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Effect of conservation agriculture on maize-based farming system in the mid-hills of Nepal

Bikash Paudel[a]*, Theodore J.K. Radovich[b], Catherine Chan-Halbrendt[a], Susan Crow[a], B.B. Tamang[c], Jacqueline Halbrendt[a] and Keshab Thapa[c]

[a]*University of Hawaii at Manoa, Department of Natural Resource and Environment Management, Honolulu, HI, USA 96822*
[b]*University of Hawaii at Manoa, Department of Tropical Plant and Soil Science, Honolulu, HI, USA 96822;*
[c]*Local Initiatives for Biodiversity, Research and Development (LI-BIRD), P.O.Box. 634, Pokhara, Kaski, Nepal*

Abstract

Conservation agriculture (CA) systems composed of intercropping and strip tillage practices were evaluated on marginalized maize-based farming system in hill region of Nepal. On-farm experimental trials were conducted on the field of 25 smallholder farmers in three villages of central mid-hill region. Results indicated that although CA systems did not increase crop yields; higher return and revenue were generated due to increased number of crop harvests and higher price of the cash crops used in intercropping. Therefore, it was concluded that smallholder farmers should adopt CA system for increasing return and improving sustainability of the farming system.

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Keywords: conservation agriculture; strip tillage; intercropping; yield; maize; millet; legume; hills, Nepal

1. Introduction

Conservation agriculture (CA) production systems have been demonstrated to be beneficial for sustainable agro-ecosystem management and agriculture intensification [1, 2]. CA system upholds three conservation principles: a) minimum soil disturbance b) permanent soil cover and c) optimum crop rotation / intercropping [1]. In most cases,

* Corresponding author.
E-mail address: paudel@hawaii.edu

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higher yields have been reported from CA systems compared to conventional systems [3, 4]. However, there are studies that reported no change or even decreases in crop yields during the initial years of practicing CA system [5, 6]. Additionally, the crop yields in CA system have been shown to be affected by many factors such as the use of commercial fertilizer, improved seed and modern inputs. Nyamangara et al. [7] suggested that higher maize yield from CA production systems in Zimbabwe was due to the use of chemical fertilizer. Grabowski and Kerr [8] also concluded that CA system without mechanization was profitable only on small plots, and with low opportunity costs of labor. Therefore, Giller et al [9] suggested that CA system might not be appropriate for all smallholder farmers in subsistence farming systems. However, FAO [1] has maintained that CA has the potential to provide sustained productivity and reduce poverty for smallholder farmers in developing countries. CA system also has the potential to mitigate climate change impacts [10]. As such, it has been promoted as a potential option for sustainable agriculture development in the hill region of Nepal.

Farming systems on sloping lands of developing countries have gone through rapid transformations to adapt to climatic, demographic and social changes. Since 63% of agriculture land is sloping land in Nepal, farming systems in hill region has also gone through many changes [11]. The pressure for cropping intensification has been steadily increasing in the hill region of Nepal due to the high population growth rate, limited arable land and low crop yields. However, with cropping intensification, anti-productive measures such as less application of organic fertilizers per unit land and reduction of fallow period in shifting cultivation land have also been observed [12]. Increased numbers of plowing and furrowing have caused higher soil erosion and nutrition loss resulting to further degradation of agricultural land [13, 14]. High rate of soil erosion is one of the major causes for low yields of maize, a major staple for poor farmers in hill region [15]. Thus, reduction of soil fertility due to high erosion and reduced application of organic matter have negatively affected productivity and sustainability of the system. Additionally, effects of global climate change have also added new challenges for sustainability [16]. Consequently, there is a pressing need to introduce alternative technologies to stimulate sustainable agricultural intensification while at the same time preventing further land degradation. The hill region of Nepal is dominated by marginalized and smallholder farmers, often facing poverty, food insecurity and malnutrition. Although 31% of the Nepalese lived under poverty level in 2009, that figure was as high as 50% among farmers [17]. Similarly, 43% of children in Nepal suffered from malnutrition in 2010, with the highest proportion found in the hill and mountain regions [18]. With global discourses on using smart climate change solutions to alleviate poverty and food insecurity, using CA system for smallholder farmers in the hill region of Nepal is pertinent. However, despite being a potential technology to deal with problems in the region, evaluations of CA systems have been rarely documented and it has never been introduced in larger scale. Few studies have indicated the potential of CA practices [19, 20], but there is a dearth of information about its feasibility on marginal production environments. Therefore, the goal of this study was to evaluate CA systems on maize-based farming system in the hill region of Nepal, and provide recommendations to the decision makers based on the results. Specific objectives of the study were: i) to evaluate the crop yields and economic return from adopting CA systems, and ii) to determine the impact of intercropping of staple and cash crops (millet and legume) for yield and economic returns under different CA systems.

