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Winter wheat yield and soil physical properties responses to different tillage and irrigation

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ABSTRACT

Adopting a better tillage system not only improves the soil properties and crop productivity but also improves water use efficiency. A field experiment was conducted over 2 years in Norman E Borlaug Crop Research Centre of the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar region of Uttarakhand, India to determine the effect of tillage systems and irrigation treatments on soil physical properties and yield of winter wheat (*Triticum aestivum* L.). Plots having conventional tillage along with frequent irrigation showed higher values of saturated hydraulic conductivity while zero tillage gaves the higher values of bulk density, mean weight diameter, plant available water capacity, effective porosity and soil organic carbon. Wheat yield was not significantly affected by tillage practices. There was a significant increase in wheat yield in the plots under I4 over I1 and water use efficiency between irrigation treatments was also significantly different. Hence, for wheat crop in a sandy loam soil of the Uttarakhand, farmers may adopt CT with four irrigations to achieve maximum yield. This information is important for farmers from the point of view of increasing production and profitability.

Keywords: Tillage; Irrigation; Yield; Soil physical properties; Water use efficiency.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.), second most important cereal crop in India, with an average annual production of 80 Mt and contribute approximately 11.79 percent in world's wheat production. Wheat is the crop which is sown and harvested every month in different parts of the world [1]. One of the main constraints in wheat production is improvement of production and profitability. In any cropping system, to increase the production there is need to improve the input use efficiency. So, to overcome this, producers started to adopt different resource conserving practices like zero tillage, surface seeding and manipulations in numbers of irrigations [2].

Tillage and irrigation can be considered as most critical management practices, as both affect the production potential of crop and soil hydro-physical properties [3]. Big issue under rainfed farming in sub-temperate regions of the Indian Himalayas is irrigation [4]. Role of irrigation is quite clear as; soil moisture deficits at critical crop growth stages can affect the wheat yield. There is correlation between tillage intensity and soil moisture regime. Hatfield and Stewart [5] reported that conservation tillage is helpful in maintaining soil moisture in comparison to intensive tillage operation. Tillage plays importnat role in changing initial state of soil which modify whole environment, like bulk density and porosity which affects the infiltration rate of soil [6]. Bhattachariya [4] and Li [7] already reported that, change in bulk density depends on the intensity of tillage systems. Different tillage systems produce different results like zero tillage (ZT) promotes SOC sequestration [8], improved soil aggregates [9] and better pore size allocation [10] while conventional tillage (CT) usually increases available water capacity and infiltration rate and decreases runoff [11]. Field experiments with zero tillage in wheat at several locations shown encouraging results [12, 13], while Cavalieri [14], reported low wheat yield under zero tillage due to formation of compact layer below the plough layer. On the other side, conventional tillage (CT) in specific ecosystems may improve some key soil properties compared to those under NT [15].

Hence, implementation of proper tillage practice in wheat system is most important for better resource conservation and in optimizing crop production. Even though the mean rainfall during wheat growing season are 37 and 191.7 mm, during 2011-2012 and 2012-2013, respectively (Table 1).

Table 1. Total rainfall received during the wheat growing season (Oct-Apr) over the years (2011-2013) at Pantnagar, Uttarakhand, India.

Years	Rainfall (mm)
2011-2012	37.0
2012-2013	191.7
Mean (2011-2013)	233

As soil moisture is available due to rain, but there is an urgent need to organize the irrigation scheduling during the crop period. Scanty literature is there regarding to the subject, how different tillage and irrigation schedules affect yield performance of wheat and soil properties. Moreover, we found no report on the scheduling of irrigation in this region under different tillage practices. Therefore, this investigation was undertaken to study the effect of tillage practices on soil physical properties, water use and grain yield of wheat crop under irrigation at critical growth stages of wheat in a sandy loam soil of the Uttarakhand.

