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Improving rice (*Oryza sativa* l.) and maize (*Zea mays* L.) productivity and soil properties under residual tillage practices in North west India

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ABSTRACT

Tillage practices have residual effects on soil properties and crop productivity. Chiseling is one such practice which showed significant residual impacts on both soil properties and crop productivity even after discontinuing the practice for two to three years. To test this hypothesis a field experiment was conducted during 2018 in an ongoing experiment initiated in 2016 at the Research Farm, Department of Soil Science, Punjab Agricultural University, Ludhiana, on rice and kharif maize in a sandy loam soil. The study included three tillage practices i.e. conventional tillage (CT), chiselling performed for one year (CH1) and chiselling performed for two consecutive years (CH2) and two irrigation regimes i.e. 4 days interval and 8 days interval in rice and IW/PAN-E ratio of 0.6 and 0.9 in maize. The experiment was conducted in split plot design with three replications. The CH2 practice produced higher rice and maize grain yield (5.91 and 6.75 t ha^{-1}) followed by CH1 (5.74 and 6.28 t ha^{-1}) and minimum under CT (5.42 and 5.24 t ha^{-1}), respectively at full irrigation regimes i.e. 4-d interval in rice and IW/PAN-E 0.9 in maize. Thousand grain weight (TGW, g) of rice and maize was also found to be maximum in CH2 (22.7 and 289.2) followed by CH1 (22.1 and 282.8) and least in CT (21.6 and 270.1). Among irrigation regimes, higher rice and maize grain yields were recorded at 4 days interval in rice and IW/PAN-E 0.9 (5.69 and 6.09 t ha^{-1}) levels than 8 days interval and IW/PAN-E 0.6 (5.23 and 5.57 t ha^{-1}), respectively. Irrigation water productivity (IWP, kg ha^{-1} mm^{-1}) of rice and maize was also significantly influenced by chiselling practice, maximum IWP was recorded at CH2 followed by CH1 and lowest under CT in both the crops. The chisel practice had also residual effect on soil penetration resistance at 20 cm soil depth with highest values under CT (2.89 and 3.14M Pa) and lowest under CH2 (1.82 and 2.23 M Pa) after maize and rice, respectively. Similarly, infiltration rate (IR) of soil was also affected by chisel practices, where maximum final IR was recorded under CH2 (2.4 and 1.6 cm hr^{-1}) followed by CH1 (2.1 and 1.3 cm hr^{-1}) and least in CT (1.6 and 1.2 cm hr^{-1}) after maize and rice, respectively. It is thus, concluded that chiselling has residual effect on soil properties as well as on rice and maize productivity.

Key words: Rice, maize, chiseling, compaction, yield, residual impacts

INTRODUCTION

Chiselling practise significantly affect soil properties and crop productivity and its residual effect prevails even after discontinuing the practice. The soil mechanical and water transmission properties along with crop productivity were reported to be improved under deep chisel. The conventional practices of cultivating crops like intensive tillage without residue management and improper use of irrigation water negatively affect the soil health, crop yield and environment conditions by affecting soil carbon loss, soil structure, and emission of greenhouse gases (Alam *et al.*2014). There are also chances of hard pan formation at subsurface soil depth due to use of excessive and heavy machinery. This hard pan restricts the root proliferation and also affects the water transmission characteristics of soil. As a solution to solve this problem, deep tillage (DT) is the most preferred practice. Soil management practices can influence water use efficiency and profile water usage (Sarkar and Singh 2007). An appropriate tillage selection can improve water availability to the crops by increasing soil moisture storage, reducing soil evaporation and allowing a better development of root system. Under water stressed condition, the deep root system helps the crop to extract water from deeper soil layers. Due to better root proliferation under DT, the crop water productivity can be increased. The DT has only modest influences on seepage and percolation rates. Irrigation levels are well known to affect crop performance. Therefore, irrigation management needs an appropriate crop monitoring taking into account the water requirements of plants and soil. The various physical properties of soil such as bulk density, porosity and water holding capacity are fundamental indicators that show the effect of tillage on soils hydraulic properties (Strudley *et*