2. Material and Methods

2.1 Study site and design

Three villages in central mid-hills of Nepal were selected for on-farm trials. The villages selected for the study were Thumka (Bhumlichok Village Development Committee - VDC), Hyakrang (Jogimara VDC) and Kholagaun (Chimkeshori VDC) villages in Gorkha, Dhading and Tanahun districts, respectively. The main criteria for selecting these villages were the dominance of marginalized 'Chepang' tribal communities in the villages. The on-farm trials were established on the lands of 25 farmers in these villages. The villages cover a wide span of altitudes ranging from 500-1000 meters, with average altitude of approximately 815, 610 and 586 meter for Thumka, Hyakrang and Kholagaun, respectively. This range has resulted in different soil and growing conditions affecting crop yields and performance. Climate conditions among the three villages are almost similar because timely monsoon rainfall is crucial for good crops' yield in all three villages. The Chepang tribal communities residing in these villages are one of the poorest and most marginalized communities in Nepal. They are primarily found in central mid-hill region of

Nepal, and have a population of about 100,000. Dominant farming system in the study sites is maize-based rain-fed system. Maize covers about 90% of the area during the first growing season (Mar-Jun) followed by second season (Jul-Nov), where legumes such as cowpea, black gram, horse gram; or millet, particularly finger millet and foxtail millet, are the preferred crops [21].

The CA treatments for the on-farm trials were determined through focus group discussions consisting of scientists, extension workers and farmers. The discussions identified three CA treatments for the system: i) CA1: maize followed by legume sole crop with full tillage (FT), ii) CA2: maize followed by millet+legume intercrop with FT (CA2), and iii) CA3: maize followed by millet+legume intercrop with strip tillage (ST). The baseline for the comparison was traditional system i.e. maize followed by millet sole crop with FT. Cowpea was used as the legume crop in 2011, while black gram was used in 2012. The change in legume species was due to over-competition of cowpea with millet. The FT practiced currently by farmers,included two deep plowing for land preparation before planting. The ST is a practice that plows a strip of land (about 20 cm wide) for planting the seeds, maintaining undisturbed land between crop rows.

2.2 Analytical Methods

Possible differences in average crop yields, average plant density, Land Equivalency Ratio (LER), competition ratio (CR) and annual total revenue (AR) among the four different treatments were evaluated using Linear Mixed Models (LMM). The general equation of LMM is as follows:

$$Y_{n\times 1} = X_{n\times p}\,\beta_{p\times 1} + Z_{n\times q}\,\mathrm{A}_{q\times 1} + \varepsilon_{n\times 1}$$