2. MATERIAL AND METHODS

2.1. Experimental site

The experiment was conducted at the Norman E Borlaug Crop Research Centre of the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. The experimental site was situated at $28^0$30'N latitude, $79^0$30'E longitude and 243.8 m altitude. The soil (0-15 cm deep) of the experimental field had a pH of 6.4, bulk density of 1.41 Mg m^{-3}, SOC of 0.73 %, available P of 14 kg ha^{-1} and available K of 145 kg ha^{-1}. The subsurface soil (15-30 cm deep) had a bulk density of 1.44 Mg m^{-3}.

2.2. Experimental design and treatments

The experiment was laid out in a two factorial randomized block design with tillage operation:
1. Zero tillage (ZT): removing weeds & previous crop residues, minimum soil disturbance was achieved with line openers for sowing,
2. Conventional tillage (CT): disc harrow were used two times up to 30 cm followed by manual land leveling in each plot and
3. Deep tillage (DT): done by plowing the field by Mold bold plough up to 45 cm followed by land leveling as first factor and application of five irrigations as second factor: I_1: crown root initiation (CRI), I_2: CRI + late tillering (LT), I_3: CRI + LT + late joining (LJ), I_4: CRI + LT + LJ + flowering (F), and I_5: CRI + LT + LJ + F + milking (M), were applied at critical growth stage. These treatments were repeated in the same plots during both the years. Each treatment was replicated three times and plot size was of 20.0 m^2.

2.3. Crop management

Shallow furrows at 3 to 5 cm depth were opened at 23 cm distance using tractor driven furrow opener and sowing of wheat (UP-2565) was done manually. The furrows were covered immediately manually. The fertilizer dose was 120:60:40

(N:P:K) kg ha^{-1}. Full rate of P as single super-phosphate, K as muriate of potash were applied at the time of sowing and, N was applied in 3 splits (1/2 at the time of sowing, 1/4 at crown root initiation stage and remaining 1/4 at pre-ear head emergence) using urea. For controlling the pre-emergence weeds Pendimethiline 3.3 liter per ha was applied on the date of sowing followed by two hand weeding at about one and two month after sowing with the help of khurpi. Crop was irrigated according to the irrigation schedules in the different treatments. Grain yield of crop was determined during both the cropping seasons.

2.4. Soil sampling and analysis

Triplicate undisturbed soil cores (15 cm high and 7.6 cm diameter) were obtained from 0-15 to 15-30 cm soil depths after the wheat harvest from each plot. Soil parameters, such as soil organic C [16], bulk density, saturated hydraulic conductivity [17] and effective porosity [18] were determined. Water retention was determined at water potentials of -30 and -1500 kPa using pressure plate apparatus. Water retention multiplied by the soil depth gives plant available water capacity.

For wheat yield estimation, crop was harvested from 2 m^2 area in the center of plot with the help of sickles and left there for sun-drying. After drying, biological and grain yield were determined. The water use efficiency (WUE) was computed as: WUE (kg ha^{-1} mm^{-1}) = grain yield (kg ha^{-1})/total water use (mm).

2.5. Statistical analysis

The laboratory and experimental data were analyzed by using standard procedure for a two factorial randomized block design with the help of computer applying analysis of variance (ANOVA) technique [19]. The differences among treatments were compared by applying F test of significance at 5% level of significance or probability. Tillage and irrigation system means were separated using the two factorial randomized block design at $P < 0.05$.

3. RESULTS AND DISCUSSION

3.1. Soil bulk density

Soil bulk density determined after the crop was higher in the ZT and I_1 plots than the other plots (Table 2) and significantly affected by tillage practices. However, application of water had considerable effect on soil bulk density. There was very little variation in bulk density values between the tilled and irrigated plots. High soil bulk value indicates less disturbance of soil under ZT plots, which creates low porosity compared to tilled plots. These results are in congruence with the studies of Bajpai and Tripathi [20] and Bhattachariya [4]. They also reported higher value of soil bulk density under ZT at the soil surface compared with tilled soil.