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al. 2008). Subsoil compaction hinders the uptake of water and plant nutrients from deeper layers, thereby resulting in lower crop yields. To overcome subsoil compaction, remediation management practices were deep tillage and selection of crops with deep root system (Prajapati *et al.* 2020). In the semi-arid and sub-tropical regions, random heavy rains during the monsoon season (late June to mid-September)cause intermittent flooding of the crop. As a result there is a reduction in crop yield due to water aeration and thermal stresses in the root zone of the crop. The water stress is more acute on the highly permeable coarse textured soils having low water retention capacity. Poorly developed root system of the crops due to the subsoil compaction having high soil strength further aggravates the problem by restricting the size of the exploitable water reservoir. Management practices to overcome these problems include the measure that promote the rooting volume of soil, improve the water supply, regulates the soil thermal regime, and help to escape flooding during the early crop growth stages. The DT in maize increased the grain yield and water use efficiency as compared to conventional and no tilled conditions (Piao *et al.* 2016). The DT increases soil porosity, saturated and unsaturated hydraulic conductivity, improves the aeration status which leads to increased soil moisture storage (Velykis 2004) in the loosened soil layer. Rice is very susceptible to water stressed conditions as compared to other crops due to its shallow root system. The DT is promising technique to dislodge the hardpan with as much as 3 MPa of mechanical resistance, which generally develops just below the plow depth in upland rice conditions. These hardpans inhibit the roots to penetrate deeper into the soil in many upland crops. The positive outcome of DT in upland rice fields is to maintain water and nutrient uptake by the crop during water deficit conditions. Many reports suggest that rice achieves higher tiller density, leaf area, and vegetative biomass under deep tilled conditions. The present study was thus undertaken to observe the residual impact of DT on soil water transmission and mechanical characteristics as well as rice and maize productivity.

MATERIAL AND METHODS

The field experiment was conducted during 2018 in an ongoing experiment initiated in 2016 at research farm of Department of Soil Science, Punjab Agricultural University, Ludhiana, Punjab, India situated at 30°54’ N latitude, 75°58’ E longitude at an altitude of 247 m above the mean sea level. The experimental area is designated with a subtropical and semi-arid climate, with hot and dry summers (April-June), wet monsoon (late June-mid September) and a cool dry winter (October-February) season. The average annual rainfall range is 650-700 mm about 75 percent of which is received by south-western monsoon in the month of July to September and light showers are received in the month of December-January by north-western monsoon. The soils were sandy loam in texture with 68.5 percent sand and 17.2 percent clay content and are slightly alkaline and non-saline in nature (pH 8.2 and EC 0.23 dS m^{-1}). The soil profile had subsurface compact layer (15-30 cm soil layer). The soils were low in soil organic carbon (0.36 percent). The study included three tillage practices i.e. conventional tillage (CT), residual impact of chiseling performed for one year (CH1) and that performed for two consecutive years (CH2) and two irrigation regimes i.e. 4 days interval and 8 days intervals in rice and IW/PAN-E ratio of 0.6 and 0.9 in maize. The experiment was conducted in split plot design with three replications. Rice (var. PR 115) and maize (var. PMH1) were sown in the first week of June with recommended fertilizer doses and maize was harvested in second week of September while rice was harvested in second fortnight of October. In CT, two discs and two cultivators operations were performed followed by planking, while in DT the field was deep ploughed with single tine chisel up to 45 cm deep apart from 50 cm spaced followed by CT. The bulk density was determined by using core method (Blake and Hartge 1986). The penetration resistance was recorded with help of a digital cone, hand-held penetrometer (CP40II; Rimik electronics, RFM Australia) upto 40 cm soil depth at four randomly selected points within a plot. *In-situ* measurement of infiltration was done using double ring infiltrometer method by Reynolds *et al* (2002). Aggregate status of soil was determined by wet sieving method (Yoder 1936).

The data was analyzed to compute mean weigh diameter (MWD) (Kemper and Rosenau 1986). The saturated hydraulic conductivity (K_s) was determined using constant head method (Reynolds *et al* 2002). Plant height was measured from ground surface to the tip of the plant at 85 DAS for maize and 110 DAS for rice. Thousand grains were counted and expressed at 14 % and 12 % moisture content for rice and maize crops, respectively. The crop biomass (t ha^{-1}) of maize and rice was recorded. For recording grain yield (t ha^{-1}), a representative area of 10 m^{-2} was selected from the centre of each plot in rice crop. In case of maize, two central rows were selected from each plot. The moisture content of the grains was recorded and crop yield adjusted at 14 % for rice and 12 % for maize, respectively. Irrigation water productivity (IWP) was calculated as the ratio of grain yield (Mg ha^{-1}) to the amount of total irrigation water applied (mm) and expressed as kg $ha^{-1}mm^{-1}$. The data was statistically analyzed in statistical package CPCS-I according to Cochran and Cox (1967) (and adapted by Cheema and Singh 1991) and it was compared at significance level of 5%.

