Agronomy Journal of Nepal. ***8****(1):219-225*
ISSN: 2091-0649 (Print)
DOI: https://doi.org/10.3126/ajn.v8i1.70896

Crop Establishment Methods Affect Plant Stand and Yield of Lentil under Rice-lentil Cropping at Khumaltar Condition

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Received: May 10, 2024
Revised: June 24, 2024
Published: October 18, 2024

ABSTRACT

Lentil variety, Maheswor Bharati, was evaluated in three establishment methods: relay, conventional tillage after rice harvest (post-rice CT), seeding by seed drill where seeds covered by minimum soil disturbance in single pass, and two rice residue heights: residue removed i.e., straw cut at 5 cm height and 30 cm residue retained at Agronomy Farm, Khumaltar from 2016/17 to 2018/19. Experiments were conducted in Randomized Complete Block design with four replications. Seeds broadcasted on standing rice during 2-16 November for relay crop; and 21-29 November for post-rice CT. Seed rates were 40 kg ha^{-1} for machine and manual line sowing and 50 kg ha^{-1} for broadcasting. Rice was harvested at 14-18 days after lentil relay. Fertilizers were applied based on soil fertility of experimental field. Significant variation was observed in plant stand, crop duration, growth and yield parameters among establishment methods; and year to year variation was also significant except for plant stand. Plant stand was greater (58-62 m^{-2}) in machine sowing with or without residue retention and manual line sowing in post-rice CT, while low (32-40 m^{-2}) in broadcasting methods either as relay or post-rice CT. Crop grew tall in relay with residue retained and machine sowing (41 cm) as compared to broadcasting in post-rice CT (33 cm). Grain yield was 46-115% and 24-83% higher in seeding by machine as compared to relay sown without residue (492 kg ha^{-1}) and broadcasting in post-rice CT (578 kg ha^{-1}), respectively.

Keywords: Lentil, plant stand, post-rice, relay, rice residue

How to cite this article:

Neupane R RK Bhattarai, P Gyawaly, B Chaulagain , S Kaduwa, TB Karki and SK Das. 2024. Crop establishment methods affect plant stand and yield of lentil under rice-lentil cropping at Khumaltar condition**.** Agronomy Journal of Nepal 8(1): 219-225. DOI: https://doi.org/10.3126/ajn.v8i1.70896

INTRODUCTION

Lentil (*Lens culinaris* Medikus ssp. culinaris) is valuable in terms of area coverage, dietary protein, soil fertility and export commodity in Nepal. In 2018/19, lentil is cultivated in 208766 ha with production and productivity of 251,185 t and 1203 kg ha^{-1}, respectively, contributing about 60% area and production under grain legumes during (MoALD 2020). Lentil is grown in 74 out of 77 districts of Nepal where Province 2 and Province 5 contribute about 73% area and production. About 95% of lentil area lies in terai and inner terai, the top lentil growing districts Dang, Kailali, Rautahat, Bardiya, Siraha, Bara and Banke account for 56% of area and production. The traditional practice of broadcasting lentil seed in the standing rice crop nearing maturity is a true form of no-till (paira or utera or relay) grown without fertilizers or any intercultural operations. The success of relay crop is entirely depending on residual moisture for germination and stand establishment and utilize leftover fertility of previous rice crop. Relay cropping is common in low lying paddy field where rice crop takes long time to mature and timely land preparation is not possible due to excessive soil moisture (Neupane and Bharati 1993, Shrestha 1996). The other popular method of sowing is broadcasting in conventional tilled soil after rice harvest (post-rice CT) where seeds are covered by planking. Farmers usually removed all crop residues i.e., cut rice straw at ground level (about 5 cm) as it is used a valuable source of livestock feed. Relay cropping of lentil with autumn sown maize or lentil intercropping with autumn planted sugarcane are the emerging patterns in central terai (Shrestha et al 2012). Relay lentil has higher benefit cost ratio of 1.26 as compared to sole crop (1.16) or mixed cropping (1.15) (Thapa Magar et al 2014).

