Soil Environ. 44(1): 53-67, 2025
DOI:doi.org/10.25252/SE/2025/253527
Online ISSN: 2075-1141
Print ISSN: 2074-9546

Tillage practices affect the soil health, water use efficiency and yield of lentil in hill torrent area of District Dera Ghazi Khan, Pakistan

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***[Received:** August 22, 2024* ***Accepted:** April 19, 2025* ***Published Online:** May 31, 2025]*

Abstract

Pre- and post-flood tillage practices were evaluated in field studies for their effects on soil health, soil water use and lentil productivity in the Mithawan hill torrent irrigated region at two sites in Dera Ghazi Khan, Punjab (Pakistan) for two consecutive years. Pre-flood tillage treatments included Mouldboard plough, Chisel plough, Disc plough, Cultivator and Farmers practice (left fallow). While post-flood tillage treatments comprised of Cultivator; Cultivator and rotavator. Soil moisture availability at flowering stage increased from 23.38% at 0-15 cm to 26.50% at 31-45 cm at site 1 during the first year. At site 2, the respective increase across increasing depth was 23.44% to 26.18%. Water productivity in chisel plough run fields as pre-flood treatment increased to 0.04 and 0.043 kg m^{-3} at site 1 and 2, respectively, during the first growing season.; however, the bulk density at site 1 reached 1.45 g cm^{-3} and 1.41 g cm^{-3} at site 1 and 1.44 g cm^{-3} and 1.42 g cm^{-3} at site 2. Moreover, soil EC and pH were reduced after the cultivation of lentil at both sites irrespective of the treatments employed. Seeds per pod (1.93), during the 1^{st} year (site 2); the heaviest 1000 grains (21.49g) during the 1^{st} year (site 2) and seed yield during 1^{st} year (420.7 and 456.3 kg ha^{-1}) and 2^{nd} year (91.1 and 73.0 kg ha^{-1}) at site 1 and 2, respectively, were highest in the chisel plough run plots of the field. The highest benefit cost ratios (1.2 and 1.4) were recorded from the same chisel plough run fields as pre-flood tillage practice followed by cultivator as post-flood tillage practice at site 1 and 2 during 2019-20, respectively. Farmers in Mithawan hill torrent command areas of Dera Ghazi Khan can have better soil moisture use for improved lentil productivity during reasonable soil water supplies. Moreover, because this area has been little researched for lentil hence more research is highly advocated for standardization of agronomic interventions besides development and provision of adaptable high yielding promising climate smart cultivars for the hill torrent hit ecologies.

Keywords: Hill torrent, lentil yield, pre and post-flood tillage, spate irrigation, water productivity

Introduction

Lentil (*Lens culinaris* L.) is an important member of family Fabaceae which has been under cultivation since 8500 years ago in the Middle East (Jat *et al*., 2013). It is the third largest cool season legume crop which accounted about 6% in global dry pulse production (Sehgal *et al*., 2021). Asia is the main region that contributes 52.3% of the global production followed by America (37.8%), Oceana (5.2%), Africa (3%), and Europe (1.7%). Canada is the world largest lentil producing country followed by India, Türkiye, Australia and USA. It is grown on an area of 9,540,000 hectares in Pakistan with the production of 4,861,000 tonnes (FAO, 2020). Less than 0.01 million ton of lentil was produced from around 0.018 million hectares area during 2017-18 (Ullah *et al*., 2020). Lentil is mainly grown in Punjab with 54.3% area followed by Khyber Pakhtunkhwa, Blochistan and Sindh with respective share of 29.9%, 8.6% and 7.2%. In Punjab, lentil is mainly grown in Rawalpindi, Chakwal, Narowal and Jehlum. While, Jaccobabad, Bajour and Nasirabad are major lentil producing regions of Sindh, Pakhtunkhwa and Blochistan, respectively (AMIS, 2014).

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Cite This Paper: Asif, M., K. Mubeen, M. Ahmad, A. Matloob and S. Ahmad. 2025. Tillage practices affect the soil health, water use efficiency and yield of lentil in hill torrent area of District Dera Ghazi Khan, Pakistan. 44(1): 53-67.

Floods originating from dry mountainous areas in the form of hill torrents are often considered as a problem. Recently in Pakistan, hill torrent floods have caused multi angle damages to humans, animals, other forms of life and infrastructure (Mubeen, 2022). Around 0.2 million acres of crops and fruit orchards in Punjab Pakistan were damaged as a result of these hill torrent floods (Mubeen and Veldman, 2022). However, the benefits these hill torrent flows offer have seldom been accounted for (Mubeen and Matloob, 2018).

There are about 200 hill torrents in Suleman range which extends mainly in Punjab and Blauchistan. The hill torrent in Punjab and Khyber Pakhtunkhwa is locally known as rodh Kohi, Nai in Sindh and called Bandit/Sailaba in Blauchistan. Hill torrents encompass about 65% of the total agricultural lands in entire Blauchistan (Nawaz and Han, 2008). Blauchistan has a higher share (55%) of hill torrents compared to Punjab with 45% hill torrents. There are 13 hill torrents in Dera Ghazi Khan and Rajan Pur, extending from Kaura to Suri Janobi. The catchment area of these hill torrents is 30772 Square kilometer which extends from Ramak to Kashmore (Ahmed *et al*., 2021). The term torrent is utilized for water carrier channels carrying flash water flows. The water flowing from hills in natural water channel is known as Rods (FAO, 2010). It is largest irrigation source through which about 23.16 km^{-3} water can be made available for irrigation (Asif and Islam-ul-Haque, 2014). It could be source of irrigation for 1.2-1.5 million hectares of Pachad area (Nawaz and Han, 2008; Qureshi *et al*., 2016). The water productivity of the hill torrent region is very low due to unpredictable flows (Ashraf *et al*., 2017).

The current yield in Pakistan is low in comparison with other lentil producing countries. The lentil cultivation is confined to marginalized lands which are not suitable for other crops. The lentil may survive in harsh environment, however, drought and heat stress at flowering stage may have drastic impacts on the yield. It is mainly grown in semi-arid regions without proper irrigation. It was estimated that 20-25 cm irrigation water and average rainfall is sufficient for a successful harvest (Samaranayaka, 2017). Since, the precipitation pattern is erratic and does not coincide with crop requirement, the lentil in rainfed conditions is subjected to frequent droughts during the growing season. There are no supplemental irrigation sources in hill torrents cultivation systems to meet the crop water requirement. The in situ moisture conservation is the only practical way to improve moisture supply to the crop. The optimal weather conditions for lentil sowing in Blauchistan are in October, while the rainy season is before October. In this case, the germination and subsequent growth is fully dependent on stored moisture in the soil (Ahmed, 2000). There, moisture conservation in the soil through deep tillage practices is one of the top priorities of rain fed agriculture (Ngigi *et al*., 2006).

The moisture conservation in the soil through tillage is very useful for reducing damages to the infrastructure and improving the moisture availability for the crops. The deep tillage operations increase the roughness of the soil surface which, in turn, reduces the velocities of the flash floods and increase the infiltration into the soil. The choice of tillage implement is very important because every tillage implement has specific tillage depth and ploughing mechanism. The shallow tillage promotes the water conservation near to the soil surface which is very prone to evaporation, especially in arid and semi-arid region. Usually, the higher tillage depth loosens the soil to greater depth and infiltration occurs to greater depth (Das *et al*., 2010, Sun *et al*., 2018). The deep tillage not only improves the volume of moisture conserved but also minimizes the moisture loss from evaporation. In this system, the emerging roots initially take up water near the soil surface. Later on, the roots grow downwards to deeper soil layers where moisture is available due to deep tillage. Therefore, deep tillage basically minimizes the occurrence of drought stress in rainfed regions. The variations in lentil yield as a result of tillage depth have been witnessed in literature (Altikat, 2013; Kiliç *et al*., 2015, Nandi *et al*., 2021). Two times Cultivator use before crop sowing under the agro normals of vidor hill torrent command area of Dera Ghazi Khan, Punjab, Pakistan resulted in better soil moisture availability, maximum chickpea seed yield and highest Benefit Cost Ratio (BCR) (Mubeen *et al*., 2023). It was shown by Nawaz *et al*. (2023) that 2 times Cultivator use before arugula crop sowing under the agro normals of Vidor hill torrent command area Dera Ghazi Khan reflected highest soil moisture conservation, siliquae per plant (106), seeds per siliquae (21), seed yield (570 kg ha^{-1}) and harvest index (32.92%).