RESULTSAND DISCUSSION

Plant growth characteristics

The plant height of rice was higher under 4-d irrigation regime (101.9 cm) than under 8-d irrigation regime (98.5) (Table 1).

Table 1: Residual effects of chiseling on plant height (cm) and thousand grain weights (g) of rice and maize under two irrigation regimes

Tillage practices	Rice				Maize			
	Plant height		Test weight		Plant height		Test weight	
	4 days	8 days	4 days	8 days	IW/PAN-E 0.6	IW/PAN-E 0.9	IW/PAN-E 0.6	IW/PAN-E 0.9
CTCTCT	99.7	96.8	21.6	20.5	235.7	243.3	265.6	270.1
CH1CH1	102.3	98.4	22.1	21.4	247.4	255.2	279.3	282.8
CH2CH2	103.6	100.3	22.7	21.5	258.9	271.5	286.5	289.2
Mean	101.9	98.5	22.1	21.1	247.3	256.7	277.1	280.7
LSD (<0.05)	Tillage =2.4 Irrigation= 1.7		Tillage = 0.5 Irrigation= 0.9		Tillage =12.6 Irrigation= 9.3		Tillage = 7.8 Irrigation= 4.7	

It varied significantly under different tillage practices. The trend was in the order CH2 >CH1 >CT at both the irrigation regimes. Shekara *et al.* (2010) reported that irrigation scheduled at IW/PAN-E = 2.5 showed significantly higher plant height. The mean maize plant height was higher (256.7) under IW/PAN-E 0.9 than 0.6 (247.3 cm). The maximum maize plant height was recorded in CH2 (271.5 cm) followed by CH1 (255.2 cm) and minimum in CT (243.3 cm) at IW/PAN-E 0.9. Memon *et al* (2013) also reported similar results in maize. The thousand grain weight of rice was observed to be maximum in CH2 (22.7 g) followed by CH1 (22.1 g) and minimum in CT (21.6 g) at 4–d irrigation regime (Table 1). It was higher in 4-d irrigation regime than 8-d irrigation regime. The mean thousand grain weight of rice was 22.1 g under 4-d and was 21.1 g under 8-d irrigation regimes. It was higher by 5.1 % under deep tilled rice than conventionally tilled rice at 4-d irrigation regime. The mean thousand grain weight was higher in IW/ PAN-E 0.9 (280.7 g) than IW/PAN-E 0.6 (277.1) (Table 1). Thousand grain weights were higher under deep tilled conditions as compared to conventional tilled conditions (Anjum *et al.*2014).The tillage and irrigation regime did not interact significantly.

Yield studies

There was significant difference in crop biomass under two irrigation regimes in both rice and maize crops. Irrespective of tillage practices, the mean crop biomass of rice was 9.1 t ha^{-1} at 4-d interval irrigation and 8.5 t ha^{-1} at 8-d irrigation level. The mean crop biomass was significantly higher by 6.6 % under 4-d than 8-d irrigation regime. Among tillage practices, maximum crop biomass of rice was recorded in CH2 (9.6 t ha^{-1}) followed by CH1 (9.2 t ha^{-1}) and minimum in CT (8.3 t ha^{-1}) at 4-d irrigation regime. The crop biomass of maize was also found to be statistically higher in CH2 (16.7 t ha^{-1}) than CT (11.6 t ha^{-1}) at IW/PAN-E 0.9. Irrespective of tillage practices, the mean crop biomass of maize was observed to be significantly higher in IW/PAN-E 0.9 (14.2 t ha^{-1})