3.2. Saturated hydraulic conductivity (Ksat)

Saturated hydraulic conductivity values under DT and I_5 plots were higher than the other plots (Table 2). The interaction effects of tillage and irrigation treatments were non-significant in the 0-15 and 15-30 cm soil layer. This is mainly due to tillage, there is reorganization of pores in tilled plots which increases the permeability of soil and degree of increment depends on the tillage depth [4, 21].

3.3. Mean weight diameter

Mean weight diameter (MWD) of soil particles decreases significantly under DT plots in both soil layer (Tables 2) and the similar effect of the different irrigation treatments was found, I_5 plots have high MWD values. There was non-significant interaction effect of tillage and irrigation treatments. The significant effects of tillage methods on MWD were mainly tillage-induced, as it affects SOC content and soil microbial activity. Lal [9] reported that zero tilled plots have higher SOC content which imparts better aggregation in soil while under DT aggregate size is less due to oxidation of exposed soil organic matter [22].

3.4. Plant available water capacity (PAWC)

Water retention capacity decreases with more tillage operations, so the PAWC, found higher in ZT plots (Tables 2) while, due to number of irrigations, there was major improvement in PAWC in both soil depths. This was mainly attributed due to the presence of higher amounts of organic matter and increased bulk density values in ZT plots, so the water retention was also higher. Similar findings were reported by Azooz [23] and Bhattachariya [4], that due to under ZT plots can hold on more soil moisture.

Table 2. Effect of tillage and irrigation on soil physical properties and soil organic C at wheat harvest (after 2 years) in surface 0-15 cm (a) and sub-surface 15-30 cm (b) layer.

Treatments	Bulk density ($Mg\ m^{-3}$)		Saturated hydraulic conductivity (unit)		Mean weight diameter (mm)		Plant available water capacity (cm/15 cm soil layer)	
	a	**b**	**a**	**b**	**a**	**b**	**a**	**b**
				Tillage (T)				
ZT	1.43	1.45	21.3	17.1	0.74	0.63	2.63	2.26
CT	1.39	1.41	21.8	17.6	0.71	0.62	2.36	1.96
DT	1.36	1.38	22.3	18.3	0.58	0.52	2.11	1.78
(P=0.05)	0.14	0.97	0.31	0.32	0.11	0.16	0.20	0.15
				Irrigation (I)				
I_1	1.42	1.45	19.8	15.7	0.60	0.52	2.22	1.77
I_2	1.40	1.42	20.7	16.5	0.64	0.55	2.28	1.93
I_3	1.39	1.41	21.7	17.6	0.68	0.60	2.38	2.02
I_4	1.38	1.40	23.0	18.8	0.72	0.63	2.44	2.10
I_5	1.37	1.39	23.9	19.8	0.75	0.65	2.51	2.19
(P=0.05)	0.12	0.12	0.40	0.41	0.14	0.21	0.26	0.20
T X I (P=0.05)	NS	NS	NS	NS	NS	NS	0.46	0.35

NS indicates not significant. ZT indicates zero tillage; CT indicates conventional tillage and DT indicates deep tillage. I_1, I_2, I_3, I_4 and I_5 indicate I_1: crown root initiation (CRI), I_2: CRI + late tillering (LT), I_3: CRI + LT + late joining (LJ), I_4: CRI + LT + LJ + flowering (F), and I_5: CRI + LT + LJ + F + milking (M), respectively.

Table 3. Effect of tillage and irrigation on effective porosity and soil organic C at wheat harvest (after 2 years).