The tillage depth regulates the volume of stored moisture in the soil through its impacts on various soil physical and chemical properties. The use of pre-flood tillage is not common among the farmers. We hypothesized that pre-and post-flood tillage implements vary with effect on soil bulk density, water productivity and lentil yield. To explore this we tested tillage implements through pre-and post-flood tillage to see how different combinations of pre- and post-flood tillage implements affect bulk density of the topsoil? We also wanted to explore that which pre-flood tillage implement results in the highest lentil yield and water productivity over farmer practice?. Moreover, studies were also carried out to explore pre-flood tillage in combination with post-flood tillage for better lentil yield and water productivity over farmer practice?

Materials and Methods

Pre-and post-flood tillage treatments

The experiment was comprised of pre-flood tillage treatment including PR1; Mouldboard plough (MBP), PR2; Chisel plough (CP), PR3; Disc plough (DP), PR4; Cultivator (Cult.) and PR5; Farmers practice (left fallow) (FP). It was followed by post-flood tillage treatments with Cultivator (PS1), Cultivator and rotavator (PS2). The experiment was conducted during the rabi season 2019-20 and 2020-21 at two selected locations in Mithawan hill torrent irrigated areas of DG Khan. Net plot area was 45 m long and 15 m wide which was harvested at maturity. The experiment was laid out in randomized complete block design (RCBD) with split block arrangement in triplicate. The pre-flood tillage treatments were kept in main plots and post-flood tillage treatments were assigned to sub-plots. Pre and post-flood tillage practices were performed before sowing of crop by dividing field into five blocks in which vertical strips were maintained for pre-flood tillage. Whereas the post-flood tillage was done prior to sowing during seedbed preparation where two horizontal strips were maintained for post-flood tillage. Water was measured after the hill torrent water diversion into dyke surrounded sites with 5 feet of ponded water depth.

Crop husbandry

Pre-flood tillage at both the sites was performed on 17th July, 2019 and 18th July, 2020 during both the years. Hill torrent flood was received on 10th August, 2019 at both the sites for first year field trial. Whereas during 2nd year field trial site 1 called "pangray wala" received hill torrent flood water on 27th July, 2020 and site 2 field called "waaray wala" received hill torrent flood water on 29th July, 2020. Later on, respective fields date of post-flood tillage employed also varied across years. During first year i.e. 2019 at both the sites post-flood tillage practices were carried out on 28th September, 2019 whereas in 2nd year of trial on 09th October, 2020. Tested implements i.e. mouldboard plough (20 cm), disc plough (30 cm), chisel plough (45-50 cm), cultivator (15-20 cm) and rotavator (10-15 cm) had variable approximate working depths. The crop was sown during the 2nd week of October during rabi season 2019-20 and 2020-21 through drilling machine with 30 cm line to line distance. The seed rate was 20 kg ha^{-1}. Pre-flood tillage was done before the reception of hill torrents floods in the field by dividing into 5 vertical blocks. In each block tillage implement like Mould board plough(MBP), Chisel plough (CP), Disc plough (DP) and Rotavator were run whereas the 5th block was left fallow as per farmer's practices for comparison and no tillage implement was applied. After the reception of floods in the fields, two horizontal blocks were marked. In one horizontal block, cultivator was run, whereas in the other block cultivator+ rotavator were used as post-flood tillage treatment followed by crop sowing. All the other agronomic practices were kept normal and uniform for all the treatments.

Observations recorded

The bulk density was measured through core method as laid out by Rai (2015). In this procedure, two smooth, barren and crack free places were selected. The lubricant was used on internal wall of core sample cylinder. The soil sample from desired depth was taken and sampler was lifted and carried without any jerk. The excess of the soil was trimmed with straight edged knife to get the exact volume. The sample was removed from sample holder. The sample was sealed in moisture box and shifted to laboratory where it was dried at 105°C till constant weight. The following equation was used

$$Bulk\ density = \frac{Oven\ dry\ weight\ of\ soil\ sample\ (kg)}{Volume\ of\ soil\ sample\ (m3)}$$

Chlorophyll contents of lentil crop plants were measured by using SPAD 502 plus Chlorophyll meter at 60 and 90 days after sowing. Randomly five lines of each crop were selected and reading was taken to determine the chlorophyll contents. The soil samples were collected before sowing and after harvesting for each site across years for assessment of EC, pH, organic matter, total nitrogen, available phosphorus and extractable potassium.

Water productivity (WP) was measured with following formula proposed by Zwart and Bastiaanssen (2004)

$$WP = \frac{Economic\ yield\ (kg)}{Water\ used\ in\ irrigation\ (m3)}$$

WP shows the water productivity and is expressed in kg m^{-3}.

Data for soil moisture % at flowering was recorded using gravimetric method. Number of functional nodules, yield parameters like number of seeds per pod, 1000 grains weight, seed yield were recorded as per standard procedures.

Statistical and Economic analyses

Data obtained were analyzed by using analysis of variance (ANOVA) techniques through use of computer-based program Statistix 8.1. For mean separation, Tukey's HSD was applied at 5% level of significance (Steel *et al.*, 1997). Moreover BCR and net income were also worked out.

Table 1: Physico-chemical properties of the soil from lentil field

Parameters	2019-20			
	Site 1		Site 2	
	Before sowing	After harvest	Before sowing	After harvest
Soil texture	Clayey			
EC (dS m^{-1})	1 .29	1.27	1.24	1.23
pH	7.81	7.80	7.76	7.74
OM (%)	0.37	0.36	0.43	0.41
Total Nitrogen (mg kg^{-1})	0.017	0.016	0.021	0.023
Available P (mg kg^{-1}	5.16	5.15	5.81	5.80
Extractable K (mg kg^{-1})	193	198	216	214
	2020-21			
EC (dS m^{-1})	1.25	1.24	1.25	1.23
pH	7.82	7.80	7.74	7.73
OM (%)	0.37	0.36	0.44	0.0.43
Total Nitrogen (mg kg^{-1})	0.018	0.017	0.024	0.023
Available P (mg kg^{-1})	5.19	5.17	5.83	5.81
Extractable K (mg kg^{-1})	195	201	216	215

Table 2: Effect of various pre and post-flood tillage practices on bulk density (g/cm^3) in the top soil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20			2020-21		
	Site 1					
	Post-Flood Tillage		Means	Post-Flood Tillage		Means
	Cultivator	Cultivator and Rotavator		Cultivator	Cultivator and Rotavator	
MB plough	1.49	1.48	1.49	1.45	1.43	1.44
Disc plough	1.50	1.48	1.49	1.45	1.43	1.44
Chisel plough	1.45	1.45	1.45	1.42	1.40	1.41
Cultivator	1.51	1.50	1.51	1.47	1.45	1.46
Farmer Practice	1.51	1.49	1.50	1.50	1.49	1.49
Means	1.49	1.48		1.45	1.44	
Tukey's HSD	Pre-flood = ns	Post-flood = ns	Interaction = ns	Pre-flood = ns	Post-flood = ns	Interaction = ns
	Site 2					
MB plough	1.46	1.49	1.47	1.42	1.42	1.42 b
Disc plough	1.47	1.48	1.48	1.42	1.41	1.42 b
Chisel plough	1.43	1.46	1.44	1.42	1.41	1.42 b
Cultivator	1.50	1.51	1.50	1.47	1.46	1.47 a
Farmer Practice	1.52	1.49	1.51	1.50	1.48	1.49 a
Means	1.47	1.48		1.45	1.44	
Tukey's HSD	Pre-flood = ns	Post-flood = ns	Interaction = ns	Pre-flood = 0.027	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

Results

Effect on soil physico-chemical properties

After 2 years of field studies, the data presented in Table 3 revealed that EC and pH were reduced after the cultivation of lentil at both the sites. However, an increase in organic matter, total nitrogen, available phosphorus, extractable potassium could not vary significantly at both sites (Table 1).