Where Y denotes the n×1 column vector of observed y_i's, X denotes n×p design matrix for p fixed effect predictors, β denotes the p×1 column vector of fixed-effect regression coefficients, Z denotes n×q known design matrix for q random effect predictors, A denotes q×1 column vector of q random-effect regression coefficients, and ε denotes the unobserved n×1 vector of residual. The explanatory variables for which the levels are randomly selected from a larger set of population are defined as '*random effects'*. The explanatory variables that are of primary interest for the study and the comparison among different levels is essential, are taken as '*fixed effect'* [22]. In this study, there were four observations (one per treatment) from 25 farmer fields over two years, hence n = 200 (i.e. 4×24×2). There were seven different y-column vectors, one for an independent variable (i.e. maize yield, maize plant density, millet yield, cowpea yield, black gram yield, LER and competition ratio). The X matrix had three-predictor variables (p) with fixed effects (i.e. treatment, year and treatment×year interaction); hence it had a dimension of 200×3. Similarly, the β matrix had one regression coefficient (β) for each fixed variable; it had a dimension of 3×1. Since village was the only one random-effect variable (q), Z was a column vector with a dimension of 200×1, and A was a scalar. LMM was chosen for this analysis because by using this method, it was possible to categorize explanatory variables into '*random effects'* and '*fixed effects'*. In this study, the village was taken as a '*random effect'* assuming that the villages were randomly selected from large number of similar types of villages in Nepal, hence the results of the study could be generalized for hill regions of Nepal. The CA treatments and year were taken as *fixed effects* because the objective of the study was to compare performance of CA systems with traditional system.

Crop yields, plant density, LER, CR and TR were taken as dependent variables in LMM. Yield and plant density of maize were the two variables used to evaluate the performance of CA treatments in the first season. The yields of all crops were recorded from on-farm CA evaluation trials adjusted for moisture and converted to ton/ha. Numbers of standing plants in plots were counted to depict the plant density per hectare. Yields of legumes and millet were dependent variables used to evaluate performance of CA treatments in the second season. Because of the intercropping component in the second season, direct comparisons of yield of one crop among treatments would neglect the benefit accrued from other crop in intercropping. Therefore, LER was used to evaluate the benefits of intercropping. The LER of sole cropping is always one; therefore an LER greater than one shows yield benefits that accrue from intercropping [23]. Two legume crops (i.e. cowpea and black gram) were used separately in intercropping treatments with millet. Therefore, to compare the performance of millet when intercropped with cowpea and black gram, a CR was used [24]. Finally, to evaluate the performance of CA treatments over an entire year, TR from all CA treatments were determined and compared. Crop yields were multiplied by respective market prices to determine the total revenue from a crop; and revenue from each crop in the system over a year was summed up to determine TR [25]. LER and CR were estimated by using following established equations [23, 24]:

$$\mathrm{LER_T} = \mathrm{LER_M} + \mathrm{LER_L} \text{ where; } \mathrm{LER_M} = \frac{\mathrm{Y_{M(Intercrop)}}}{\mathrm{Y_{M(sole\ crop)}}} \text{ and } \mathrm{LER_L} = \frac{\mathrm{Y_{L(Intercrop)}}}{\mathrm{Y_{L(sole\ crop)}}}$$

Where LER_T = total LER, LER_M =LER of millet, LER_L = LER of legume, $Y_{M(intercrop)}$ = yield of millet in intercropping (tons/ha), $Y_{M(sole\ crop)}$ = yield of millet in sole cropping, $Y_{L(intercrop)}$ = Yield of legumes in intercropping (ton/ha), $Y_{L(sole\ crop)}$= yield of legume in sole cropping

$$CR_M = \frac{\mathrm{LER_M}}{\mathrm{LER_L}} \times \frac{\mathrm{R_M}}{\mathrm{R_L}}$$

Where CR_M = competition ratio of millet to legume, R_M = proportion of area of millet and R_L = proportion of area of legume. The CR_M was the interest of the study because, millet was the main crop needed for household consumption in the region. The area of millet and legume in intercropping was equal; hence both R_M and R_L were 0.5.