Soil moisture stress at early germination and reproductive stages; and high temperature during pod filling stage

and nutrient deficiency are the major abiotic constraints limiting lentil production in Nepal (Shrestha et al 2012). Monsoonal rainfall in Nepal contributes around 80% of the annual rainfall (1800 mm), while rainfall during winter, pre- and post-monsoon seasons contribute 3.5%, 12.5% and 4.0%, respectively (DHM 2015). Increase in temperatures, occurrence of frequent drought and changing rainfall patterns (annual decrease 1.3 mm/year) are the consequences of climate change that have profound effect on crop production (DHM 2017, Malla 2008). Thakur and Karki (2018) reported decline in rainfall from November to April adversely affecting winter and spring crops in Nepal. The concept of conservation agriculture is based on minimum soil disturbance (zero/minimum tillage), surface crop residues retention and diversified and economically viable crop rotations for achieving sustainable and resource efficient crop production practices (Farooq and Siddique 2015). No-till practice are cost savings, ensure timely planting and increase water use efficiencies (Kumari et al 2011) and therefore considered valuable option for drier conditions where increased soil water could increase yield (Fuhrer and Chervet 2015). Timely planting in no-till system helps crops to escape adverse effects of terminal water stress and rising temperatures (Kumari et al 2011). In general, no-till performs best relative to conventional tilled under water-limited conditions (Pittelkow et al 2015) as indicated by more productive relay planting than post-rice as adequate soil moisture enabling earlier establishment and therefore better seed yield (Ali et al 1993). However, relay system lacks proper residues to cover soil surface and efficient weed management option and crop may suffer in case of excessive rainfall during growing season in low lying field. Until now the major emphasis is given on development of lentil varieties and improved production technologies such as optimum sowing date, seed priming under post-rice and rice relay system. There has been very limited research done in conservation based technologies thus study was aimed to evaluate the impact of tillage and residue retention on lentil productivity under rice-lentil system of mid hill.

MATERIALS AND METHODS

Experiments on tillage and rice residue management in lentil were conducted at Agronomy Farm, Khumaltar (Latitude 27°39' N, Longitude 85°10' E; 1360 masl), Nepal during 2016/17 (year 1), 2017/18 (year 2) and 2018/19 (year 3). Three tillage: relay, conventional tillage after rice harvest (post-rice CT), seeding by single pass seed drill machine in no-till, and two rice stubble heights: 5 cm (no residues) and 30 cm (residues retained) were evaluated in RCB design with four replications under upland in year 1 and lowland in year 2 and 3. Six treatments were i) relay with no residues (farmer practice 1), ii) relay with 30 cm rice straw standing, iii) manual line sowing in post-rice CT, iv) broadcast in post rice-CT (farmers practice 2), v) single pass by seed drill with no residues and vi) single pass by seed drill with 30 cm rice residues retained. Lentil variety used was Maheswor Bharati. Seeds were broadcasted on standing rice on 4 November 2016, 16 November 2017 and 3 November 2018, while seeding in post-rice treatments were done on 29 November 2016, 21 November 2017 and 26 November 2018. Seed rates were 40 kg ha^{-1} for manual line and machine seeding and 50 kg ha^{-1} for broadcasting. Spacing used was 25 cm between rows and continuous seeding within row. Rice crop was harvested 2-3 weeks after seeding i.e., third to last week of November in relay system. Fertilizers @ 20:40:20 N:P2O5:K2O kg ha^{-1} applied as basal in year 1, while no fertilizers applied in year 2 and 3 due to high soil fertility of the experimental plots. Gross plot areas were 20 m^2 in year 1, 15-18 m^2 in year 2 and 12 m^2 in year 3; and net harvest areas were 12 m^2, 4 m^2 and 10-12 m^2 for year 1, 2 and 3, respectively. Plots were irrigated 1-2 times depending upon soil moisture status (year 1: 17 November, 4 December; year 2: 14 November and year 3: 1 November). Weeds were removed manually during first week of February in year 1 and 3, and first week of January in year 2, and plots were kept free of weeds whenever possible. Plant population in upland trial of 2016 in particular relay planting was affected by severe moisture stress as seeds were exposed to insects and birds (5-30% damage), and silt deposition from deep boring irrigation water.