Bulk density

The data pertaining to impact of pre and post-flood tillage treatments and their interactions on bulk density is presented in Table 2. Soil bulk density was not significantly affected by the tillage treatments; however, pre-flood tillage showed significant effect at site 2 during 2020-21. The MBP, DP and CP resulted the lowest and similar values of the bulk density with each other. The highest values of the bulk density were achieved from farmer practices followed by rotavator application. Both the treatments i.e. farmer practice and rotavator application produced statistically similar value of the bulk density with each other. The bulk density values varied from 1.45 to 1.51 and 1.44 to 1.51 for site 1 and site 2, respectively, during 2019-20. The respective ranges for the second year were 1.41 to 1.49 and 1.42 to 1.49 at site 1 and 2, respectively. The differences in the bulk density due to pre-flood tillage were greater than the post-flood tillage treatments. The interactive effects of the pre and post-flood tillage treatments were statistically non-significant irrespective of experimental year and sites. Like other parameters, the values of the bulk density were relatively greater in the 2019-20 in comparison with the 2020-21.

Table 3a: Effect of various pre and post-flood tillage on soil moisture contents (%) at various depths during 2019-20 at lentil flowering

Treatments	2019-20					
	Site 1			Site 2		
	Soil Depth (cm)					
	0-15	16-30	31-45	0-15	16-30	31-45
Pre-flood tillage (PR)						
M.B plough (PR1)	20.77 ab	23.85 ab	26.37 a	21.73 ab	22.54 ab	25.65 a
Disc plough (PR2)	19.49 ab	21.72 ab	24.27 ab	19.99 b	20.20 ab	22.82 ab
Chisel plough (PR3)	23.38 a	24.93 a	26.50 a	23.44 a	24.20 a	26.18 a
Cultivator (PR4)	18.35 b	20.63 ab	23.21 ab	19.26 b	19.94 b	22.04 ab
Farmer practice (PR5)	17.42 b	19.20 b	21.20 b	18.37 b	18.79 b	20.48 b
Tukey's HSD	4.51	5.48	3.83	3.39	4.16	5.01
Post-flood tillage (PS)						
Cult. (PS1)	19.78	21.85	23.74	20.52	20.86	23.30
PS2 (PS2)	19.98	22.28	24.87	20.59	21.41	23.56
Tukey's HSD	ns	ns	ns	ns	ns	ns
Interaction						
PR1 × PS 1	20.53	23.98	25.89	21.40	22.54	25.14
PR1 × PS 2	21.02	23.71	26.84	22.06	22.54	26.15
PR2 × PS 1	19.34	21.88	23.69	19.98	19.55	22.75
PR2 × PS 2	19.64	21.56	24.85	20.00	20.85	22.88
PR3 × PS 1	23.42	24.15	25.00	23.41	23.89	26.07
PR3 × PS 2	23.35	25.72	28.00	23.47	24.50	26.30
PR4 × PS 1	18.55	20.35	23.23	19.51	19.82	22.20
PR4 × PS 2	18.15	20.92	23.19	19.00	20.06	21.89
PR5 × PS 1	17.08	18.90	20.92	18.32	18.49	20.36
PR5 × PS 2	17.76	19.50	21.47	18.42	19.09	20.59
Tukey's HSD	ns	ns	ns	ns	ns	ns

Values represented by different letters differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

Soil moisture content at flowering stage

At flowering, the highest moisture contents were recorded from the CP application as pre-flood tillage treatment followed by tillage with M.B plough. The lowest soil moisture was obtained from the FP. The impact of post-flood tillage and interactive effects of pre and post-flood tillage was non-significant on soil moisture contents. The trend was consistent for all the soil depth and both the experimental sites during the first growing season (Table 3a). The data presented in Table 3b demonstrated the highest values from CP and lowest from the FP during the second year of experiment. Like the first-year results, the post-flood tillage and interaction between pre and post-flood tillage did not produce statistically significant variation in soil moisture contents irrespective of the soil depth and experimental sites.

Table 3b: Effect of various pre and post-flood tillage on soil moisture contents (%) at various depths during 2020-21 at lentil flowering

Treatments	2020-21					
	Site 1			Site 2		
	Soil Depth (cm)					
	0-15	16-30	31-45	0-15	16-30	31-45
Pre-flood tillage (PR)						
M.B plough (PR1)	16.07 ab	18.57 a	20.40 a	16.07 ab	18.69 ab	20.54 a
Disc plough (PR2)	14.23 ab	15.08 ab	16.88 b	14.96 b	14.55 b	16.96 b
Chisel plough (PR3)	18.40 a	19.56 a	20.49 a	18.98 a	20.44 a	21.12 a
Cultivator (PR4)	13.71 ab	14.91 ab	16.48 b	14.29 b	14.93 b	16.89 b
Farmer practice (PR5)	12.35 b	13.63 b	14.20 b	12.71 b	14.22 b	15.38 b
Tukey's HSD	5.19	5.85	3.00	3.90	4.53	2.95
Post-flood tillage (PS)						
Cultivator (PS1)	14.74	16.02	17.37	15.11	16.51	18.06
Cultivator and Rotavator (PS2)	15.16	16.67	18.02	15.69	16.62	18.29
Tukey's HSD	ns	ns	ns	ns	ns	ns
Interaction						
PR1 × PS 1	15.74	18.12	19.89	15.40	18.65	20.53
PR1 × PS 2	16.39	19.01	20.91	16.74	18.72	20.55
PR2 × PS 1	13.88	14.93	16.40	14.84	14.55	16.91
PR2 × PS 2	14.58	15.22	17.36	15.09	14.56	17.02
PR3 × PS 1	18.24	19.12	20.01	18.67	20.43	20.96
PR3 × PS 2	18.56	20.00	20.97	19.29	20.44	21.27
PR4 × PS 1	13.86	14.28	16.37	13.97	14.93	16.67
PR4 × PS 2	13.56	15.54	16.59	14.62	14.93	17.11
PR5 × PS 1	11.98	13.65	14.15	12.69	13.98	15.24
PR5 × PS 2	12.72	13.61	14.24	12.72	14.45	15.52
Tukey's HSD	ns	ns	ns	ns	ns	ns

Values represented by different letters differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

Water productivity

The water productivity was significantly affected by the pre-flood tillage treatments (Table 4). The CP significantly resulted in the highest water productivity over all pre-flood treatments at experimental sites during both the years. The tillage with rotavator produced statistically similar values for water productivity with farmer's practice for both the experimental sites and years. The variations in the water productivity were also non-significant between MBP and DP. The influence of post-flood tillage was also non-significant for the water productivity. Moreover, the interactive effects of pre and post-flood tillage were also non-significant.

Chlorophyll contents at 60 and 90 DAS

The data on impact of pre-flood tillage practices on chlorophyll revealed significant differences for the year 2020-21 for both the sites. The variations in chlorophyll contents at 60 days ranged from 27.87 to 35.37 for site 1 and 26.97 to 37.78 for site 2 during 2019-20. However, these variations were statistically non-significant. The variations in chlorophyll contents due to post-flood tillage were minor and statistically non-significant during both the years at both experimental sites. The maximum values of chlorophyll contents were achieved in CP treatment during 2020-21 at both the experimental sites. While, the lowest chlorophyll contents were recorded where rotavator was applied as pre-flood tillage. The chlorophyll contents recorded from CP were statistically similar with DP. Likewise, chlorophyll contents in rotavator were statistically similar to both the MBP and farmer's practices adopted fields. None of the post-flood tillage and interaction between pre and post-flood tillage treatments significantly affected the chlorophyll contents at both the sites during both the years. On overall basis, the chlorophyll values during 2020-21 were relatively smaller than 2019-20 (Table 7).

