have been revealed and the soil moisture and SOC were higher in ZT soil where CT recorded higher soil temperature than ZT. This improvement in soil properties is directly related to crop growth as ZT crops are less subjected to stress (temperature and moisture) than in CT. Amgain et al (2020) have given the very remarkable study on this line in the semi-arid soil with 9 diversified cropping systems. Marahatta et al (2014) reviewed such and more improvements in soil properties due to CA that are beneficial in terms of agricultural production. It does not necessarily mean that crops yield are higher but may decrease or remain stable during initial years of transition from conventional to conservation agricultural based practices (Laborde et al 2019).

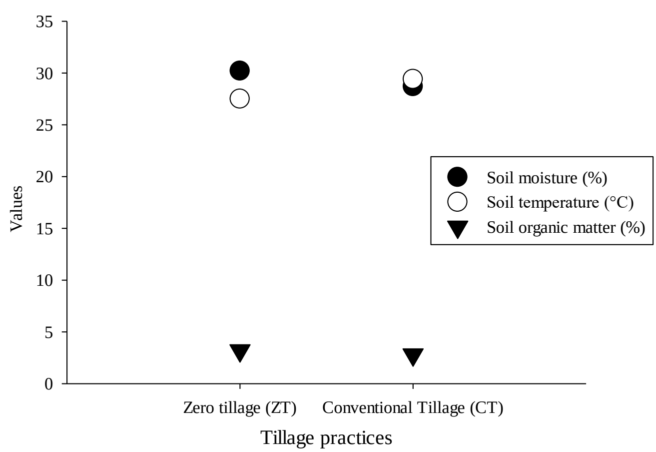

Figure 5. Soil moisture (%), soil temperature (˚C) and soil organic matter (%) influenced by tillage practices at Khumaltar, 2022

Transition to conservation agriculture based practices from conventional agriculture

Having around 55 % of sloppy and fragile agricultural lands in the mountains (Paudel et al 2017), crop production on these lands without proper management is likely to invite more environmental problems in Nepal (Clay et al 2014). Improving soil productivity while conserving soil and mitigating the effects of climate change in these degraded lands can be achieved by adopting conservation agriculture based practices. Nepalese farming system is characterized by small holding, resource poor and low input subsistence farming system. Despite having multifaceted benefits, CA based crop management practices are difficult to scale-out in the rural farming communities who are the major contributors in food security in Nepal. However, some argue the performance of CA to be context specific and larger time frame required to realize the tangible benefits. Resource limited farming communities cannot afford to compromise the yield penalty during initial years of transition to CA (Rapsomanikis, 2015). Crop residue where it can be used in livestock feed might conflict with adopting conservation agriculture. The lack of local knowledge, lack of available equipment to test reduced tillage techniques, lack of effective alternative techniques to control pests, and small farm sizes to be other hindrances of transition to conservation agriculturemore than the findings as reported earlier (Clay et al 2014). In the limelight of this issues, we must devise a potential site specific conservation agriculture management strategy to develop appropriate and farmer's friendly technology for conservation and resilience of fragile farm lands.Concentrated study or quantify the benefits of moisture conservation, soil carbon sequestration, and soil temperature buffer effect on the crop production, economics, soil properties and environment is inevitable in CA to foster more convincing benefits over CT. CA helps to enhance soil physical, chemical and biological properties to make conducive environment for better and sustainable crop growth, conserves agro-ecosystem and to conserve resources for profitable agricultural systems (Amgain et al 2019, 2020, Karki et al 2014; Marahatta et al 2014).

CONCLUSIONS

Winter crops yields were influenced by CA practices when the winters are drier in the mid hills. CA could possibly be the alternative crop management option to address burgeoning problem of soil erosion, climate change and increased production costs and sustain small-holder farmers provided that more concrete and precise CA management strategies along with government policy-supported programs to accelerate adoption of CA in the mid-hills of Nepal.

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AUTHORS' CONTRIBUTION

P Gyawaly conceptualized the manuscript and analysed data, R Shrestha conducted the field trial, generated data and performed data analysis and other authors assisted with write-up and editing.

CONFLICTS OF INTEREST

The authors have no any conflict of interest to disclose.

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