The study used ANOVA results of type III test for evaluating the fixed effects. It also used estimates and standard error of prediction for random effects. Point estimates (estimated mean±standard error (SE) at 95% confidence level (CL)) were used for comparisons of crop yield, density and revenue. Additionally, interval estimates (i.e. mean±confident interval (CI) at 95% CL) were also used for comparison of LER and CR.

3. Results and discussion

3.1. Maize yields and plant density under different CA treatments

Average maize yields ranged from 2.05-2.2 and 1.67-2.2 ton/ha, respectively for year 1 (2011) and year 2 (2012) (Table 1), which were much lower than national average of 2.8 ton/ha [26]. There was significant reduction of maize yield in year 2 compared to year 1. Farmers attributed the lower yield of maize yield in 2012 to relatively unfavorable rainfall conditions. However, LMM results showed that there was no significant difference in maize yield by CA treatments. Thus, results failed to demonstrate increase in maize yield due to CA systems. However, results also did not support previous findings claiming significant yield loss of maize under minimum tillage [27].

Table 1. Yield and plant density of maize (*Zea mays*) in 2011 and 2012 under different treatments derived from on-farm trials conducted in three villages in central mid-hills of Nepal.

Year	Treatments[a]	Yield (ton/ha)[b]	Plant density (plants/m^2)[b]
2011 (Year 1)	Traditional	2.11 ± 0.27	3.46 ± 0.68
	CA1	2.20 ± 0.27	3.56 ± 0.68
	CA2	2.19 ± 0.27	3.51 ± 0.68
	CA3	2.05 ± 0.27	3.02 ± 0.68
2012 (Year 2)	Traditional	1.95 ± 0.25	3.17 ± 0.66
	CA1	2.20 ± 0.25	3.30 ± 0.66
	CA2	2.00 ± 0.25	3.34 ± 0.66
	CA3	1.67 ± 0.25	3.05 ± 0.66
	ANOVA		
Sources of variation			
A. Fixed effects	Year (Y)	*	NS
	Treatments (T)	NS	NS
	Y x T	NS	NS
B. Random effect	Village	Estimate	Estimate
	Hyakrang	0.40 ± 0.22^{NS}	1.28 ± 0.65^{NS}
	Kholagaun	-0.20 ± 0.22^{NS}	-0.72 ± 0.65^{NS}
	Thumka	-0.20 ± 0.22^{NS}	-0.56 ± 0.65^{NS}

[a] traditional = maize-millet with FT; CA1 = maize-legume with FT, CA2 =maize-millet+legume with FT; CA3 = maize-millet+legume with ST; $^{NS}P>0.05$, $^*P<0.05$

[b] The values are LS means± SE at 95% CL. For random factor, the value is estimate±SE at 95% CL.

Maize being the most important crop and the main staple food for poor farmers in hill region of Nepal, the need for a yield increasing technology is critical. Even though CA systems did not increase maize yield, it also did not reduce it. If farmers had to sacrifice significant crop yields in the initial CA transition years, it would pose a great challenge for subsistence farmers to adopt CA system. However, it was found that smallholder farmers in the study sites could transform their production system to CA system without suffering significant yield losses.

The average plant density of maize in CA3 was 3.04 plants/m^2, which was 11% lower compared to that of CA2 (3.42 plants/m^2) (Table 1). Similarly, the average yield of maize in CA3 was 1.86 ton/ha, which was also 11% lower compared to 2.09 ton/ha of CA2. The Pearson's correlation coefficient between maize yield and plant density was 0.48 (significantly higher than 0 at 95%). Thus, it was evident that maize yield in CA3 could be increased by increasing the plant density. Lower plant density in CA3 was caused by problems with germination of maize seed under ST practice. Therefore; practices that help to improve germination and increase crop resistance in the early seedling stages would further improve the performance of CA systems. Improved management of soil cover through mulching or cover crop, and introduction of seed planting machines can be probable solutions.

