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Improvement in productivity and profitability of farmers through soil chiseling practices in wheat in *Majha* region of Indian Punjab

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Abstract
The present study has explored the integrative influence of soil chiseling practices on wheat yield and farmers' profitability. The study was carried out in the farmers' field during 2017-18 and 2018-19 of district Tarn Taran, a *Majha* region of Indian Punjab. The study involved ploughing of field with chiesler plough by recommended method prior to sowing of wheat crop. The results showed 10.8 and 8.8% increase in wheat yield over farmers' practice during 2017-18 and 2018-19, respectively. The various growth indices registered a favourable improvement over farmers practice though they were statistically similar. Similarly, the net returns and B:C ratio increased significantly to the tune of 16.7 & 14.4 in 2017-18 and 8.8 & 7.8% in 2018-19, respectively. The magnitude of increase in production and monetary efficiencies over farmers' practice were to the extent of 10.7 & 16.3 in 2017-18 and 8.9 & 14.2% in 2018-19, respectively. Above presentation revealed that soil chiseling improved the overall crop growth and productivity in comparison to general farmers' practices not involving the same owing to favourable influence on soil permeability and allow the water to infiltrate in soil, improved aeration, root penetration and nutrient acquisition from deeper layers.

Keywords: Net returns, profitability, production efficiency, soil chiseling and wheat

Introduction
The soils especially, clayey one forms hardpan just below the topsoil layer (30-45 cm depth) that does not allow the water to pass through it. The crop roots not be able to penetrate and spread down through this hard layer. These hardpans are usually formed due to crystallization of salts, formation of compact and hard molecules that do not provide sufficient space for water or air to pass through. There are several factors that cause the formation of hardpans in sub soil such as vast fluctuations in pH, application of chemicals, improper preparation of soil, non-uniform soil and fertilizers, soil erosion, excessive irrigation, etc. Poor quality water containing high sodium content also cause flocculation/dispersion of soil particles and suspends silt in the soil water solution causing blockage of soil pores, which prevents movement of water into and through the soil, causes run off and fertile topsoil loss via erosion and reduces seed germination. It create obstacle to roots for expanding, severely reduces aeration and infiltration, makes soil non-fertile and acts as a barrier to nutrient acquisition by crop plants.

Wheat is one of the most important crops of the Punjab region, but the increasing problem of water stagnation due to hardpans formation in many pockets is decreasing its yield potential. The many farmers of the *Majha* region including Tarn Taran district are facing the problem of water stagnation after irrigation or heavy rainfall for several days in their fields especially in wheat crop leading to yellowing, stunted crop stand and in turn low yield and income. Further, heavy use of fertilizer in stunted crop without knowing the facts is further reducing the wheat yield and also deteriorating the soil structure and health. In above scenario, loosening of soil by breaking hard layer in sub soil is very much essential to improve water and root penetration as well as aeration for better plant growth and vigour.

Mechanical chiseling using chiseler plough to disrupt the compacted layer of soils has been proven as a win-win technology to overcome said problem. Soil chiseling is the practice of loosening the soil, without inverting and with a minimum of mixing of the surface soil, to shatter restrictive layers below normal plough depth that inhibit water movement or root development. This practice increases soil porosity and decreases bulk density (Colonego and Rosolem 2010; Nunes *et al.* 2014) [6, 21], thus improves soil permeability, promotes root development and in turn better crop stand. Improved root system also exerts a favourable influence on soil aggregation directly (Martins *et al.* 2009) [19] and indirectly through acceleration of organic carbon mineralization and consequently, influence soil aggregation state (Fabrizzi *et al.* 2009) [8]. Moreover, soil biological and biochemical properties also improved significantly owing to changes produced by soil management i.e. soil chiseling practices (Visser and Parkinson 1992; Garcia *et al.* 2013) [24, 10].

The awareness on soil chiseling to overcome said problem and improvement in soil physical properties and in turn crop yield is lacking among the farmers of the district. Thus, keeping in view the beneficial influences of soil chiseling especially in soil having the problem of water stagnation due to hardpans, frontline demonstration involving soil chiseling practices were implemented in farmer' fields suffering from this problem so that favourable effects of this practice may be demonstrated among farmers of the district to improve their wheat productivity and income.