than IW/PAN-E 0.6 (12.8 t ha^{-1}). The tillage and irrigation regimes did not interact significantly. Shekara *et al* (2010) reported higher crop biomass under deep tilled than conventional tilled under water deficit conditions. The crop biomass was more under deep tilled conditions due to improved physical environment of the soil which facilitates better root proliferation. And above ground biomass is the function of the below ground biomass i.e. root system. Better the root system more will be the exploration of soil volume by plant roots for water and nutrients, more will be the translocation of water and nutrients and hence the above ground biomass. Cai *et al* (2014) reported an increase of 14.6 percent in biomass under deep tillage as compared to conventional tillage. The tillage practices significantly affected the grain yield of both the crops. The rice grain yield was significantly higher under CH2 (5.91 t ha^{-1}) than CT (5.42 t ha^{-1}) at 4-d irrigation level (Table 2). This could be due to better root proliferation in deep tilled plots which results in more water and nutrient availability to the crop. The shallow and compacted topsoil in conventional tilled plots not only restricts the root development of plants, but hinders their absorption of nutrients and water (Wang *et al* 2008).The rice grain yield was higher under 4-d irrigation interval (5.69 t ha^{-1}) than the 8-dirrigation interval (5.23 t ha^{-1}). The rice grain yield was also observed to be lowest in conventionally tilled plots at 8-d irrigation regime. The mean grain yield of maize was 8.5 % higher under IW/PAN-E 0.9 than 0.6. Among the tillage practices, it was maximum in CH2 (6.75 t ha^{-1}) followed by CH1 (6.28 t ha^{-1}) and minimum in CT (5.24 t ha^{-1}) at IW/PAN-E 0.9. Similar trend of maize grain yield was observed for different tillage practices at IW/PAN-E 0.6 irrigation regime. This could be due to higher root proliferation, more availability of water and nutrients under deep tilled plots contributed to higher grain yield.

Table 2: Residual effects of chiseling on biomass yield (t ha^{-1}) and grain yield (t ha^{-1}) of rice and maize under two irrigation regimes

Tillage practices	Rice				Maize			
	Biomass yield		Grain yield		Biomass yield		Grain yield	
	4 days	8 days	4 days	8 days	IW/PAN-E 0.6	IW/PAN-E 0.9	IW/PAN-E 0.6	IW/PAN-E 0.9
CTCT CT	8.3	7.6	5.42	5.08	10.4	11.6	4.81	5.24
CH1CH1	9.2	8.8	5.74	5.26	13.3	14.4	5.73	6.28
CH2CH2	9.6	9.1	5.91	5.35	14.8	16.7	6.16	6.75
Mean	9.1	8.5	5.69	5.23	12.8	14.2	5.57	6.09
LSD (<0.05)	Tillage = 0.6 Irrigation= 0.4		Tillage = 0.8 Irrigation= 0.3		Tillage = 2.6 Irrigation= 1.4		Tillage = 0.5 Irrigation= 0.4	

Irrigation water productivity

The irrigation water productivity (IWP) of rice was 8.72 kg ha^{-1} mm^{-1}under 8-days interval and 6.77 kg ha^{-1} mm^{-1}under 4-day interval which was due to less irrigation water input under 8-days interval (Fig. 1). Among the tillage practices, it was higher by 5 % under CH2 than CT at 8-d interval.

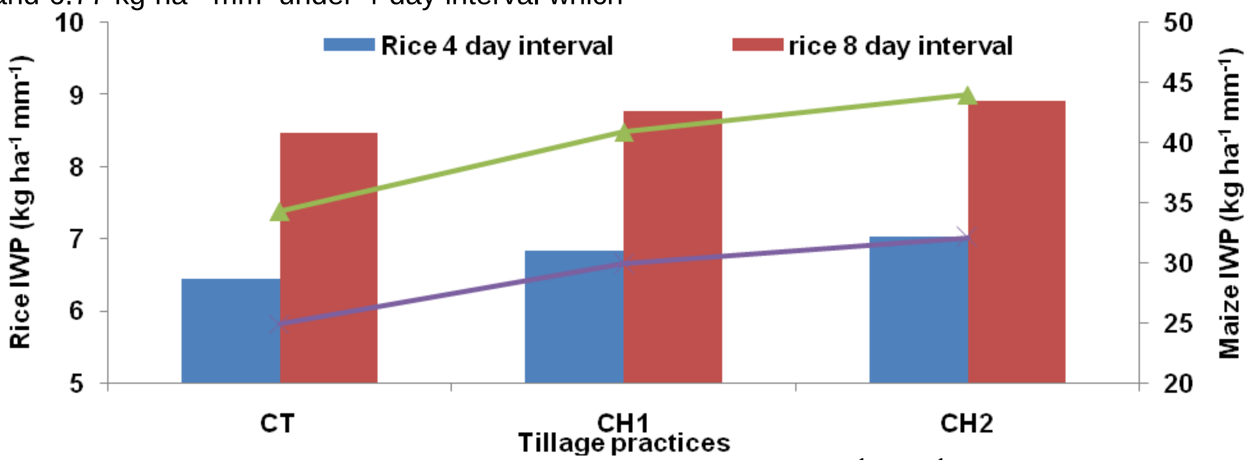

Fig. 1: Effect of chiseling on irrigation water productivity (kg ha^{-1} mm^{-1}) of rice and maize at two irrigation regimes