3.2 Yield of millet and legumes

Millet and legume crops were grown following the maize harvest. It was found that millet yield was significantly affected by intercropping. The average yield of millet in sole cropping was 0.93 tons/ha, which was higher than millet grown as an intercrop with either of legume crop (Table 2). Additionally, millet yield was also significantly affected by year (p=<0.001). Millet yield in year 2 (in millet+black gram intercropping) was significantly higher than year 1 (in millet+cowpea intercropping). However, tillage system did not affect the millet yield because the difference in millet yield in CA2 and CA3 was not statistically significant. Both CA2 and CA3 had a similar millet+legume intercropping combination with different tillage practices (i.e. CA2 was FT, while CA3 was ST); hence any difference in yield, if it was significant, could have been attributed to tillage practice. Thus, it was found that farmers could maintain the similar yield of millet by incorporating ST practices.

Table 2. Yield of millet (*Eleusine coracana*), black gram (*Vigna mungo*) and cowpea (*Vigna unguiculata*) in 2011 and 2012 in millet+legume intercropping systems with different CA systems in central mid-hills of Nepal

Year	Treatments[a]	Millet (ton/ha)[b]	Black gram (ton/ha)[b]	Cowpea (ton/ha)[b]
2011 (Year 1)	CA2	0.41±0.13		0.652±0.18
	CA3	0.34±0.13		0.592±0.18
2012 (Year 2)	CA2	0.76±0.16	0.156±0.03	
	CA3	0.73±0.16	0.147±0.03	
		ANOVA		
Sources of variation				
A. Fixed effects	Treatment (T)	NS	NS	NS
	Year (Y)	***	-	-
	Y x T	NS	-	-
B. Random effect	Village	Estimate	Estimate	Estimate
	Hyakrang	0.237±0.13[NS]	-0.037±0.03[NS]	0.21±0.18[NS]
	Kholagaun	-0.13±0.13[NS]	0.011±0.03[NS]	-0.286±0.18[NS]
	Thumka	-0.107±0.13[NS]	0.027±0.03[NS]	0.076±0.18[NS]

[a] CA2=maize-millet+legume with FT, CA3=maize-millet+legume with ST; [NS]P>0.05; ***P<0.001;
[b] The values are LS means± SE at 95% CL. For random factor, the value is estimate±SE at 95% CL.

Farmers selected cowpea as the legume intercrop in year 1, which was replaced by black gram in year 2. Average yields of cowpea and black gram in sole cropping systems were 0.92 tons/ha and 0.32 tons/ha, respectively, which were higher than the crop yields under millet+legume intercropping regimes with either FT or ST. In millet+cowpea intercropping, cowpea produced 0.65 and 0.59 tons/ha with FT and ST, respectively (Table 2). Similarly, in millet+black gram intercropping, black gram produced 0.16 and 0.15 tons/ha under FT and ST, respectively. Though there was reduction of yield for legume crops in intercropping, it was balanced by the production of additional millet. Moreover, the millet+legume intercropping system would improve nitrogen fixation in the soil. The legume crops also garner higher prices than millet in market. For these reasons, millet and legume intercropping would be advantageous for the farmers in terms of food security, financial gain and soil improvement potentials.

3.3 Land Equivalency ratio (LER)

LER was used to compare the overall yield gain from the intercropping treatments of CA2 and CA3 in comparison to sole cropping treatments (i.e. traditional and CA1). The benefits of intercropping from CA2 and CA3 were tested for statistical significance by comparing the confidence interval (CI) of LER values generated from the LMM analysis with one (i.e. LER value of sole cropping). The CI of LER for CA2 was 1.08-1.39, where the lower bound was higher than one at a 95% CL, while that for CA3 was 0.93-1.24, where the lower bound was lower than one (Table 3). Therefore, it was concluded that the intercropping of millet and legume had a significantly higher LER than the sole cropping under FT, but these benefits did not hold true for ST. As such, LER compares the total land required for sole cropping of two crops to yield the same amount of production under an intercropping regime [23]. The average LER of CA2 was 1.24, which indicated that by practicing intercropping with FT, a 24% increase of millet and legume yields compared to sole cropping was possible. However, practicing intercropping with ST only increased yield by 11% as compared to sole cropping which was not statistically significant. Although the LER of CA2 was significantly higher and the LER of CA3 was not different than one, the LER of CA2 and CA3 were also significantly not different at 95% CL. Additionally, the average LERs of CA3 were also greater than one for both years. Therefore, results suggested that if farmers adopt CA3, they would not suffer significant short-term yield losses compared to sole cropping, though it should be recognized that a higher LER was possible by adopting CA2. Hence, it can be argued that farmers could either benefit or maintain overall production rates by adopting CA systems.