Soil type

Soil of Agronomy Farm was silty loam with moderate acidic soil pH (5.43), medium in total nitrogen, available potash; high in available phosphorus whereas organic matter was low (Amgai 2018).

Temperatures and rainfall

Mean maximum temperatures from sowing to physiological maturity (November to April) were 22.3˚C in 2016/17 (year 1), 22.6˚C in 2017/18 (year 2) and 23.1˚C in 2018/19 (year 3) while mean minimum temperatures were 8.7˚C, 7.1˚C and 7.8˚C in year 1, 2 and 3, respectively (data not shown). Mean maximum temperature from sowing to early flowering was slightly higher for year 3 as compared to year 1 and 2, while mean minimum temperature was greater for year 1 (Figure 1). Total rainfall recorded from sowing to maturity were 272.9 mm, 201.3 mm and 644.5 mm, respectively in year 1, year 2 and year 3 (Figure 1).Total annual rainfall from October to September were 1099 mm in year 1, 1073 mm in year 2 and 1237 mm in year 3 (AGD 2017, AGD 2018, AGD 2019). There was almost no rainfall during vegetative stage (November to December), while year 3 received the highest rainfall of 120 mm during reproductive stage (January-February), and the minimum of 14.4 mm in year 1 and 9.7 mm in Year 2 (Figure 1). Year 3 received higher winter rain as compared to year 1

and 2.

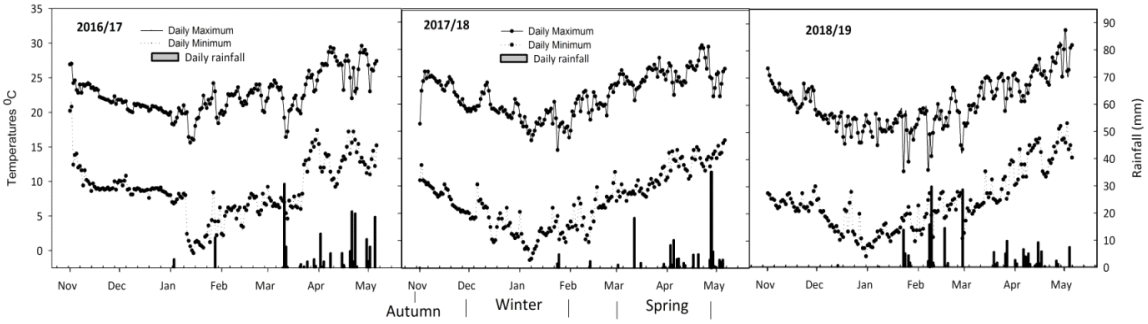

Figure 1: Daily minimum (dot lines) and maximum (solid lines) temperatures and rainfall (solid bar) during lentil growing season in Khumaltar during 2016-17 to 2018-19

Statistical analysis

Data were recorded on crop duration, plant height, yield and yield components and straw dry matter. Five plant samples were taken to measure plant height and yield components. Quadrant size 1 m x 1 m was placed at 4 places in a plot for final plant stand and dry matter estimation. Grain yield was taken from whole plot basis. Straw was oven-dried for 72 hours (80 ^{o}C) to estimate dry matter. Five hundred seed counted to calculate hundred seed weight (oven-dry basis). Data were analyzed using GenStat Discovery Edition. SPSS 16.0.

RESULTS AND DISCUSSION

Plant population

In year 1, number of plants at harvest ranged from 7-24 m^{-2} with the lowest in relay sowing and the maximum in manual line sowing in CT and machine sown with residues (Figure 2). Similarly, final stand ranged from 48-75 m^{-2} in year 2 and 35-90 m^{-2} in year 3 with mean value 65 and 71 m^{-2}, respectively. Combine analysis showed good plant population under machine sown with residues retained, followed by machine seeding without residues and line sowing in CT (Table 1). Relay and broadcasting method of sowing had significant less numbers of plant population except year 2. Plant population was affected by establishment methods in year 1 and year 3 that might have been contributed by rainfall patterns during growing season, rice varieties used, drainage system, land leveling, soil moisture and fertility status of experimental plots. In year 2, quadrants were used for plant sampling and thus comparatively small net area harvest as some plots were damaged due to drainage repair.