The higher IWP under CH2 was due to more yields under deep tilled than the conventional tilled plots. For maize the mean IWP was higher under IW/PAN-E 0.6 by 26.1 % than under 0.9. The difference was statistically significant. Among different tillage practices, it was significantly higher under CH2 (32.1 kg ha^{-1} mm^{-1}) than CT (24.9 kg ha^{-1} mm^{-1}) at IW/PAN-E 0.9. Similarly IWP of maize was observed to be maximum in CH2 (44.0 kg ha^{-1} mm^{-1}) followed by CH1 (40.9 kg ha^{-1} mm^{-1}) and minimum in CT (34.3 kg ha^{-1} mm^{-1}) at IW/PAN-E 0.6. It was thus 22.1 % higher under deep tilled than conventional tilled plots, because of higher yields in deep tilled plots than conventional tilled plots. The tillage and irrigation regimes did not interact significantly.

Table 3: Effect of chiseling on soil penetration resistance (M Pa) and bulk density (Mg m^{-3}) after rice harvesting

Tillage practices	Soil depth (cm)							
	5	10	15	20	25	30	35	40
	Penetration resistance (M Pa)							
CTCT CT	1.15	2.64	2.83	3.14	2.86	2.65	2.68	2.75
CH1CH1	0.93	2.23	2.65	2.96	2.19	2.25	2.35	2.30
CH2CH2	0.72	1.76	1.88	2.23	2.18	1.82	1.95	1.80
Mean	0.93	2.21	2.45	2.78	2.41	2.24	2.33	2.28
LSD (<0.05)	0.26	0.42	0.38	0.48	0.25	0.41	0.38	0.46
	Bulk density (Mg m^{-3})							
CTCT CT	1.48	1.54	1.66	1.73	1.67	1.63	1.64	1.65
CH1 CH1	1.45	1.51	1.63	1.68	1.63	1.59	1.62	1.62
CH2 CH2	1.39	1.41	1.57	1.64	1.58	1.55	1.60	1.61
Mean	1.44	1.49	1.62	1.68	1.63	1.59	1.62	1.61
LSD (<0.05)	0.04	0.06	0.05	0.05	0.06	0.04	NS	NS

Soil physical characteristics

Penetration resistance (PR) and soil bulk density after rice harvesting under different tillage practices has been presented in Table 3, while after maize harvesting is presented in Fig 2. At 20 m soil depth maximum PR was recorded under CT (2.89 and 3.14 M Pa) followed by CH1 (1.96 and 2.96 M Pa) and least in CH2 (1.82 and 2.23 M Pa) after maize and rice, respectively. Similarly soil bulk density at 20 m soil depth was maximum in CT (1.68 and 1.73 Mg m^{-3}) followed by CH1 (1.62 and 1.68 Mg m^{-3}) and minimum in CH2 (1.60 and 1.64 Mg m^{-3}) after maize and rice, respectively.