Table 3. CR of millet to legume (CR_M) and LER of millet+legume intercropping in 2011 and 2012, derived from on-farm trials conducted in three central mid-hills villages of Nepal in 2011 and 2012.

Year	Treatments[a]	CR_M[b]			LER[c]		
		Mean	Lower Bound	Upper bound	Mean	Lower Bound	Upper bound
2011 (Year 1)	CA2	0.70	0.39	1.01	1.21	1.07	1.35
	CA3	0.71	0.40	1.02	1.11	0.97	1.25
2012 (Year 2)	CA2	2.81	0.69	4.92	1.27	1.03	1.5
	CA3	3.99	1.69	6.29	1.06	0.82	1.29

ANOVA

Sources of variation		CR_M	LER
A. Fixed effect	Year (Y)	***	NS
	Treatment (T)	NS	NS
	Y x T	NS	NS
B. Random effect	Village	Estimate[d]	Estimate[d]
	Hyakrang	0.174±0.135[NS]	0
	Kholagaun	-0.078±0.137[NS]	0
	Thumka	-0.096±0.138[NS]	0

[a] CA2=maize-millet+legume with FT, CA3 = maize-millet+legume with ST;
[b] CR is compared to 1 i.e. if lower bound of CR_M is higher than 1, millet has higher competitiveness than legume;
[c] LER is compared to 1 i.e. if the lower bound of LER is higher than 1, intercropping provides higher yield than sole cropping;
[NS]P>0.05; ***P<0.001;
[d] For random factor, the values are estimate± standard error.

There was no significant difference in total LER between the year 1 and year 2. However, there were differences in the contribution of individual crops to total LER in year 1 and year 2. The LER of a single crop can be compared with 0.5 when both crops are grown in equal areas in intercropping. LER higher than 0.5 for a crop shows yield advantage in intercropping compared with sole cropping, while less than 0.5 indicates a yield loss [23]. For CA2, the LER of cowpea and millet in year 1 were 0.69 (57.4%) and 0.52 (42.6%), respectively. Similarly, the LER of black gram and millet in year 2 were 0.53 (41.97%) and 0.74 (58.03%), respectively. Thus, millet+legume intercropping with FT system derived simultaneous yield advantages from both crops in both years. But, millet+legume intercropping with ST system could not generate such a simultaneous yield advantages. The LER of millet for CA3 was 0.46 (41.6%) in year 1, which was 0.70 (59.1%) in year 2. Hence, the gain from intercropping was contributed by cowpea (58%) in year 1, while it was contributed by millet (59%) in year 2. The incremental contribution of millet in year 2 had important implications because farmers preferred black gram to cowpea to improve the yield of millet,, and it was subsequently observed in the results. Although cowpea and black gram are cash crops fetching much higher prices in the market as compared to millet, the decision to replace cowpea by black gram (to increase millet yield) indicated a higher affinity of farmers toward millet grain than to market profit.

The study could have used the method of yield equivalent for comparing performance of sole cropping and intercropping. Yield equivalent comparisons can be done by converting yields of different crops to 'yield equivalent' of one crop by taking a weighing factor such as market price [28]. However, LER is a better measure for this study since it allows comparison of the biomass yield irrespective of prices, ultimately better suited for the condition of the research sites where very little production is sold in the market.