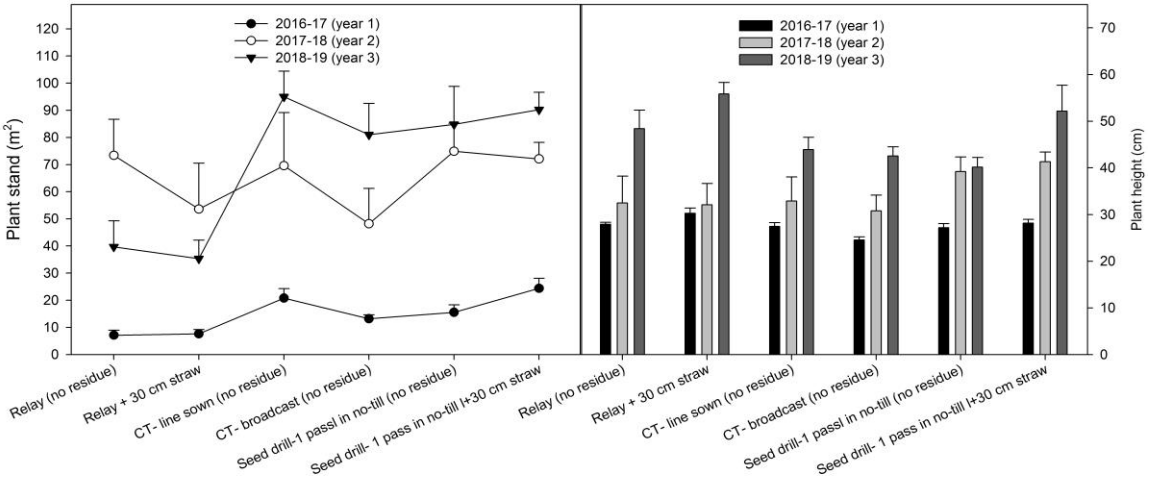

Figure 2: Plant population at harvest and plant height of lentil variety Maheswor Bharati as affected by method of sowing at Khumaltar (2016/17 to 2018/19)

Lentil growing season in year 1 was very dry and only 14.4 mm rainfall recorded during reproductive stage. Also, soil moisture was depleted faster with use of early maturing high yielding rice variety under upland environment. Therefore, supplemental irrigation was given two weeks after seeding and during first week of December at flowering stage to ensure better establishment and growth. In year 3, proceeding rice variety used

was hybrid, and therefore plots were watered prior to seeding to ensure better establishment. In general, lower plant stand in relay sown or broadcasting in tilled soil might have been due to exposure of seed to drier condition or to birds, while good plant stand in manual line sowing in post-rice CT or seeding by single pass of seed drill with or without rice residues indicated the proper seed coverage for germination and establishment. Islam et al (2015) also reported maximum plant population in minimum till furrows planting and the lowest in relay sowing method might be due to seed damage by insect and birds in the field before germination. Similarly, Bandyopadhyay et al (2016) reported quicker surface soil drying when lentil was relay with short stubble residues (10 cm) as compared to tall (20 cm) stubble residues. Darai et al (2012) also reported dependence of plant stand and grain yield on the soil moisture under relay sowing. Greater soil moisture content, water holding capacity and infiltration rate was found under mulch condition, followed by 40 cm standing rice stubble as compared to 20 cm standing rice stubble and residual removal (Das et al 2019).

Crop maturity and growth

Days from sowing to physiological maturity, plant height and numbers of main branch per plant varied significantly among establishment methods and year, and significant establishment methods x year interaction for these parameters (Table 1). Crop duration for relay crops was 2 weeks longer as it was sown earlier than post-rice crops (Table 1). Overall, crops matured 8 days earlier in year 1 and 25 days in year 3 as compared to year 2 (Table 1).