Table 4: Effect of various pre and post-flood tillage practices on water productivity of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20			2020-21		
	Site 1					
	Post-Flood Tillage		Means	Post-Flood Tillage		Means
	Cultivator	Cultivator and Rotavator		Cultivator	Cultivator and Rotavator	
MB plough	0.033	0.035	0.034 b	0.006	0.006	0.006 b
Disc plough	0.031	0.032	0.032 bc	0.006	0.005	0.005 bc
Chisel plough	0.040	0.040	0.040 a	0.008	0.009	0.009 a
Cultivator	0.027	0.028	0.028 cd	0.005	0.005	0.005 cd
Farmer Practice	0.028	0.028	0.028 d	0.004	0.004	0.004 d
Means	0.032	0.033		0.006	0.006	
Tukey's HSD	Pre-flood = 0.0042	Post-flood = ns	Interaction = ns	Pre-flood = 0.0013	Post-flood = ns	Interaction = ns
			Site 2			
MB plough	0.037	0.037	0.037 b	0.006	0.006	0.006 b
Disc plough	0.033	0.035	0.034 b	0.005	0.005	0.005 b
Chisel plough	0.043	0.044	0.043 a	0.007	0.007	0.007 a
Cultivator	0.030	0.030	0.030 c	0.004	0.004	0.004 c
Farmer Practice	0.028	0.027	0.028 c	0.003	0.004	0.003 c
Means	0.034	0.035		0.005	0.005	
Tukey's HSD	Pre-flood = 0.0039	Post-flood = ns	Interaction = ns	Pre-flood = 0.00061	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

Table 5a: Effect of various pre and post-flood tillage practices on chlorophyll contents at 60 days after sowing of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20			2020-21		
	Site 1					
	Post-Flood Tillage		Means	Post-Flood Tillage		Means
	Cultivator	Cultivator and Rotavator		Cultivator	Cultivator and Rotavator	
MB plough	27.40	31.53	29.47	26.73	31.20	28.97 abc
Disc plough	30.57	29.00	29.78	29.57	30.67	30.12 ab
Chisel plough	33.74	37.00	35.37	32.74	33.67	33.20 a
Cultivator	26.90	28.83	27.87	23.57	24.17	23.87 c
Farmer Practice	29.27	30.30	29.78	26.60	29.30	27.95 bc
Means	29.57	31.33		27.84	29.80	
Tukey's HSD	Pre-flood = ns	Post-flood = ns	Interaction = ns	Pre-flood = 5.25	Post-flood = ns	Interaction = ns
			Site 2			
MB plough	29.87	35.40	32.63	26.80	29.17	27.98 bc
Disc plough	33.87	29.27	31.57	31.27	30.73	31.00 ab
Chisel plough	37.80	37.77	37.78	34.33	36.50	35.42 a
Cultivator	27.23	26.70	26.97	24.40	24.50	24.45 c
Farmer Practice	33.47	26.27	29.87	28.20	26.90	27.55 bc
Means	32.45	31.08		29.00	29.56	
Tukey's HSD	Pre-flood = ns	Post-flood = ns	Interaction = ns	Pre-flood = 5.72	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

Table 5b: Effect of various pre and post-flood tillage practices on chlorophyll contents at 90 days after sowing of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20			2020-21		
	Site 1					
	Post-Flood Tillage		Means	Post-Flood Tillage		Means
	Cultivator	Cultivator and Rotavator		Cultivator	Cultivator and Rotavator	
MB plough	37.73	41.53	39.63	35.73	39.53	37.63
Disc plough	40.57	41.67	41.12	38.23	39.00	38.62
Chisel plough	46.33	47.00	46.67	42.33	42.33	42.33
Cultivator	36.90	39.83	38.37	33.57	36.50	35.03
Farmer Practice	38.27	38.63	38.45	34.93	35.30	35.12
Means	39.96	41.73		36.96	38.53	
Tukey's HSD	Pre-flood = ns	Post-flood = ns	Interaction = ns	Pre-flood = ns	Post-flood = ns	Interaction = ns
			Site 2			
MB plough	42.67	43.67	43.17	34.67	36.63	35.65 b
Disc plough	43.07	42.67	42.87	37.40	36.00	36.70 b
Chisel plough	49.00	49.97	49.48	43.40	43.00	43.20 a
Cultivator	38.33	39.80	39.07	32.87	37.67	35.27 b
Farmer Practice	39.93	40.67	40.30	37.53	36.30	36.92 b
Means	42.60	43.35		37.17	37.92	
Tukey's HSD	Pre-flood = ns	Post-flood = ns	Interaction = ns	Pre-flood = 4.92	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

The variations in chlorophyll contents at 90 days revealed non-significant impact of post-flood tillage at both experimental sites during both the years. However, the pre-flood tillage treatments resulted in significant variation in 2020-21 at site 2 only. The variations in chlorophyll contents due to pre-flood tillage treatments ranged between 38.37 to 46.67 and 39.07 to 49.48 for site 1 and site 2 during the year 2019-20, respectively. The respective variations for the second year were 35.03 to 42. 33 and 35.27 to 43.20, respectively. The differences in chlorophyll contents due to post-flood tillage ranged from 39.96 to 41.73 for site 1 and 42.60 to 43.35 for site 2 during 2019-20. The respective ranges of chlorophyll contents for the second year were 36.96 to 38.53 and 37.17 to 37.92 for site 1 and site 2, respectively. The maximum chlorophyll values in 2020-21 at site 2 were recorded from CP run fields out of pre-flood treatments; whereas, the rest of pre-flood treatments did not result significantly higher values over farmer practice. The interaction between pre and post-flood tillage treatments revealed non-significant values of chlorophyll. Among the years, the year 2019-20 had higher chlorophyll values than 2020-21 (Table 5a and 5b).

Number of functional nodules

The data on the number of functional nodules revealed the significant impact of the pre-flood tillage treatments irrespective of experimental sites and years (Table 6). The CP exceeded all the pre-flood tillage treatments for the number of the functional nodules and the trend have been consistent during both the years and experimental sites. During 2019-20, the CP run fields produced statistically similar number of functional nodules with MBP run fields at site 1. Similar results were recorded during 2020-21 at site 2. However, during 2020-21, the CP treatments had statistically similar number of the functional nodules with DP treatments at site 1 and significantly different from MB plough run fields. Except CP, none of the pre-flood tillage treatments resulted statistically higher values over farmer practice at both the sites during 2019-20. The similar was the case at both sites during 2020-21. The impact of post-flood tillage and interaction between pre and post-flood tillage had been non-significant for the number of functional nodules. Out of the years, the highest number of functional nodules were recorded during 2019-20 as compared to the year 2020-21.

Number of branches per plant

The data given in Table 7 highlighted that the effect of pre-flood tillage on number of branches per plant was significant for both the sites during 2019-20. While, it remained significant only for site 2 during 2020-21. Among the pre-flood tillage treatments, the maximum number of branches per plant were achieved from the CP treatment. However, it was statistically at par with plants of plot where MB Plough and DP were run at both the sites during first year. The minimum number of branches were recorded in FP. In 2019-20, the CP did not statistically exceed the DP and MBP. Similarly, the use of rotavator produced statistically similar number of branches with farmer’s practices at both sites for first year of study. During 2020-21, none of pre-flood tillage treatments except CP differed significantly with each other for site 2. Moreover, the number of branches per plant recorded for CP was statistically similar with MBP during 2020-21 at site 2. The effect of post-flood tillage was not significant irrespective of experimental year and site. The interaction between pre and post-flood tillage remained non-significant for number of branches per plant throughout the experiment.