Materials and Methods

Study area

Tarn Taran is one of the border districts, lies in the North West frontier of the Punjab, India. It lies between 31° 7' and 32° 3' North latitude and 74° 29' and 75° 23' in the East longitude. The climate of the district classified as tropical steppe, semi-arid and hot, which is mainly characterized by general dryness except for a short period during southwest monsoon season. During the summer months i.e. from April to June, weather is very hot and dry. The weather becomes humid and cloudy during July to September. The average rainfall of the district is 482.9 mm. The temperature and rainfall pattern of the study site during the wheat cropping season i.e. 2017-18 and 2018-19 has been presented in Figure 1 and Figure 2, respectively.

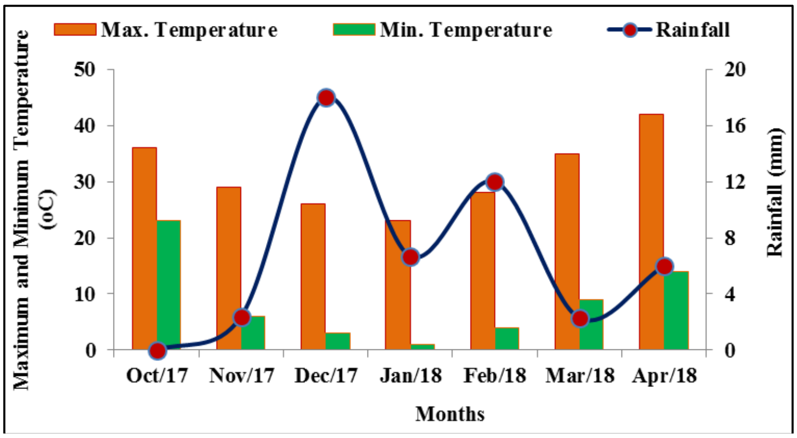

Fig 1: Temperature and rainfall data of experimental area during crop season (2017-18)

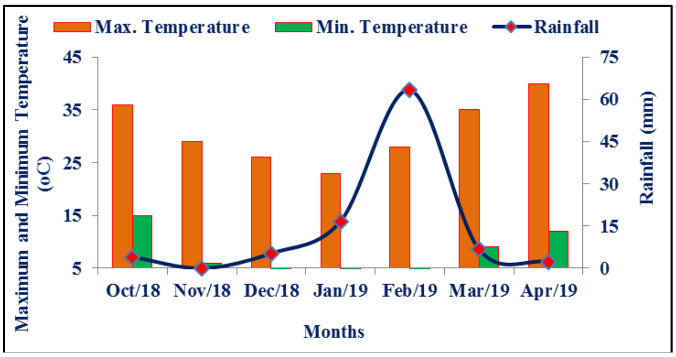

Fig 2: Temperature and rainfall data of experimental area during crop season (2018-19)

Experimental detail

The study was carried out at different locations in the farmers' field of district Tarn Taran for consecutive two years i.e. 2017-18 and 2018-19. The frontline demonstrations involving soil chiseling practice prior to sowing of wheat were implemented in farmers' fields having the problem of water stagnation. The farming situations were irrigated with tubewell as source of irrigation. The wheat variety HD 2967 was grown by the farmers. The experimentations were carried out at 5 different locations during both the years. Each experimental location further had 3 sub-locations with similar practices. The farmers' practice was taken as an average of farmers' practices existing at 5 different locations (without soil chiseling) as it was almost similar. The farmers were motivated to follow soil chiseling practice by adopting different technological tools such as training programmes, demonstrations, advisory, etc (Plate 1). Representative soil samples (0-15cm) were collected from different locations before sowing of wheat crop, air dried, ground and sieved through 2 mm sieve. The samples were analyzed for pH, EC, organic carbon, P and K content following standard procedures. The average soil fertility status of different locations including farmers' practice was: pH 8.7, EC 0.39 dSm^{-1}, organic carbon 0.43%, available N, P & K 400, 28 and 278 kg ha^{-1}. The common agronomic practices including seed, fertilizers were followed at all the experimental locations and are given below:

Plate 1: Awareness of farmers on soil chiseling and its usage

Table 1: The common agronomic practices including seed, fertilizers were followed at all the experimental locations and are given below:

Experimental location	Particulars
Location I	Soil Chiseling + 137.5 kg DAP ha^{-1} + 225 kg urea ha^{-1}
Location II	Soil Chiseling + 137.5 kg DAP ha^{-1} + 225 kg urea ha^{-1}
Location III	Soil Chiseling + 137.5 kg DAP ha^{-1} + 225 kg urea ha^{-1}
Location IV	Soil Chiseling + 137.5 kg DAP ha^{-1} + 225 kg urea ha^{-1}
Location V	Soil Chiseling + 137.5 kg DAP ha^{-1} + 225 kg urea ha^{-1}
Farmers' Practice	No Soil Chiseling + 137.5 kg DAP ha^{-1} + 225 kg urea ha^{-1}

Note:
1. Each experimental location further had 3 sub-locations with similar practices. The farmers' practice was taken as average of farmers' practices existing at 5 different locations as it was almost similar.
2. In all the experimental locations and farmers' practice, seed was applied @ 100 kg ha^{-1}, beside that application of herbicide and fungicide was done by the farmers at recommended rates

Experimental layout
The experiments were conducted at five main locations (*considered as treatment*) with 3 sub-locations (*replication*). The same agronomic practices were followed at each location with similar crop variety. Beside that there was a farmers' practice, which was taken as average of farmers' practices existing at 5 different locations as it was almost similar. Thus, the mean of 5 locations were compared with farmers' practice to see the effect of soil chiseling at different locations over farmers' practice over the region. The 'Randomized Block Design (RBD)' was followed for the allocation of treatment to experimental units (Gomez and Gomez 1984) [11]. However, certain variation in yield and other parameters were noticed at different experimental locations probably due to the compounded influence of soil (*variation in soil nutrient status & extent of hardpans or water stagnation*), climate and soil chiseling, etc. Hence, to avoid any bias in the experiment resulting from the influence of above unknown factors randomization was followed.

Soil chiseling
Cross sub soiling at 1.0 m spacing was done before preparing the field at all the experimental locations. This was done by tractor drawn sub-soiler (chiseler) to the depth of 45-50 cm. Planking was done to break the clods followed by preparation of fine seed bed. This helped in breaking the hard pan, increased water infiltration rate and better root development of wheat plants (Anonymous 2020) [2].
In farmers' practice, the field was disked twice followed by cultivators and planking operation to a fine seed bed.

Crop Growth indices
Plant height and dry matter accumulation
In order to assess the plant growth indices in wheat crop, the periodical plant height (cm) was taken at 2 different stages i.e. 60 and 120 DAS of crop growth using a metre scale, from ground level to tip of the tallest leaf in extended position. The dry matter accumulation (g $plant^{-1}$) was recorded twice (60 & 120 DAS) during crop growth period. The five randomly selected plants were removed from each location. Above plant samples were dried in an oven at 60ºC for 72 hours and their weights were recorded. The average weight of above five plants was expressed as dry matter accumulation.

1000 grain weight
One thousand grains were counted from the harvest produce. The sample was collected after the threshed-product optimally dried. Their weight (g) was recorded using electronic balance and expressed in grams.

Absolute, relative and crop growth rate
'Absolute growth rate (AGR)' is the total gain in height by a plant within a specific time interval, which is calculated by the formula given by Dube (2011) [7].

$$\text{AGR (cm day}^{-1}) = \frac{H_2-H_1}{t_2-t_1}$$

The 'Relative growth rate (RGR)' is determined using the formula given by Fisher (1921) [9]:

$$\text{RGR (g g}^{-1}\text{day}^{-1}) = \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{t_2 - t_1}$$

The '*Crop growth rate (CGR)*' is the efficiency of the complete crop over a specific soil area. It is estimated with following formula:

$$\text{CGR (g plant}^{-1}\text{day}^{-1}) = \frac{W_2 - W_1}{t_2 - t_1}$$

Where, H_1 and H_2 are plant height at t_1 and t_2 times
W_1 = Weight of dry matter at sampling time (t_1)
W_2 = Weight of dry matter at sampling time (t_2)
In present study above observations were taken at 60 (t_1) and 120 days (t_2) after sowing (DAS)