Table 1: Mean plant stand, maturity days, numbers of main branche and plant height of lentil var. Maheswor Bharati under different establishment methods at Khumaltar (2016/17 to 2018/19)

SN	Treatments	Final stand (m^2)	Maturity days	No. main branches /plant	Plant height (cm)
	Tillage and Residue Management (TRM)				
1.	Relay (no residue)	40	161	2	36
2.	Relay + 30 cm rice straw standing	32	161	2	39
3.	CT - Line sown (no residue)	62	148	3	35
4.	CT - Seed broadcast (no residue)	48	147	3	33
5.	Seed drill - single pass in no-till (no residue)	58	147	3	36
6.	Seed drill - single pass in no-till + 30 cm rice straw retained	62	147	3	41
	Mean	**50**	**152**	**2**	**37**
	Year (Y)				
1.	Year 1 (2016-17)	15	149	3	28
2.	Year 2 (2017-18)	35	141	2	35
3.	Year 3 (2018-19)	71	166	2	47
	P **value (TRM)**	<.001	<.001	0.005	0.003
	LSD (<0.05)	17	2	0.3	4
	Year (Y)	0.149	<.001	<.001	<.001
	LSD (<0.05)	-	2	0.2	3
	TRM x Y	0.140	<.001	0.618	0.013
	CV (%)	33	5	15	14

Plant height grew taller in year 3 (40-56 cm), followed by 25-30 cm in year 1 and 32-41 cm in year 3 (Figure 2). Mean plant height was highest (41 cm) in relay crop with rice residues retained and machine seeding, while the shortest (33 cm) win seed broadcasting in post-rice CT (Table 2). Relay lentils had few numbers of main branches/plant, with greater numbers in year 1 (Table 2).

Grain yield and yield components

Grain yield (p=<0.001), numbers of pod/plant (p=0.012), seeds/pod, seed size and straw dry matter varied significantly among establishment methods and year, with significant establishment method x year interaction for straw dry matter yield (Table 2, Figure 3). Numbers of pods/plant ranged from 34-49 in year 1, 55-93 in year 2 and 60-122 in year 3 (Figure 3). Combine analysis showed that relay sown lentil with 30 cm rice stubble standing produced the highest 87 pods/plant, followed by machine seeding with rice stubble retained and relay with residues removed (74/plant), while the lowest of 54/plant when seed broadcasted in post-rice CT (Figure 3). Number of unfilled pods per plant was non-significant (p=0.348) among establishment treatments (6-8/plant) with significant yearly variation (p=<0.001) of 3/plant in year 1-9/plant in year 2 and 3 (data not presented). Relay sown with residues removed had less number of seed/pod than other establishment methods (Table 2).

Similarly, relay crop had smaller seed as compared to machine sown or line/broadcasting in CT. Relay crop with 30 cm rice straw standing had larger seed size and high numbers of seed/pod might be due to improve soil moisture or nutrition as compared to relay without stubble retained.