3.4 Competition Ratio (CR) of millet with different legume (CR_M)

CR was used to assess the relative degree of interspecies competition between two crops in the intercropping system. When the CR of a crop is higher than one, the crop is said to be more competitive than the other crop in intercropping and vice-versa [24]. It was found that the CR of millet was higher in millet+black gram intercropping as compared to millet+cowpea intercropping, indicating that millet performed better in intercropping with black gram as compared to cowpea (Table 3). The average CR of millet in year 1 (with cowpea) was 0.71, which was significantly lower than one at a 95% CL, but the CR of millet in year 2 (with black gram) was 3.4, which was significantly higher than one. Farmers preferred higher competitiveness of millet to legumes because millet is the primary crop in the intercropping regime. Results also showed that CR of millet was significantly higher than one in ST (CI 1.21-3.49, mean 2.35) but not in FT (CI 0.71-2.80, mean 1.75) at 95% CL. Therefore, it was concluded that millet had higher competitiveness to legume under ST system as compared to FT. As farmers in study sites have high preference for millet, this can be an additional motivation for farmers to adopt ST.

3.5 Annual total revenue (TR)

The TR from different CA treatments and the traditional system were used to compare the year round performance of cropping systems. By comparing TR, it was possible to include the performance of all crops in the cropping system (i.e. maize, millet, cowpea and black gram) in a single value and compare across treatments [25]. Result showed that the TR was significantly affected by year ($p=<0.001$) (Table 5). It was clearly seen that, on an average, the TR in year 1 was significantly higher than that in year 2. Two major factors contributed to the reduction of TR in year 2: a) lower yield of maize in the second year due to untimely monsoon and rainfall and, b) replacement of cowpea by black gram. Although black gram fetched about 30% higher price than cowpea in market, it produced only less than half yield compared to cowpea. That is why, even though replacing cowpea by black gram increased the yield of millet, it resulted in lower revenue for the farm.

The results also indicated that the TR was significantly affected by CA treatment ($p=0.03$). CA1 generated significantly higher TR than the traditional system. TR from both treatments with intercropping practices (CA2 and CA3) were between traditional system and CA1, and they were significantly not different to either of them. Even though the sole legume system in the second season produced the highest TR, intercropping of millet and legume would be the optimum improvement to current system by considering farmers' preference for producing millet due to socio-cultural reasons. The difference of TR between CA2 and CA3 was not significant at 95% CL, hence it was concluded that ST did not affected TR. Additionally, lower labor was required to practice ST than FT (based on experience of farmers); hence CA3 was better than CA2 in terms of profitability. Although net profit was not analyzed in the study, annual revenues provided a rough estimate for it since the input and labor opportunity costs were relatively low in the system.

Table 4. Average TR generated in 2011 and 2012 by different CA treatments derived from on-farm trials conducted in three villages in central mid-hill regions in Nepal

Year	Treatments[a]	Annual total revenue ($/ha)[b]
2011 (Year 1)	Traditional	1000±174.8
	CA1	1425±174.8
	CA2	1378±174.8
	CA3	1268±174.8
2012 (Year 2)	Traditional	936±155.5
	CA1	1131±155.5
	CA2	1093±155.5
	CA3	949±155.5
	ANOVA	
Sources of variation		
A. Fixed effects	Year (Y)	***
	Treatment (T)	*
	Y x T	NS
B. Random effect	Village	Estimate[c]
	Hyakrang	263.2[NS]±144.4
	Kholagaun	-133.6[NS]±144.7
	Thumka	-129.6[NS]±144.7

[a] Traditional= maize-millet with FT, CA1= maize-legume with FT, CA2=maize-millet+legume with FT, CA3 = maize-millet+legume with ST;
[b] 1$ = 85 NRs for conversion, [NS]P>0.05; *P<0.05; ***P<0.001;
[c] The values are LS means±SE at 95% CL. For the random factor, the value is estimate±SE at 95% CL