Economic analysis

$$\text{Gross returns (₹ ha}^{-1}) = \text{Yield (q ha}^{-1}) \times \text{price of produce (₹ kg}^{-1})$$

$$\text{Net returns (₹ ha}^{-1}) = \text{Gross returns (₹ ha}^{-1}) - \text{cost of cultivation (₹ ha}^{-1})$$

$$\text{Benefit cost ratio (B:C ratio)} = \frac{\text{Gross returns (₹ ha}^{-1})}{\text{Cost of cultivation (₹ ha}^{-1})}$$

Production and monetary efficiencies
Production efficiency (PE) (kg ha^{-1} day^{-1}) of rice-wheat cropping system was computed using following expression:

$$\text{PE} = \frac{\text{Economic yield of wheat (kg ha}^{-1})}{\text{No. of days of crop season i.e. 160}}$$

Profitability in terms of monetary efficiency (ME) (₹ ha^{-1} day^{-1}) was calculated using following formula:

$$\text{ME} = \frac{\text{Net returns of wheat (₹ ha}^{-1})}{\text{No. of days of crop season i.e. 160}}$$

Statistical Analysis
The data generated on various parameters was statistically analyzed using *F*–test as per the procedure given by Gomez and Gomez (1984) [11]. Least significance difference (CD) values at P=0.05 were used to determine the significant differences between treatment means.

Results and Discussion
Plant height and dry matter accumulation
The plant height was registered statistically similar in all the locations and farmers' practice at initial stage of crop growth

i.e. 60 DAS during both the year of investigation (Table 1). However, at 120 DAS, plant height in different locations was registered significantly higher by 5.0% and 5.4% as compared to farmers practice during 2017-18 and 2018-19, respectively (Table 1). Similarly, during both the years, the dry matter accumulation did not differ significantly in different locations and farmers' practice at 60 DAS, however, DMA was recorded significantly less by 11.3% and 9.9% in farmers' practice, respectively than different locations involving soil chiseling practice during both the year of study (Table 1). The similar plant height and dry matter accumulation at initial stages of crop growth was probably due to less developed root system and proportionately lesser plant vigour/height. But, as the crop advance towards maturity, the root development also increases but the presence of hardpans didn't allow the roots to penetrate and expand further, causes water stagnating conditions, poor aeration, etc (Wang *et al.* 2019) [25], which ultimately resulted in lesser plant growth and development on later stages leading to lesser plant height and dry matter accumulation, as the case in farmers' practice (Plate 2). However, soil chiseling loosens the soil by shattering restrictive layers below normal plough depth and improves soil porosity, water movement (soil permeability) or root development (Colonego and Rosolem 2010; Nunes *et al.* 2014) [6, 21] resulted in more plant height and dry matter accumulation as the case in trial locations involving soil chiseling. Kahlon and Chawla (2017) [14] also obtained significantly higher plant height in wheat and maize following deep tillage practice as compared to conventional tillage in Indian Punjab.

They attributed increased plant height and dry matter accumulation under deep tillage to enhanced nutrients and moisture availability than conventional tillage practices. Raza *et al.* (2005) [22] also observed that hardpan significantly reduced the nutrients uptake and yield of maize fodder, whereas chisel broken hardpan increased the yield of above crop significantly.

Plate 2: Comparison of crop sown after soil chiseling (L) Vs farmers' practices (R). The farmers practice showing poor crop stand due to water stagnation problem in the field

1000 grain weight

Higher value of 1000 grain weight was obtained at different locations with soil chiseling practice in comparison with farmers' practice, though they were statistically at par with each other (Table 1). The magnitude of increase in above parameter following soil chiseling practice in different locations was to the tune of 2.3% and 4.8%, respectively over farmers practice (Table 1). The more grain weight than farmers' practice is due to better crop growth and development which resulted in bolder and good weighted seed (Plate 3). Actually soil chiseling create preferred paths for the flow of water and the preferred flow created by fibrous roots also guided and facilitated water infiltration into deeper soil layers (Jiang *et al.* 2018) [13], which reduce the problem of water stagnation and aeration and resulting in better crop growth and in turn healthier grains. The thousand grain weight was registered higher under deep tillage practice in wheat crop than conventional one also by Kahlon and Chawla (2017) [14]. They also attributed this character as a major yield contributing factor.