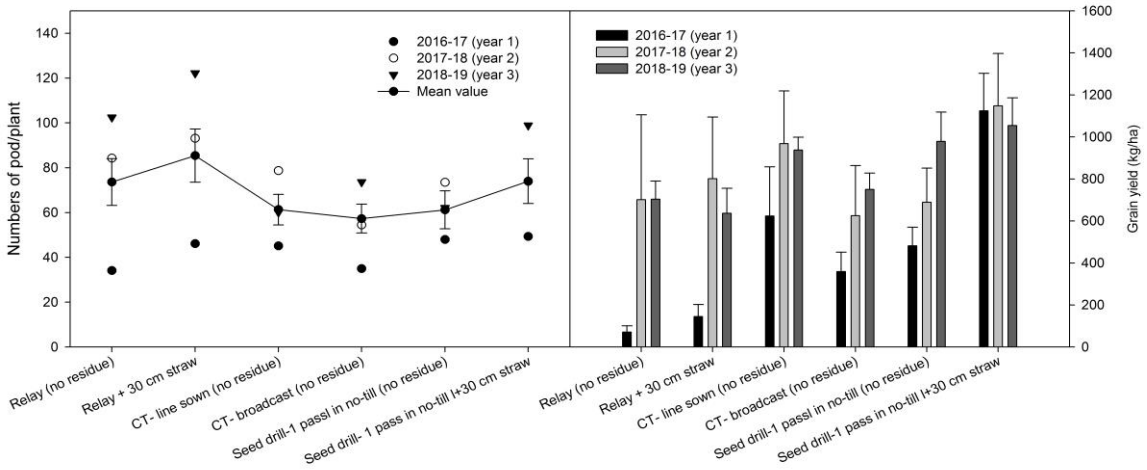

Figure 3: Numbers of pods and grain yield of lentil variety Maheswor Bharati as affected by method of sowing at Khumaltar

Machine sown with residues retained had more than double the mean grain yield as compared to farmer's practice of relay sowing without rice residue retained (Table 2). Similarly, machine or CT manual line sowing with no residue retained produced 45-70% higher grain yield than relay crop. There was 24-83% yield advantage in seeding by seed drill with or without residue as compared to CT broadcasting. Similar trend was observed in straw dry matter production. Machine sown with 30 cm rice residue retained and CT manual line sowing with no residues had 46-115% higher straw dry matter production than relay sown without residues (Table 2). Straw dry matter production ranged from 217 (relay with no residues) to 1517 kg ha^{-1} (machine sown with residues) in year 1, 1301 (relay with no residues) to 4477 kg ha^{-1} (machine sown with residues) in year 2 and 963 (relay with no residues) to 2814 kg ha^{-1} (CT manual line sowing) in year 3 (data not presented). Overall straw dry matter production was greatest in year 2 and the lowest in year 1 (Table 2).

Table 2: Mean grain and yield parameters of lentil var. Maheswor Bharati under different establishment methods at Khumaltar (2016/17 to 2018/19)

SN	Treatments	Seeds /pod	100 seed weight (g)	Grain yield (kg ha^{-1})	Straw dry matter (kg ha^{-1})
	Tillage and Residue Management (TRM)				
1.	Relay (no residue)	1.7	2.1	492	990
2.	Relay + 30 cm rice straw standing	1.9	2.2	527	865
3.	CT-Line sown (no residue)	1.9	2.3	843	2205
4.	CT-Seed broadcast (no residue)	1.8	2.3	578	1474
5.	Seed drill-single pass in no-till (no residue)	1.8	2.3	717	1797
6.	Seed drill-single pass in no-till +30 cm rice straw	1.9	2.3	1056	2636
	Mean	**2**	**2.2**	**702**	**1661**
	Year				
1.	Year 1 (2016-17)	1.7	2.2	468	748
2.	Year 2 (2017-18)	1.9	2.1	796	2480
3.	Year 3 (2018-19)	1.9	2.0	843	1755
	P value **(TRM)**	0.002	0.016	<.001	<.001
	LSD <0.05)	0.1	0.1	253	589
	Year (Y)	<.001	<.001	<.001	<.001
	LSD <0.05)	0.1	0.10	179	416
	TRM xY	0.084	0.135	0.322	0.021
	CV (%)	8	8	44	43

Dry matter production was severely affected when lentil was relayed or seed broadcasted in tilled soil mainly due to poor plant population caused by unfavorable condition for seed to germinate properly. Lentil relay with rice residues retention may be efficient in terms of saving energy, labor, soil moisture and maintaining grain yield provided the plant population was optimum. Good crop performance was observed when seeding by seed drill in no-till soil with or without rice residue or line sowing after tillage. In both cases seeds were fully covered resulting in good establishment. Studies conducted elsewhere also showed lentil yield advantage in no-till planting as compared to CT. Farmer's participatory trials in eastern Indo-Gangetic Plain showed reduce wilt incidence and improve lentil grain yield (1.53 t ha^{-1}) under no-till as compared to CT (1.22 t ha^{-1}) and surface seeding (0.91 t ha^{-1}) (Kumari et al 2011). In Bangladesh, minimum tillage with furrow planting of lentil gave 17% higher yield than relay planting (1.37 t ha^{-1}), contributed by good establishment, taller plants, higher numbers of primary branches, pods per plant, seeds per pod and larger seed size (Islam et al 2015). Minimum tillage or no tillage with residue retention through mulch or 40 cm rice stubble standing produced significantly higher seeds per pod, pods per plant, 1000 seed weight and yield as compared to tillage with residue removed (Das et al 2019). Similarly, trial conducted at the University of Idaho showed about 108% higher yields of no-till lentils as compared to CT (Guy and Lauver 2006). No-till is effective with the use of crop residue as mulch when moisture was limiting (Lal et al 2007). No-till yields of legume crops was found to be similar to CT or even yield increase particularly where water is limiting to crop growth (Pittelkow et al 2015).