Number of pods per plant

The data pertaining the number of pods per plant is presented in Table 8. It showed significant impact of pre-flood tillage treatments only for site 1 during 2019-20. The maximum values were recorded from CP treatment. While the differences between MBP, DP and rotavator were statistically non-significant. Except CP, none of the pre-flood treatments produced statistically higher number of pods per plant over farmer practice. The trait was not influenced by the post-flood tillage treatments. The impact of post-flood tillage and interaction between pre and post-flood tillage remained non-significant for both the years and experimental sites. During the second year, the number of pods per plant were about four times less in comparison with the first year.

Number of grains per pod

The Table 9 revealed significant impact of pre-flood treatments on number of grains per pods during both the years for site 1. There were significant differences for site 2 during 2019-20. The CP application produced significantly higher number of grains per pod than all other pre-flood treatments at site 1 and site 2 during 2019-20. However, it produced statistically similar values with the MBP during 2020-21 at site 1. The differences in the number of grains per pod were statistically non-significant between MBP and DP. The use of rotavator as pre-flood tillage did not exceed the farmer practices for the number of grains per pods. The post-flood tillage treatments and interactive effects of pre and post-flood tillage did not result in significant variations in number of grains per pods irrespective of experimental site or year.

Table 6: Effect of various pre and post-flood tillage practices on number of functional nodules of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20			2020-21		
	Site 1					
	Post-flood Tillage			Post-flood Tillage		
	Cultivator	Cultivator and Rotavator	Means	Cultivator	Cultivator and Rotavator	Means
MB plough	5.17	5.53	5.35 a	1.90	2.03	1.97 b
Disc plough	3.93	4.37	4.15 b	2.30	2.85	2.58 ab
Chisel plough	6.30	5.53	5.92 a	2.90	3.50	3.20 a
Cultivator	4.48	4.53	4.51 b	2.63	2.23	2.43 b
Farmer Practice	3.77	3.87	3.82 b	2.30	1.83	2.07 b
Means	4.73	4.77		2.41	2.49	
Tukey's HSD	Pre-flood = 0.83	Post-flood = ns	Interaction = ns	Pre-flood = 0.69	Post-flood = ns	Interaction = ns
	Site 2					
MB plough	4.17	5.03	4.60 b	2.17	1.83	2.00 ab
Disc plough	4.57	5.00	4.78 b	1.73	1.73	1.73 bc
Chisel plough	6.23	6.20	6.22 a	2.23	2.40	2.32 a
Cultivator	4.97	4.57	4.77 b	1.80	1.60	1.70 bc
Farmer Practice	4.30	4.90	4.60 b	1.53	1.43	1.48 c
Means	4.85	5.14		1.89	1.80	
Tukey's HSD	Pre-flood = 1.07	Post-flood = ns	Interaction = ns	Pre-flood = 0.42	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

Table 7: Effect of various pre and post-flood tillage practices on number of branches per plant of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20			2020-21		
	Site 1					
	Post-Flood Tillage			Post-Flood Tillage		
	Cultivator	Cultivator and Rotavator	Means	Cultivator	Cultivator and Rotavator	Means
MB plough	13.11	13.14	13.13 abc	5.11	5.48	5.30
Disc plough	12.65	13.82	13.24 ab	4.72	5.09	4.91
Chisel plough	15.34	15.59	15.46 a	5.50	6.19	5.85
Cultivator	11.57	11.87	11.72 bc	5.24	5.20	5.22
Farmer Practice	10.32	10.70	10.51 c	4.99	4.43	4.71
Means	12.60	13.02		5.11	5.28	
Tukey's HSD	Pre-flood = 2.651	Post-flood = ns	Interaction = ns	Pre-flood = ns	Post-flood = ns	Interaction = ns
	Site 2					
MB plough	14.19	13.99	14.09 a	4.72	5.12	4.92 ab
Disc plough	13.70	14.06	13.88 a	4.70	4.16	4.43 b
Chisel plough	15.47	15.13	15.30 a	5.47	6.13	5.80 a
Cultivator	11.76	11.29	11.53 b	4.89	3.96	4.43 b
Farmer Practice	11.93	11.76	11.84 b	3.60	4.42	4.01 b
Means	13.41	13.25		4.68	4.76	
Tukey's HSD	Pre-flood = 1.697	Post-flood = ns	Interaction = ns	Pre-flood = 1.035	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

Table 8: Effect of various pre and post-flood tillage practices on number of pods per plant of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20			2020-21		
	Site 1					
	Post-Flood Tillage			Post-Flood Tillage		
	Cultivator	Cultivator and Rotavator	Means	Cultivator	Cultivator and Rotavator	Means
MB plough	50.89	54.32	52.61 b	12.56	12.99	12.77
Disc plough	51.68	54.15	52.92 b	13.51	12.49	13.00
Chisel plough	58.31	59.16	58.74 a	12.98	13.50	13.24
Cultivator	49.10	52.89	50.99 b	10.76	11.56	11.16
Farmer Practice	49.55	49.62	49.59 b	10.22	9.62	9.92
Means	51.91	54.03		12.01	12.03	
Tukey's HSD	Pre-flood = 4.429	Post-flood = ns	Interaction = ns	Pre-flood = ns	Post-flood = ns	Interaction = ns
	Site 2					
MB plough	50.22	49.41	49.82	9.89	9.77	9.83
Disc plough	50.56	50.07	50.32	9.46	10.00	9.73
Chisel plough	53.48	55.15	54.32	10.82	10.15	10.48
Cultivator	50.80	46.62	48.71	8.14	9.62	8.88
Farmer Practice	50.30	49.92	50.11	9.96	9.92	9.94
Means	51.07	50.23		9.65	9.89	
Tukey's HSD	Pre-flood = ns	Post-flood = ns	Interaction = ns	Pre-flood = ns	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

Table 9: Effect of various pre and post-flood tillage practices on number of grains per pod of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20 Post-Flood Tillage: Cultivator	Cultivator and Rotavator	Means	2020-21 Post-Flood Tillage: Cultivator	Cultivator and Rotavator	Means
Site 1						
MB plough	1.75	1.74	1.75 b	1.55	1.57	1.56 ab
Disc plough	1.69	1.70	1.70 bc	1.45	1.57	1.51 b
Chisel plough	1.89	1.90	1.90 a	1.69	1.63	1.66 a
Cultivator	1.69	1.63	1.66 cd	1.55	1.43	1.49 b
Farmer Practice	1.60	1.62	1.61 d	1.55	1.47	1.51 b
Means	1.72	1.72		1.56	1.54	
Tukey's HSD	Pre-flood = 0.067	Post-flood = ns	Interaction = ns	Pre-flood = 0.109	Post-flood = ns	Interaction = ns
Site 2						
MB plough	1.78	1.79	1.78 b	1.54	1.57	1.56
Disc plough	1.69	1.74	1.72 bc	1.53	1.52	1.53
Chisel plough	1.93	1.93	1.93 a	1.61	1.65	1.63
Cultivator	1.71	1.70	1.71 bc	1.55	1.57	1.56
Farmer Practice	1.66	1.65	1.66 c	1.51	1.54	1.52
Means	1.76	1.76		1.55	1.57	
Tukey's HSD	Pre-flood = 0.110	Post-flood = ns	Interaction = ns	Pre-flood = ns	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