Treatments	Effective porosity ($m^3\ m^{-3}$)	Soil organic carbon (%)
	Tillage	
ZT	0.187	0.76
CT	0.174	0.74
DT	0.162	0.70
(P=0.05)	0.11	0.39
	Irrigation	
I_1	0.164	0.73
I_2	0.170	0.74
I_3	0.175	0.70
I_4	0.179	0.74
I_5	0.184	0.75
(P=0.05)	0.14	NS
T X I (P=0.05)	NS	NS

NS indicates not significant. ZT indicates zero tillage and CT indicates conventional tillage and DT indicates deep tillage. I_1, I_2, I_3, I_4 and I_5 indicate I_1: crown root initiation (CRI), I_2: CRI + late tillering (LT), I_3: CRI + LT + late joining (LJ), I_4: CRI + LT + LJ + flowering (F), and I_5: CRI + LT + LJ + F + milking (M), respectively.

Table 4. Effect of tillage practices and irrigation levels on grain yield and water use efficiency of wheat.

Treatments	2011-2012					2012-2013				
	Grain yield (kg/ha)	Irrigation (mm)	Rainfall (mm)	Water use (mm)	Water use efficiency (kg/ha/mm)	Grain yield (kg/ha)	Irrigation (mm)	Rainfall (mm)	Water use (mm)	Water use efficiency (kg/ha/mm)
Tillage										
ZT	2946	300	37	337	15.8	3583	300	191.7	491.7	9.9
CT	3438	300	37	337	18.2	3933	300	191.7	491.7	11.0
DT	3340	300	37	337	18.2	3708	300	191.7	491.7	10.5
(P=0.05)	222.52				1.34	168.92				0.46
Irrigation										
I_1	2911	60	37	97	30.0	3430	60	191.7	251.7	13.6
I_2	3180	120	37	157	20.2	3569	120	191.7	311.7	11.4
I_3	3027	180	37	217	13.9	3736	180	191.7	371.7	10.0
I_4	3486	240	37	277	12.5	4173	240	191.7	431.7	9.6
I_5	3602	300	37	337	10.6	3798	300	191.7	491.7	7.7
(P=0.05)	287.27				1.73	256.00				0.59
TXI (P=0.05)	NS				NS	377.73				1.39

NS indicates not significant. ZT indicates zero tillage, CT indicates conventional tillage and DT indicates deep tillage. I_1, I_2, I_3, I_4 and I_5 indicate I_1: crown root initiation (CRI), I_2: CRI + late tillering (LT), I_3: CRI + LT + late joining (LJ), I_4: CRI + LT + LJ + flowering (F), and I_5: CRI + LT + LJ + F + milking (M), respectively.

3.5. Effective porosity

Although the effective porosity was significantly different under tilled plots, under ZT plots inclination in porosity in 0-15 cm soil layer was observed when compared with other plots (Table 3). Irrigation treatments had also noticeable effect on the porosity of soil. ZT management practice reduces number of large pores and increases small pores, due to this high effective porosity are maintained. Pagliai [24] reported that pores, i.e. macro as well as micro, are important to maintain the water holding capacity, good soil structure and soil-plant-water relationships.

3.6. Soil organic C (SOC)

Soil organic C contents in 0-15 cm soil depth were higher under zero tillage (ZT) than other ones, while irrigation and the interaction effects of tillage and irrigation produces non-significant ($P < 0.05$) effect (Table 3). According to Kay and Vanden Bygaart [25] less disintegration of the soil matrix under ZT plots slows down the SOC mineralization and imparts higher concentration of SOC. Tillage accelerates the decomposition and C mineralization rate of organic matter [26]. Similarly, Koga and Tsuji [27], Presley [28] and Mukherjee and Lal [29] also reported that SOC is significantly higher in ZT plots due to less soil interruption in comparison to tilled ones.