CONCLUSIONS

Lentil seeding in single pass seed drill machine in no till soil with or without rice residues retained and manual line sowing in conventional tillage favored good crop establishment, better growth and hence higher grain yield as compared to farmer's practice of relay sowing with rice residue removed or seed broadcasting in tilled soil with residue removed. Crop establishment and yield performance in relay sowing or seed broadcasting in tilled soil depended upon initial soil moisture status, soil type, land type and preceding rice crop. Minimum tillage or no-till with residues retention performed best under rainfed conditions in dry climates where grain yields are often equal or higher than conventional tillage practices. Though the no-till or minimum till method of planting requires initial investment to procure suitable zero-till machine, it could be the best option in terms of timely planting, establishment, yield and soil moisture maintenance.

ACKNOWLEDGEMENTS

Authors would like to extend sincere thanks to field technicians Mr Subindra Balami and Mrs Rojina Shrestha, Agronomy Division for support in conduction of experiment and data collection.

AUTHOR'S CONTRIBUTION

Reshama Neupane: Experiment design and execution, data analysis and manuscript preparation

CONFLICT OF INTEREST

The authors declare no conflict of interests or personal relationships that could have appeared to influence the work reported in this paper. The authors have no any conflict of interest to disclose.

REFERENCES

AGD. 2017. **In:** Annual Report 2073/74 (2016/17), Agronomy Division, NARC, Khumaltar, Lalitpur, Nepal.

AGD. 2018. **In:** Annual Report 2074/75 (2017/18). Agronomy Division, NARC, Khumaltar, Lalitpur, Nepal.

AGD. 2019. **In:** Annual Report 2075/76 (2018/19). Agronomy Division, NARC, Khumaltar, Lalitpur, Nepal.

Ali M, CS Saraf, PP Singh, RB Rewari and IPS Ahlawat. 1993. Agronomy of lentil in India. **In:** Lentil in South Asia, Proceedings of the seminar on lentil in South Asia (W Erskine and MC Saxena eds). New Delhi, India. (International Center for Agricultural Research in the Dry Areas, Aleppo, Syria), **pp.**103-137

Amgain R. 2018. Effect of nutrient sources on soybean yield and soil properties under mid hill condition of Nepal. Master thesis. Agriculture and Forestry University, Faculty of Agriculture, Rampur Chitwan, Nepal, **p.** 72.

Bandyopadhyay PK, KC Singh, K Mondal, R Nath, PK Ghosh, N Kumar, PS Basu and SS Singh. 2016. Effects of stubble length of rice in mitigating soil moisture stress and on yield of lentil (*Lens culinaris* Medik) in rice-lentil relay crop. Agricultural Water Management. **173**: 91-102.

Darai R, A Sarker, DB Gharti, BP Wagle and RK Neupane. 2012. Increasing lentil productivity through the application of low-cost technologies in rice-based cropping system in Nepal. **In**: Third International Agronomy Congress Agriculture Diversification, Climate Change Management and Livelihoods, November 26-30, 2012, Volume: I, IARI, Pusa Campus, New Delhi, India.