Grain legume crops such as black gram and cowpea are major cash crops in hill region of Nepal. About 85% of cowpea and 68% of black gram produced by farmers in the study sites were sold in 2011, which accounted about 26% of the household cash income [21]. There has been steady increase in market demand of pulses in Nepal due to increased consumption and exports [29]. Black gram and lentil are two main pulses, however, only black gram can be grown in upland conditions of hill farming system. As such, cowpea is not a pulse but it has recently emerged as main cash crop for upland farmers in hill region near to market centers. Thus, in general, market demand would support the adoption of CA1. However, increased demand of legume crops can have a negative effect for CA2 and CA3 because farmers may prefer legume sole crop to intercropping. Adoption of CA3 might have additional challenges because ST practice is a new technology in the region. Additionally, Reed et al. [30] reported that although farmers placed high value on soil fertility, they were unaware of the advantages of ST. Therefore, demonstration of the benefits of ST on soil quality and accompanied training and capacity building of the farmers would be required for the expediting adoption of CA3.

3.6 Cost of production and long-term benefits

The analysis did not consider the difference in cost of production due to the low input costs and general challenges in accurately collecting this type of data. There were virtually no external inputs in the system. Farmers saved their seeds for the next planting season; and fertilizer inputs were limited to farmyard manure. Therefore, labor requirement was the only factor that could cause the cost of production to vary among the CA treatments. However, analysis of labor requirement would also have little implication since almost all the labor required for crop production were supplied by the household. Additionally, labor savings was found to be less important for the farmers as compared with yield, profit and soil health [30]. Very low opportunity costs of the labor resulted from limited off-farm wage earning opportunities and a large proportion of people depending on agriculture sector might be the reason for lower importance of labor saving in the villages. For this reason, the adoptability of CA system would be less affected by the requirements of labor, until the required labor could be supplied by household or by the traditional exchange system. The analysis also did not include the long-term benefits of CA system with regards to soil fertility and ecosystem health due to the short timespan of the trials. Various studies have identified the positive effects of legume intercropping and conservation tillage to the soil fertility, environment and ecosystem health [31, 32]. If it were possible to include these long-term benefits in the analysis, the advantage of CA system would have further increased. So, excluding these benefits did not produce any positive bias for CA system in the analysis.

4. Conclusion

The study concluded that the average yield of maize for CA systems were similar or higher than the traditional system in the hill region of Nepal. Maintaining plant density of maize was found to be an important factor for increasing yield under CA system, hence techniques that improve the germination and resistance of crops in the early seedling stage would further increase the benefits of CA systems. Although average yields of second season crops (millet, cowpea and black gram) from millet+legume intercropping were significantly lower than sole cropping, the analysis of LER indicated that intercropping had a higher overall return. It was also concluded that ST practice did not reduce the yield of millet and legumes in intercropping systems. Although the maize-legume system generated the highest revenue, the revenue generated from maize followed by millet+legume intercropping system was also significantly not different. It was found that ST offset the average yield advantage accrued from millet+legume intercropping, the yield from ST was nevertheless similar or better than the traditional system. Therefore, it was concluded that, while some of the CA systems provided higher average yields and returns, none of them showed significant reduction. Selection of the legume in a millet+legume intercrop was found to be important for the feasibility of CA system. Therefore, it was concluded that CA had the potential to increase yields and returns, however this also requires adopting a suitable cropping system. In conclusion, even though this was not a long-term evaluation of CA system, it was found that CA system is feasible for the marginal production environments of poor, smallholder farmers in the hill region of Nepal. Therefore, to speed up the adoption of CA systems by farmers, the government should educate the farmers on the benefits of CA over the long term, while informing that the returns might be limited in the initial years of implementation.

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