3.7. Wheat yield

Wheat yield did not affect significantly due to reduction in tillage operation during both the cropping seasons as there was only 491.0 kg ha^{-1} and 350.0 kg ha^{-1}wheat yield decline under ZT in comparison to CT (Table 4). Irrigation treatments also showed significant yield differences during both the years of the study. Analysis of the experimental data, wheat yield was not significantly different under different tillage practices, but less cost of cultivation and early sowing of crop under ZT is the main benefit [21]. During the 2011-2012, wheat yields were significantly affected by different levels of irrigation, with higher yield in the plots under I_4 over I_1 and I_5 over I_1. During 2012-2013, results again showed the similar trend as recorded in 2011-2012. Plots under I_4 had statistically similar grain yield as the plots under I_1. Thus, our results during 2011-2013 indicated that the cost of cultivation may be reduced under I_4 plots by saving one-irrigation because there was not too much difference in yield between I_4 and I_5 irrigation plots. The reason for achieving the higher yield under conventional tillage and deep tillage is proper field preparation, lesser weed competition and enrichment of the nutrient in the plough zone, where roots of the crop had sufficient nutrient and water availability to gain or optimizing the yield target. Similar results were also reported by Singh [30] and Gangwar [31] they observed that among the different tillage levels, conventional tillage recorded the highest grain yield of wheat followed by RT and ZT. Increased yield with conventional tillage over zero tillage in wheat was also reported by several workers [32, 33]. The lower yield in zero tillage plots was mainly due to heavy crop/weed competition. Higher grain yield (1830 kg ha^{-1}) and straw yield (2820 kg ha^{-1}) of wheat (cv. Sonalika), was reported when irrigations were applied five times at crown root initiation, tillering, jointing, flowering and dough stages by Cheema [34]. Singh and Patel [35] reported that stress at tillering, flowering and grain filling stages reduced both grain yield and plant biomass in wheat. Singh and Patel [35] also reported mean grain yield of 458 kg ha^{-1}, when plots were irrigated before sowing only (BS), 1328 kg ha^{-1} when irrigation was applied at BS + crown root initiation (CRI) and 1826 kg ha^{-1} when full irrigations were applied as per the requirement of the crop.

3.8. Water use efficiency (WUE) of wheat

CT showed higher value of water use about 13.8% in 2011-12 and 10.0% in 2012-2013 (Table 4) as compared to ZT plots. WUE values were also similar, because there was no significant difference in yield among the tillage treatments. Under different irrigation treatments, WUE values differ significantly because water use values increases frequently with the number of irrigations. Similar findings were reported by Bhattacharya [10] who conducted an experiment on sandy clay loam soil in Almora and observed that WUE was highest in more tilled plot in comparison to zero tillage plots and decreases with increase in the number of irrigation. Deshmukh [36] also found that the highest WUE (8.64 kg ha^{-1} mm^{-1}) when one irrigation was applied at crown root initiation stage. Lower values for WUE were recorded when irrigation frequency increased from one to five (7.65 kg ha^{-1} mm^{-1}).

4. CONCLUSION

The study has revealed that it is possible that under ZT there was more SOC content over CT and DT. More tillage operation will cause more disruption of soil and its physical properties in the surface soil layer. Also, there were no significant differences in yield and WUE of wheat due to different tillage practices. The superiority of ZT is also due to less loss of water via leaching due to better rearrangement of pore size classes for faster water transmission under saturated conditions. There was a significant increase in wheat yield in the plots where four irrigations were applied over one-irrigation or over two irrigations. Soil properties (SOC, bulk density and saturated hydraulic conductivity) measured after harvest of crop during both the cropping seasons did not significantly affected by irrigation treatments. Hence, for wheat crop in a sandy loam soil of Uttarakhand, farmers may adopt CT with four irrigations for achieving maximum yield and they can save the cost of one irrigation. If there was water stress for irrigation, ZT may be adopted due to improve SOC status, soil physical properties, for saving machine, labor and irrigation water cost. However, ZT practice may be also be adopted with proper chemical weed management practices.

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AUTHORS' CONTRIBUTION

GM and HSK contibuted equally to this work. The final manuscript has been read and approved by both authors.

TRANSPARENCY DECLARATION

The authors declare no conflicts of interest.

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