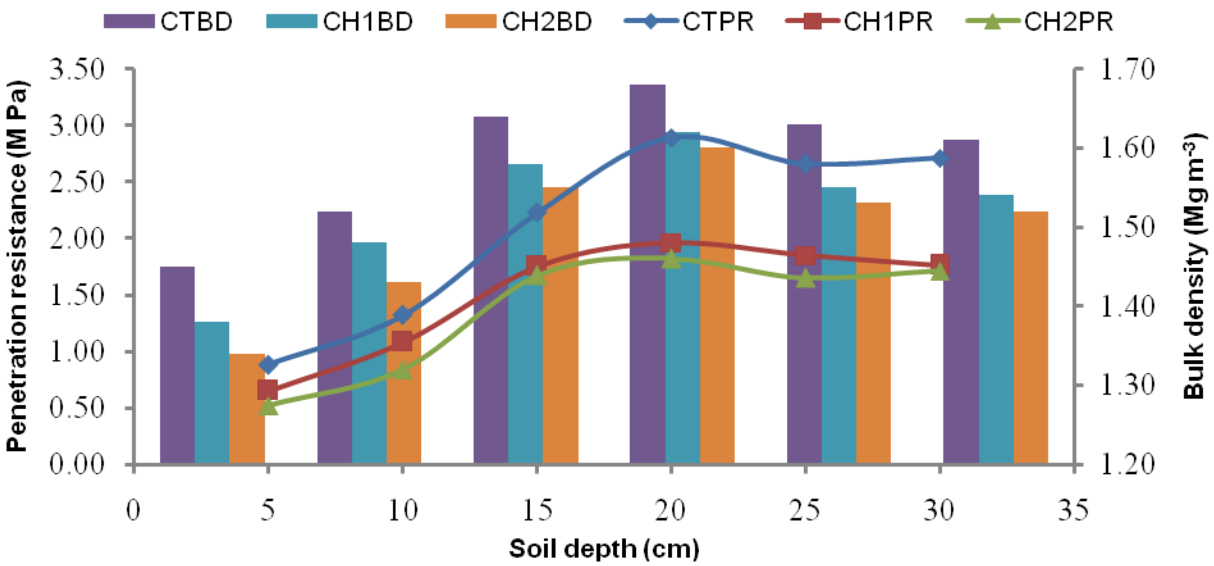

Fig. 2: Effect of chiselling on soil penetration resistance (M Pa) and soil bulk density (Mg cm-3)

Higher PR under CT might be due to hard pan formation at sub surface layer through number of field operations with use of heavy machinery. Highest values of PR under CT and lowest values under DT (particularly in sub surface layer) have also been reported by Zhao *et al* (2014). Maximum saturated hydraulic conductivity (*Ks*) was recorded under CH2 (1.7 and 1.6 cm hr^{-1}) followed by CH1 (1.6 and 1.5 cm hr^{-1}) and least in CT (1.4 and 1.3 cm hr^{-1}) after maize and rice, respectively. No significant difference in the mean weight diameter was observed among different tillage practices, however, it was maximum in CT (0.65 and 0.62 mm) followed by CH1 (0.64 and 0.60 mm) and minimum in CH2 (0.62 and 0.59 mm) after maize and rice, respectively (Table 4). Maximum final infiltration rate (IR) was recorded under CH2 (2.4 and 1.6 cm hr^{-1}) followed by CH1 (2.1 and 1.3 cm hr^{-1}) and least in CT (1.6 and1.2 cm hr^{-1}) after maize and rice, respectively. Similarly cumulative infiltration was also observed to be maximum in CH2 (38.0 and 19.1 cm) followed by CH1 (36.2 and 16.9 cm) and minimum in CT (33.6 and 15.3 cm) after maize and rice, respectively (Table 4). Moroke *et al.*(2009) observed higher IR in DT than CT due to ample amount of macro pores which led to fast entry of water into the soil profile.

Table 4: Effect of chiseling on soil saturated hydraulic conductivity (SHC: cm hr^{-1}), infiltration rate (IR: cm hr^{-1}), cumulative infiltration (CI: cm) and mean weight diameter (MWD: mm) of soil after rice and maize harvesting

Tillage practices	Rice				Maize			
	SHC	IR	CI	MWD	SHC	IR	CI	MWD
CTCTCT	1.3	1.2	15.3	0.62	1.4	1.6	33.6	0.65
CH1CH1	1.5	1.3	16.9	0.60	1.6	2.1	36.2	0.64
CH2CH2	1.6	1.6	19.1	0.59	1.7	2.4	38.0	0.62
Mean	1.5	1.4	17.1	0.60	1.6	2.0	35.9	0.64
LSD (<0.05)	NS	NS	2.2	NS	NS	0.6	3.4	NS

From the results, it is observed that the residual impact of chiselling practice significantly affected both soil characteristics and crop productivity. The chiselling reduced soil penetration resistance and improves water transmission. The residual effect of deep tillage had significant effect on plant height, thousand grain weight, crop biomass and rice and maize yields. Irrigation water productivity was also observed to be higher in chiselled plots. It is thus, concluded that in soils where problem of hard pan formation persist at sub surface depth, the residual impact of deep tillage will help in improving soil mechanical as well as water transmission characteristics along with improvement in rice as well as maize productivity.

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