Plate 3: Crop vigour following soil chiseling practice

Table 1: Effect of soil chiseling practice on growth indices of wheat crop

Particulars	Plant Height (cm)				Dry matter (g/plant)				1000 grain weight (g)	
	2017-18		2018-19		2017-18		2018-19		2017-18	2018-19
	60 DAS	120 DAS	60 DAS	120 DAS	60 DAS	120 DAS	60 DAS	120 DAS		
Location I	39.2	83.4	38.1	81.7	2.27	10.6	2.31	9.8	40.2	37.2
Location II	38.9	81.1	37.7	81.7	2.27	10.2	2.33	9.8	39.8	38.3
Location III	38.8	81.3	38.1	80.9	2.31	10.3	2.29	9.6	39.6	38.2
Location IV	39.3	82.9	39.4	82.1	2.25	10.9	2.34	10.1	38.7	38.6
Location V	39.0	81.8	37.9	80.6	2.27	10.3	2.31	9.6	40.1	39.0
Farmers' Practice	38.9	78.2	38.1	77.2	2.26	9.4	2.32	8.9	38.8	36.5

SE (m)	0.77	0.82	0.41	0.79	0.020	0.31	0.019	0.45	0.49	0.52
LSD (P=0.05)	NS	2.62	NS	2.52	NS	NS	NS	NS	NS	NS

Table 2: Effect of soil chiseling practice on yield and economics of wheat crop

Particulars	2017-18			2018-19		
	Yield	Net Returns	B:C ratio	Yield	Net Returns	B:C ratio
Location I	52.5	62973	3.24	48.2	54015	2.56
Location II	51.7	61585	3.19	50.0	57266	2.65
Location III	49.8	58231	3.07	49.3	56100	2.62
Location IV	52.1	62279	3.21	49.3	55978	2.61
Location V	49.9	58520	3.08	48.1	53831	2.55
Farmers' Practice	46.2	52042	2.85	45.0	48440	2.41
SE(m)	0.67	1164.8	0.042	0.56	1035.3	0.030
LSD (P=0.05)	2.14	3717.8	0.133	1.79	3304.6	0.094

Absolute, relative and crop growth rate

The soil chiseling practice prior to sowing of wheat crop resulted in higher growth rate as compared to farmers practice. The average increase in 'absolute growth rate (AGR)' was significantly higher by 9.5 and 10.4% at different locations in comparison with farmers practice, respectively during both the year of experimentation (Fig 3 & 4). Similarly, magnitude of increase in 'relative growth rate (RGR)' in different locations with soil chiseling was higher by 5.8 and 5.2%, respectively over farmers' practice during 2017-18 and 2018-19, though they were did not differ statistically and found at par (Fig 3 & 4). The 'crop growth rate (CGR)' also follow the similar trend as that of RGR and the values of CGR were numerically higher under soil chiseling than farmers' practice, but statistically similar during both the year of study (Fig 3 & 4). The above parameters are derived from plant height and dry matter accumulation; hence any factor affecting plant height and dry matter will also influence the absolute, relative and crop growth rate directly. The soil chiseling promotes higher root proliferation both laterally and vertically downward because of loosened soil conditions performed by deep ploughing the field, which results in enhanced nutrients and moisture availability and in turn better plant growth. Memon *et al.* (2013) [20] also registered higher maize plant height following deep tillage than conventional method because of enhanced nutrients and moisture availability in deep tillage than conventional one.

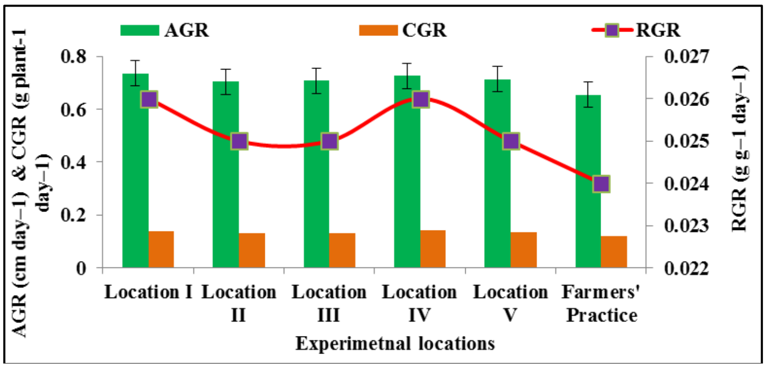

Fig 3: Effect of soil chiseling practice on growth indices of wheat during 2017-18. *Bars represent CD values at P=0.05 to determine the significance differences among treatment means*