Table 10: Effect of various pre and post-flood tillage practices on 1000 grains weight (g) of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20 Post-Flood Tillage: Cultivator	Cultivator and Rotavator	Means	2020-21 Post-Flood Tillage: Cultivator	Cultivator and Rotavator	Means
Site 1						
MB plough	18.85	19.99	19.42	13.38	14.66	14.02
Disc plough	18.58	18.49	18.54	14.25	14.59	14.42
Chisel plough	21.23	21.31	21.27	15.63	15.41	15.52
Cultivator	18.66	18.35	18.51	13.66	13.35	13.51
Farmer Practice	17.43	18.19	17.81	13.43	13.26	13.35
Means	18.95	19.27		14.07	14.25	
Tuckey's HSD	Pre-flood = ns	Post-flood = ns	Interaction = ns	Pre-flood = ns	Post-flood = ns	Interaction = ns
Site 2						
MB plough	19.71	19.63	19.67	12.57	13.43	13.00 b
Disc plough	19.08	19.00	19.04	12.95	13.56	13.26 ab
Chisel plough	21.79	21.19	21.49	14.45	14.59	14.52 a
Cultivator	19.12	19.34	19.23	12.79	12.91	12.85 b
Farmer Practice	18.31	18.25	18.28	11.94	11.92	11.93 b
Means	19.60	19.48		12.94	13.28	
Tukey's HSD	Pre-flood = ns	Post-flood = ns	Interaction = ns	Pre-flood = 1.409	Post-flood = ns	Interaction = ns

Values represented by different letters differed significantly at 5% probability level using Tuckey's HSD test
ns = Non-significant

Table 11: Effect of various pre and post-flood tillage practices on biological yield (kg ha^{-1}) of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20 Post-Flood Tillage: Cultivator	Cultivator and Rotavator	Means	2020-21 Post-Flood Tillage: Cultivator	Cultivator and Rotavator	Means
Site 1						
MB plough	1252.86	1271.68	1262.27 b	195.02	201.02	198.02 b
Disc plough	1199.48	1230.95	1215.22 b	181.48	165.64	173.56 bc
Chisel plough	1530.95	1533.49	1532.22 a	246.62	284.15	265.39 a
Cultivator	1007.95	1078.81	1043.38 c	147.95	145.48	146.72 cd
Farmer Practice	1087.62	1089.93	1088.77 c	127.62	123.26	125.44 d
Means	1215.77	1240.97		179.74	183.91	
Tukey's HSD	Pre-flood = 115.22	Post-flood = ns	Interaction = ns	Pre-flood = 31.22	Post-flood = ns	Interaction = ns
Site 2						
MB plough	1402.88	1476.37	1439.63 b	196.21	193.04	194.63 b
Disc plough	1376.54	1416.07	1396.30 bc	196.87	193.40	195.14 b
Chisel plough	1590.46	1609.48	1599.97 a	225.46	232.81	229.14 a
Cultivator	1315.62	1325.58	1320.60 c	151.28	148.92	150.10 c
Farmer Practice	1149.33	1165.33	1157.33 d	132.67	121.99	127.33 c
Means	1366.97	1398.57		180.50	178.03	
Tukey's HSD	Pre-flood = 114.43	Post-flood = ns	Interaction = ns	Pre-flood = 23.543	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

1000-grains weight

None of the treatments factors either pre-flood tillage, post-flood tillage or their interaction resulted in significant variations for 1000 grains weight. The highest 1000 grains weight in pre-flood tillage treatments was recorded with CP in 2019-20 for site 1 and site 2. The similar trend was also confirmed during 2020-21 for both the sites. All the pre-flood tillage treatments resulted in heavier 1000 grains over Farmer practice. The variations due to pre-flood tillage treatments were higher compared to the differences in 1000 grains weight due to post-flood tillage treatments (Table 10).

Biological yield

The data on biological yield (Table 11) highlighted significant effect of pre-flood tillage for both years at all locations. It was observed that the highest biological yield was recorded in CP tillage and lowest values were obtained from FP among all pre-flood tillage treatments. Both the MBP and DP produced statistically similar values of biological yield overall years and sites. The use of rotavator as pre-flood treatment did not improve biological yield significantly over FP for site 1 during both the years. The impact of post-flood tillage treatments on biological yield

Table 12: Effect of various pre and post-flood tillage practices on grains yield (kg ha^{-1}) of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20			2020-21		
	Site 1					
	Post-Flood Tillage		Means	Post-Flood Tillage		Means
	Cultivator	Cultivator and Rotavator		Cultivator	Cultivator and Rotavator	
MB plough	348.33	370.88	359.60 b	64.99	66.21	65.60 b
Disc plough	326.46	338.93	332.70 bc	59.80	55.60	57.70 bc
Chisel plough	416.24	425.24	420.74 a	86.24	95.91	91.08 a
Cultivator	285.55	297.27	291.41 c	47.27	50.60	48.94 cd
Farmer Practice	291.06	293.60	292.33 c	41.06	39.60	40.33 d
Means	333.53	345.18		59.87	61.58	
Tukey's HSD	Pre-flood = 45.137	Post-flood = ns	Interaction = ns	Pre-flood = 14.322	Post-flood = ns	Interaction = ns
	Site 2					
MB plough	387.84	388.08	387.96 b	61.17	59.08	60.13 b
Disc plough	349.12	368.56	358.84 b	57.45	56.56	57.00 b
Chisel plough	453.48	459.21	456.34 a	73.14	72.87	73.01 a
Cultivator	312.95	319.03	315.99 c	42.28	38.36	40.32 c
Farmer Practice	290.91	288.26	289.59 c	36.25	36.93	36.59 c
Means	358.86	364.63		54.06	52.76	
Tukey's HSD	Pre-flood = 40.875	Post-flood = ns	Interaction = ns	Pre-flood = 5.682	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

Table 13: Effect of various pre and post-flood tillage practices on harvest index (%) of lentil during 2019-20 and 2020-21 at site 1 and site 2

Pre-flood Tillage	2019-20			2020-21		
	Site 1					
	Post-Flood Tillage		Means	Post-Flood Tillage		Means
	Cultivator	Cultivator and Rotavator		Cultivator	Cultivator and Rotavator	
MB plough	27.74	29.16	28.45	33.40	33.05	33.23
Disc plough	27.20	27.58	27.39	33.02	33.52	33.27
Chisel plough	27.14	27.67	27.41	35.03	33.66	34.34
Cultivator	28.32	27.68	28.00	33.24	36.03	34.64
Farmer Practice	26.81	26.92	26.86	32.60	32.12	32.36
Means	27.44	27.80		33.46	33.68	
Tukey's HSD	Pre-flood = ns	Post-flood = ns	Interaction = ns	Pre-flood = ns	Post-flood = ns	Interaction = ns
	Site 2					
MB plough	27.65	26.33	26.99 ab	31.20	30.55	30.87
Disc plough	25.38	26.04	25.71 bc	29.17	29.27	29.22
Chisel plough	28.50	28.72	28.61 a	32.77	32.10	32.43
Cultivator	23.81	24.06	23.93 c	28.00	27.10	27.55
Farmer Practice	25.44	24.76	25.10 bc	27.39	30.48	28.94
Means	26.16	25.98		29.71	29.90	
Tukey's HSD	Pre-flood = 2.064	Post-flood = ns	Interaction = ns	Pre-flood = ns	Post-flood = ns	Interaction = ns

Values represented by different letters in the table differed significantly at 5% probability level using Tukey's HSD test
ns = Non-significant

was not significant. The interaction between pre-flood and post-flood tillage treatments also remained non-significant during both the years. The values of lentil biological yield were about six times less in 2020-21 in comparison with 2019-20.

Grain yield

The data pertaining to grain yield across various pre-flood and post-flood tillage practices is presented in Table 12. Grain yield varied significantly among the pre-flood tillage treatments, being maximum with CP and minimum in farmer's practice. The grain yield did not differ significantly between MBP and DP run fields. All the pre-flood tillage practices resulted in a significant increase in grain yield compared to farmer's practice except with the rotavator run fields which produced statistically similar grains yield with farmer's practices. The combination of PS2 as post-flood tillage resulted in higher grain yield than the use of Cult. alone. However, the differences were statistically non-significant. The interactive effects of pre and post-flood tillage were also non-significant for grain yields during both the years at both locations. The year 2020-21 produced about six times less grain yield than 2019-20.