Das A, J Layek, GI Ramkrushna, K Rangappa, R Lal, PK Ghosh, BUChoudhury, S Mandal, B Ngangom, U Dey and N Prakash. 2019. Effects of tillage and rice residue management practices on lentil root architecture, productivity and soil properties in India's Lower Himalayas. Soil and Tillage Research. 194 accessed in December 2020 from https://www.sciencedirect.com/science

DHM. 2015. Draft report study of climate and climatic variation over Nepal. Government of Nepal Ministry of Science, Technology and Environment Department of Hydrology and Meteorology, Nepal. Hydrological and Meteorological Research Centre and Consultancy Pvt. Ltd, **p.** 9 (http://www.dhm.gov.np/climate/).

DHM. 2017. Observed climate trend analysis in the districts and physiographic regions of Nepal (1971-2014), **p.** 35, Department of Hydrology and Meteorology, Kathmandu, Nepal

Farooq M and KHM Siddique. 2015. Conservation Agriculture: concepts, brief history, and impacts on agricultural systems. **In:** Conservation Agriculture, (M Farooq and KHM Siddique eds), ISBN 978-3-319-11620-4 (eBook), Springer International Publishing Switzerland, **pp.**3-17

Fuhrer J and A Chervet. 2015. No-tillage: long-term benefits for yield stability in a more variable climate? Procedia Environmental Sciences. **29**:194-195

Guy SO and M Lauver. 2006. http://a-cs. confex.com/crops/responses/2006am/1023.pdf

Islam MR, MK Uddin and MO Ali. 2015. Performance of lentil varieties under relay and minimum tillage conditions in T. aman rice. Bangladesh J. Agril. Res. **40(**2):271-278.

Kumari S, RG Singh, C Piggin, A Haddad, S Ahmed and Raj Kumar. 2011. No-till lentil: An option for profitable harvest in dry areas. https://www.researchgate.net/publication/259760934 Retrieved on: 09 June 2016)

Lal R, D Reicosky and J Hanson. 2007. Evolution of the plow over 10000 years and the rationale for no-till farming. Soil Tillage Res. **93**:1-12

Malla, G. 2008. Climate change and its impact on Nepalese agriculture: Review paper, Journal of Agriculture and Environment. **9**:62-71.

MoALD. 2020. Pulse Crops. **In:** Statistical information on Nepalese Agriculture 2075/76 (2018/19). Ministry of Agriculture and Livestock Development, Planning and Development Co-operation Co-ordination Division, Statistics and Analysis Section, Singhadurbar, Kathmandu, Nepal, **pp.**79-98.

Neupane RK and MP Bharati. 1993. Agronomy of lentil in Nepal. **In:** Lentil in South Asia. Proceedings of the Seminar on Lentil in South Asia (W Erskine and MC Saxena eds), (International Center for Agricultural Research in the Dry Areas, Aleppo, Syria), New Delhi, India, **pp.**139-145

Pittelkow CM, BA Linquist, ME Lundy, X Liang, KJvan Groenigen, J Lee, Nvan Gestel, J Six, RT Venterea and Cvan Kessel. 2015. When does no-till yield more? A global meta-analysis. Field Crops Research. **183**:156-168

Shrestha R. 1996. Effect of planting dates and seed rates on lentil (var. Simal) in Khumaltar. **In:** National Winter Crop Research Workshop held at Regional Agricultural Research Station, Bhairahawa, Nepal from Sept. 12-15, 1996

Shrestha R, RK Neupane and NP Adhikari. 2012. Status and future prospects of pulses in Nepal. **In:** Current Status and Future Prospect of Pulse Production in SAARC Countries, 24-25 October 2011, Kathmandu, Nepal. SAARC Agriculture Centre (SAC), Momin Offset Press, Dhaka, Bangladesh, ISBN 978-984-33-5402-0 pp.109-138.

Thakur, S.B. and G. Karki. 2018. Climate Change Impacts on Agriculture and Livestock in Nepal. The Journal of Agriculture and Environment. **19**:108-117.

Thapa Magar DB, D Gauchan and R Darai. 2014. Varietal adoption and marketing of lentil in the mid and far western terai region of Nepal. Adv Plants Agric Res **1(**5): 00026. DOI: 10.15406/apar