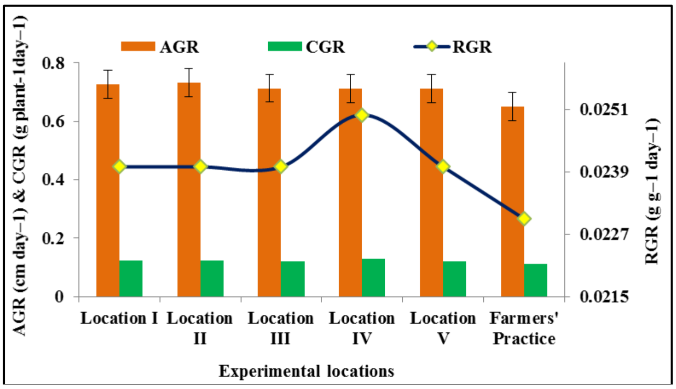

Fig 4: Effect of soil chiseling practice on growth indices of wheat during 2018-19. *Bars represent CD values at P=0.05 to determine the significance differences among treatment means*

Yield and Profitability

The soil chiseling practice showed a favourable and significant influence on yield, net returns and benefit: cost ratio of wheat crop during both the year of experimentation. The magnitude of increase in wheat yield involving soil chiseling operation at different locations (average) was significantly higher by 10.8 and 8.8% during 2017-18 and 2018-19, respectively in comparison with farmers' practice of the region (Table 2). The net returns and B:C ratio registered a significant respective increases of 16.7 & 14.4% during 2017-18 and 8.8 & 7.8% during 2018-19 in different location following soil chiseling as compared to farmers' practice (Table 2). As discussed in earlier, variation in yield and other growth parameters at different locations were observed probably due to the summative influence of soil (*variation in soil nutrient status & extent of hardpans or water stagnation*), climate and soil chiseling, etc. Chiseling decreases soil bulk density in deep tillage due to shattering and loosening of soil up to 45-50 cm depth (Kahlon and Chawla 2017) [14] resulting in reduction in compaction and increase in porosity (more porous soil). Moreover, soil under chiselling results in a favourable physical environment for root growth (Betz *et al.* 1998; Cavalieri *et al.* 2006) [3, 5]. As the penetration resistance decreases, soil helps in maintaining effective plant rooting and facilitates good water and nutrient uptake by plants from deeper layers, which subsequently help in improving the crop yield, similar the case in present study.

Wang *et al.* (2019) [25] also obtained 21.9 and 11.3% significantly higher wheat grain yield in sub-soiling tillage during 2016 and 2017, respectively. They stated that sub-soiling tillage improved the resilience of winter wheat under adverse climate condition and it is essential to deepen the plough pan in soil to obtain higher yield as chiseling decreased the soil bulk density and increased water retention in the soil. Since sub-soiling improves soil physical conditions and increases wheat yield, it is essential to follow this practice in problematic areas. Further, in view of the deterioration of soil structure caused by continuous rotary tillage, chiseling at 35-40 cm may provide improvements, by increasing soil stable infiltration rate, water consumption and grain yield (Kuang *et al.* 2020) [16]. As in farmers' practice the soil chiseling was not done before sowing of wheat crop, there is problem of water stagnation and poor infiltration for more days following irrigation or rain leading to yellowing, stunted crop stand probably due to poor aeration in roots and lesser nutrient uptake, which ultimately led to low yield and returns in case of farmers' practice. Similar explanation was given by Wang *et al.* (2019) [25] for lesser wheat yield in rotary tillage method.

The higher net returns and B:C ratio in locations involving soil chiseling over farmers practice is due to higher yield in the former. The results obtained from present study also supported by the findings of Raza *et al.* (2005) [22]. Many researchers recommended the chisel plough once in three years for normal cultivated soils (Ishaq *et al*. 2003; Ahmed *et al*. 1996) [12, 1]. Beside, several studies have witnessed improved soil properties, nutrient-use efficiency and crop water productivity following sub-soiling/chiseling (at a depth of 35–40 cm) because of increased water infiltration by removing the resistance from the solid bottom layer (Kaur and Arora 2019; Varsa *et al.* 1997; Bogunovic *et al*. 2018) [15, 23, 4], which ultimately promote crop growth and development in comparison with conventional tillage methods.