Harvest index

The impact of pre-flood tillage, post-flood tillage and their interaction was non-significant for harvest index except in 2019-20 for site 2. In 2019-20 at site 2, the use of CP resulted in a significant increase in harvest index values over the other treatments except for MBP in which differences were non-significant between CP and MBP. Similarly, the DP did not produce significant variations in harvest index

Table 14a: Detail of fixed and variable cost (Rs. ha^{-1})

Operations / input	No. of operations / input quantity	Cost (Rs. ha^{-1}) during 2019-20			Cost (Rs. ha^{-1}) during 2020-21		
	Fixed cost (PKR)						
Bund making	1	12355			14826.0		
Cost of sowing	1	4571.4			4942.0		
Seed rate	30 kg	7413.0			9884.0		
Harvesting cost	1	3088.8			3706.5		
Threshing cost	1	4942.0			6177.5		
Total fixed cost		**32370.1**			**39536.0**		
	Variable cost (PKR)						
		Pre-flood	**Post-flood**	**Total**	**Pre-flood**	**Post-flood**	**Total**
M.B Plough + Cultivator	1+1	6177.5	2718.1	8895.6	7413	3212.3	10625.3
M.B Plough + Cultivator and Rotavator	1+1+1	6177.5	5436.2	11613.7	7413	6424.6	13837.6
Disc Plough + Cultivator	1+1	6177.5	2718.1	8895.6	7413	3212.3	10625.3
Disc Plough + Cultivator and Rotavator	1+1+1	6177.5	5436.2	11613.7	7413	6424.6	13837.6
Chisel Plough + Cultivator	1+1	7413	2718.1	10131.1	8648.5	3212.3	11860.8
Chisel Plough + Cultivator and Rotavator	1+1+1	7413	5436.2	12849.2	8648.5	6424.6	15073.1
Cultivator + Cultivator	1+1	2718.1	2718.1	5436.2	3212.3	3212.3	6424.6
Cultivator + Cultivator and Rotavator	1+1+1	2718.1	5436.2	8154.3	3212.3	6424.6	9636.9
Farmer Practice+ Cultivator	1	3953.6	2718.1	6671.7	5189.1	3212.3	8401.4
Farmer Practice + Cultivator and Rotavator	1+1	3953.6	5436.2	9389.8	5189.1	6424.6	11613.7

Table 14b: Economic analysis of various pre-and post-flood tillage practices in lentil during 2019-20 and 2020-21 at site 1 and site 2

Treatments	2019-20							2020-21						
	Site 1													
	Fixed Cost (Rs ha^{-1})	Variable Cost (Rs ha^{-1})	Total Cost (Rs ha^{-1})	Grains Yield (kg ha^{-1})	Gross Income (Rs ha^{-1})	Net Income (Rs ha^{-1})	BCR	Fixed Cost (Rs ha^{-1})	Variable Cost (Rs ha^{-1})	Total Cost (Rs ha^{-1})	Grains Yield (kg ha^{-1})	Gross Income (Rs ha^{-1})	Net Income (Rs ha^{-1})	BCR
M.B Plough + Cultivator	32370.1	8895.6	41265.7	348.3	78374.3	37108.6	0.9	39536.0	10625.3	50161.3	65.0	16247.5	-33913.8	-0.7
M.B Plough + Cultivator and Rotavator	32370.1	11613.7	43983.8	370.9	83448.0	39464.2	0.9	39536.0	13837.6	53373.6	66.2	16552.5	-36821.1	-0.7
Disc Plough + Cultivator	32370.1	8895.6	41265.7	326.5	73453.5	32187.8	0.8	39536.0	10625.3	50161.3	59.8	14950.0	-35211.3	-0.7
Disc Plough + Cultivator and Rotavator	32370.1	11613.7	43983.8	338.9	76259.3	32275.5	0.7	39536.0	13837.6	53373.6	55.6	13900.0	-39473.6	-0.7
Chisel Plough + Cultivator	32370.1	10131.1	42501.2	416.2	93654.0	51152.8	1.2	39536.0	11860.8	51396.8	86.2	21560.0	-29836.8	-0.6
Chisel Plough + Cultivator and Rotavator	32370.1	12849.2	45219.3	425.2	95679.0	50459.7	1.1	39536.0	15073.1	54609.1	95.9	23977.5	-30631.6	-0.6
Cultivator + Cultivator	32370.1	2718.1	35088.2	285.6	64248.8	23724.4	0.7	39536.0	6424.6	45760.6	47.3	11817.5	-37355.4	-0.8
Cultivator + Cultivator and Rotavator	32370.1	5436.2	37806.3	297.3	66885.8	23643.3	0.6	39536.0	9636.9	49172.9	50.6	12650.0	-39735.2	-0.8
Farmer Practice+ Cultivator	32370.1	6671.7	39041.8	291.1	65488.5	26446.7	0.7	39536.0	8401.4	47937.4	41.1	10265.0	-37672.4	-0.8
Farmer Practice + Cultivator and Rotavator	32370.1	9389.8	41759.9	293.6	66060.0	24300.1	0.6	39536.0	11613.7	51149.7	39.6	9900.0	-41249.7	-0.8
	Site 2													
M.B Plough + Cultivator	39536.0	8895.6	41265.7	387.8	87264.0	45998.3	1.1	39536.0	10625.3	50161.3	61.2	15292.5	-34868.8	-0.7
M.B Plough + Cultivator and Rotavator	39536.0	11613.7	43983.8	388.1	87318.0	43334.2	1.0	39536.0	13837.6	53373.6	59.1	14770.0	-38603.6	-0.7
Disc Plough + Cultivator	39536.0	8895.6	41265.7	349.1	78552.0	37286.3	0.9	39536.0	10625.3	50161.3	57.5	14362.5	-35798.8	-0.7
Disc Plough + Cultivator and Rotavator	39536.0	11613.7	43983.8	368.6	82926.0	38942.2	0.9	39536.0	13837.6	53373.6	56.6	14140.0	-39233.6	-0.7
Chisel Plough + Cultivator	39536.0	10131.1	42501.2	453.5	102033.0	59531.8	1.4	39536.0	11860.8	51396.8	73.1	18285.0	-33111.8	-0.6
Chisel Plough + Cultivator and Rotavator	39536.0	12849.2	45219.3	459.2	103322.3	58103.0	1.3	39536.0	15073.1	54609.1	72.9	18217.5	-36391.6	-0.7
Cultivator + Cultivator	39536.0	2718.1	42254.1	313.0	70413.8	29889.4	0.7	39536.0	6424.6	45960.6	42.3	10570.0	-38602.9	-0.8
Cultivator + Cultivator and Rotavator	39536.0	5436.2	44972.2	319.0	71781.8	28539.3	0.6	39536.0	9636.9	49172.9	38.4	9590.0	-42795.2	-0.9
Farmer Practice+ Cultivator	39536.0	6671.7	39041.8	290.9	65454.8	26413.0	0.7	39536.0	8401.4	47937.4	36.3	9062.5	-38874.9	-0.8
Farmer Practice + Cultivator and Rotavator	39536.0	9389.8	41759.9	288.3	64858.5	23098.6	0.6	39536.0	11613.7	51149.7	36.9	9232.5	-41917.2	-0.8

over MBP. The DP and rotavator also had statistically similar values of harvest index with FP. Unlike grains and biological yield, the year 2020-21 had greater harvest index value than 2019-20 (Table 13).

Economic analysis

The data regarding economics of various pre-flood and post-flood tillage practices for lentil production in spate irrigated areas is presented in Tables 14a and 14b. It showed that all the treatments produced higher economic returns over the FP. The maximum economic returns of Rs. 51152.8 ha^{-1} at site 1 during 2019-20 were recorded from the combined use of CP as pre-flood and cultivator as post-flood practice. The similar results were also confirmed from the site 2. The maximum BCR value of 1.2 was also recorded from this combination. During second year of the experiment, the crop performance was very poor due to lack of the rains and soil moisture and none of treatments exceeded the expenses.