Production and monetary efficiencies

On the pattern of above parameters production and monetary efficiencies increased significantly as result of soil chiseling operation carried out before wheat sowing. The magnitude of increase in production efficiency with soil chiseling operation was to the extent of 10.7 and 8.9% during 2017-18 and 2018-19, respectively than farmers' practice (Fig 5 & 6). Likewise, monetary efficiency showed a positive and significant increase by 16.4 and 14.3%, respectively over farmers practice during both the year of investigation (Fig 5 & 6).

The increases in crop yields resulted in higher production efficiency. Similarly, monetary efficiency was higher after following recommended soil chiseling as a result of higher returns (Kumar *et al.* 2015 & 2019) [18, 17]. As the yield increase there are more net returns and more profit margins than farmers' practice not involving soil chiseling. The same reasoning as given under crop yield and net returns parameters holds true here also.

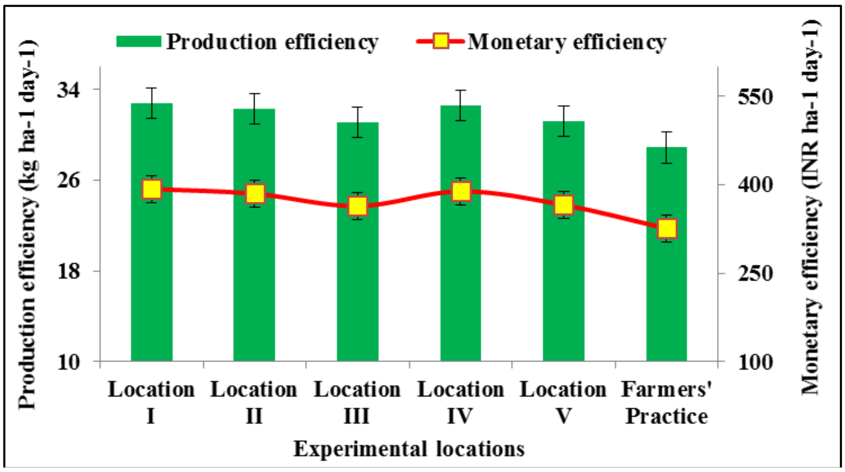

Fig 5: Effect of soil chiseling practice on production and monetary efficiencies of wheat during 2017-18. Bars represent CD values at P=0.05 to determine the significance differences among treatment means

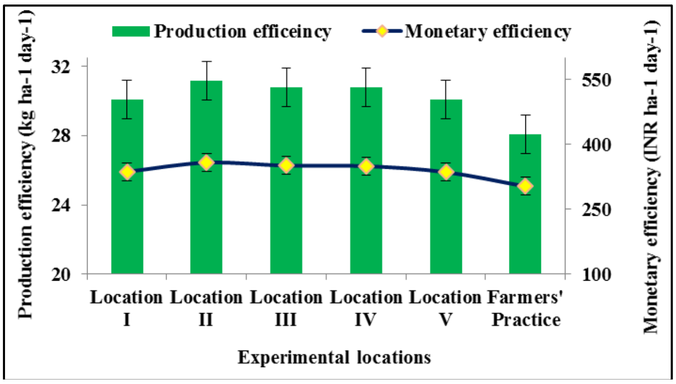

Fig 6: Effect of soil chiseling practice on production and monetary efficiencies of wheat during 2018-19. *Bars represent CD values at P=0.05 to determine the significance differences among treatment means*

Conclusion

The results of the experiment showed that soil chiseling led to enhanced plant growth which got reflected in higher growth indices and yield, which in turn ensure better returns in comparison to farmers' practice as reflected in production and monetary efficiencies. The chiseling prior to wheat sowing helped in reducing the soil compaction by lowering soil bulk density, improve aeration and provide better environment for root proliferation ensuring water and nutrient uptake from deeper soil layers. Thus, soil chiseling may be good option to the resource poor farmers, who face the problem of water stagnation after irrigation or heavy rainfall and loss in yield and income.

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