Discussion

Reduction in soil bulk density due to pre-flood tillage practice can be attributed to reduced compaction and improved soil porosity. The lower bulk density values in chisel plough tillage reveals less compaction to facilitate water and air movement in the soil. Our results are in consonance with the outcomes from studies of Alam *et al*., 2014 and Li *et al*., 2020 who observed minimum bulk density values in deep tillage over zero, minimum and conventional tillage. Depending on the tillage depth, the changes in soil properties are mainly confined to superficial soil layer in which root growth occurs (Fatumah *et al*., 2021). As a consequence of the tillage operation, water infiltration and conservation are likely to be enhanced. Conventional tillage reduced bulk density, increased porosity in plough layer compared with zero tillage (Lipiec *et al*., 2006). The bulk density represents the over picture of soil physical health and water retention (Jin *et al*., 2007). The state of soil compaction is positively related with the values of bulk density. The higher values of bulk density reflect less soil porosity and ultimately reduced water infiltration. Reduced soil compaction and bulk density with CP favors root growth. The low bulk density values and higher water contents in deep tillage treatments have been confirmed regarding tillage impacts on maize in central China (Ji *et al*., 2013). Reported soil differences are generally not statistically proven and largely marginal. Since soil sampling was not performed in the rhizosphere. In the bulk soil, plant-induced changes in soil nutrient availability are hardly detectable. Nevertheless, an interesting aspect is the consistently low levels of plant available Olsen P, reaching only 5 mg kg^{-1} soil. This demonstrates strong P fixation due to the high soil pH and is likely a limiting factor for crop cultivation on the respective field sites. Similarly low values of organic matter and total N were detected. The differences in pre-flood tillage for bulk density were more pronounced when compared with post-flood tillage practices. However, the interaction of pre and post-flood tillage practices for bulk density of top soil was non-significant. Hence different combinations of pre and post-flood tillage implements tested could not significantly affect bulk density of top soil in hill torrent areas.

The nitrogen fixation process in the roots of legume crops is very popular which is also influenced by tillage systems in addition to management practices. Both the diversity and number of rhizobia are affected by tillage practices (Muoni *et al*., 2022). The tillage systems basically influenced the soil water contents which further affects the inorganic soil nitrogen which is important for biological nitrogen fixation (Matus *et al*., 1997). In our treatments, there were considerable variations in the soil moisture which influence the nitrogen fixation process. The comparative study on the impact of various tillage practices on the soil physical properties in wheat-mungbean-rice cropping system also revealed the increased values of cumulative infiltration rate and available water contents in deep tillage over zero tillage, minimum tillage, conventional tillage and deep tillage (Alam *et al.*, 2014). It would ultimately affect the root growth and other developmental processes of the crops. Therefore, deep tillage is taken as necessary action of the crop production in rainfed areas. The field capacity (%), permanent wilting point (%) and available water (cm) in soil was improved with increased tillage depth (Alam and Salahin, 2013).

Deep tillage improves the infiltration and conserves the moisture in deep soil layers. Higher root density of lentil in deeply ploughed soil as compared to shallow tillage has been reported by Zaman and Islam, 2020. The higher root mass also enables the crop to efficiently use available water in the soil and increases the relative drought tolerance in deep tillage over shallow tillage practices. Therefore, deep tillage implements like CP increased overall growth performance of the crop. Deep tillage during fallow period resulted in maximum yield benefits, which is mainly attributed to improved moisture contents in the soil (Feng *et al.*, 2021). It was also previously observed that CP had the maximum soil moisture contents in 15-45 cm soil depth and highest infiltration rate over the disc ploughing, ridging and no tillage (Makki and Mohamed, 2008). Because of its greater tillage depth, the water in chisel ploughed plot does not fully lost from surface due to evaporation and ensure improved season long water supply.

The choice of the post-flood tillage for land preparation is important. However, the results of the present study highlighted no clear difference due to post-flood tillage implements. The selection of pre-flood tillage system is more important than the post-flood tillage system for improving the crop yield through improved moisture conservation. The soil moisture contents have effects on the soil formation, nutrient and other material mobilization and the growth of the crops. The deep tillage implements like chisel plough and MBP have larger tillage depths. Usually, the higher tillage depth loosens the soil to greater depth and infiltration occurs to greater depth (Sun *et al.*, 2018; Das *et al.*, 2010). Therefore, the moisture conservation in the soil through deep tillage practices is one of the top priorities of rainfed agriculture (Ngigi *et al.*, 2006).

The lower values of various recorded parameters with shallow tillage implements like rotavator and cultivator were the result of poor water storage in the soil. The infiltration rate was maximum in tillage with CP followed by DP and MBP (Abu-Hamdeh, 2004). Deep tillage with CP is likely to improve the root growth due to its ability to loosen the soil to greater depth. In this way, it supplies more moisture to growing crop. The positive trend in root mass density with tillage depth has been witnessed (Alam and Salahin, 2013). The higher grain yield of the lentil in CP treatment could be mainly attributed to improved values of yield formation traits.

The variations in soil moisture contents among tillage implements are explained by the differences in mode of action of these implements. CP performs the deep tillage operation with limited soil disruption because it does not invert or turn the soil. The moisture is lost from upper soil layers during land preparation. The moisture contents in the upper layers governs the germination and seedling establishment. It seems to be the main limiting factor for crop production particularly in arid environment. The choice of tillage implements may play a role in minimizing the losses (Liu *et al.*, 2021). However, the post-flood tillage implements used in this study did not result in variations for soil moisture contents in neither upper soil layers, nor deeper soil layers. Therefore, the land preparation with cultivator may be preferred to avoid any additional expense for rotavator as post-flood tillage.

The variations in final yield might be the result of cumulative effects of the differences in water availability and nitrogen supply. The highest yield was obtained from chisel run fields having higher tillage depth. There was lesser yield during second year at both the locations due to almost no rains during the growing season especially at flowering. The yield forming parameters like number of pods per plant, number of seed per pod and 1000 grains weight also varied with tillage practices. The significant increase in grain yield and biomass in CP treatment also confirms the results of the Alam *et al.* (2014) who also reported maximum yield of mungbean in deep tillage than zero tillage, minimum and conventional tillage systems. The low yield with DP over mouldboard and CP have been already confirmed for groundnut (Akhtar *et al.*, 2005).

CP along with cultivator has the maximum benefit cost ratio. It is basically combining effect of less additional cost and higher yield as compared to other treatments. Although the lowest cost was observed in rotavator as pre-flood and cultivator as post-flood tillage but the treatment was not economically attractive due to low yield. Pre-flood tillage with CP proved to be the best practice for moisture conservation following the MBP treatment (Aboudrare *et al.* 2006).

Conclusion

Compared to farmer practice, all the tested pre-and post-flood tillage treatments showed improved water and lentil productivity. Pre and post-flood tillage implements tested in varying combinations could not significantly affect bulk density of top soil in Mithawan hill torrent command areas. All primary tillage implements tested during pre-flood tillage showed an increase in lentil yield over farmer practice (no tillage). Among tested pre-flood tillage implements, chisel plough resulted in better lentil yield and water productivity in growing season with reasonably good rains and soil moisture in Mithawan hill torrent command areas of DG Khan. Pre-flood tillage through chisel plough augmented with post-flood tillage through cultivator proved to be economically feasible combination in synergism for improved water and lentil productivity compared with other tested tillage implements. More research is however needed to standardize agronomic applications of lentil in conjunction with soil moisture retention in rhizosphere besides assessment based provision of adaptable high yielding climate resilient lentil cultivars in hill torrent areas for better and sustainable productivity.

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