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Effect of soil compaction and irrigation schedules on growth and development of wheat with different dates of sowing

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Abstract
Wheat is an important crop for India and Uttarakhand which is sown during November-December and is harvested in April. Area, production, and productivity of wheat were 3.79 lakh- ha, 8.78 lakh metric tonnes, and 23.16 q ha^{-1}, respectively, in Uttarakhand (during 2015-16) which is even lower than the average productivity of wheat in India. Lower productivity of wheat in Indian and Uttarakhand context is due to temperature and soil moisture stress. Light texture soils (viz. sandy loam) having excessive permeability mainly because of their coarse texture, looseness and poor organic matter content, compaction has desirable effects on soil physical conditions. Moisture retention capacities of these soils are very low and more than one third of applied or rain water gets lost by deep percolation. In present investigation different irrigation schedules, compaction levels and sowing dates treatments were studied to find out their best suited levels and their interactions with the growth and development of wheat crop that majorly determines the yield of wheat crop. The field experiments were conducted in a sandy loam soil with wheat cv. UP-2565 under three compaction levels (C) viz. no compaction (C_1), 2 passes of 500 kg RCC roller (C_2) and 4 passes of roller (C_3) ; three irrigation schedules (I) viz. irrigation at 30 % depletion from available soil moisture (ASM)- I_1, irrigation at 40 % depletion from ASM- I_2 and irrigation at 50 % depletion from ASM- I_3 at three dates of sowing (D) viz. 5 Nov. (D_1), 20 Nov (D_2) and 5 Dec (D_3) with three replications during two consecutive rabi seasons of 2014-15 and 2015-16. The maximum plant height (cm) was obtained at 100 DAS with D_1 (109.92 and 114.38 cm), C_2 (105.89 and 110.04 cm) and I_1 (104.55 and 108.58 cm during 2014-15 and 2015-16, respectively). The maximum LAI was observed at 80 DAS with D_1 (3.89 and 4.02), C_2 (3.57 and 3.59 during 2014-15 and 2015-16, respectively) and I_1 (3.46) was found to be higher over the LAI with other irrigation schedules during 2014-15 and 2015-16. The maximum root length density (cm cm^{-3} of soil) was observed at 0-15 cm soil depth under D_1 (1.27 and 1.13 cm cm^{-3} of soil) and C_2 (1.18 and 1.03 cm cm^{-3} of soil), respectively. RLD at 0-15 cm soil depth was higher with I_1 (1.16 and 1.0 cm cm^{-3}of soil during 2014-15 and 2015-16, respectively). Days to seedling emergence was highest with D_3 (7.92 and 8.11), C_3 (7.60 and 7.69, during 2014-15 and 2015-16, respectively) and I_2 (6.53) and I_1 (6.72) during 2014-15 and 2015-16, respectively. Days to anthesis were significantly more with D_1 (91.49 and 81.94), C_3 (90.12 and 76.16) and I_1 (87.96 and 79.17 during 2014-15 and 2015-16, respectively). Days taken to physiological maturity was highest in D_1 (135.39 and 125.45), C_3 (131.85 and 120.19) and I_1 (129.37 and 119.00 during 2014-15 and 2015-16, respectively).

Keywords: compaction, irrigation schedules, growth, development, wheat and sowing dates

Introduction

Wheat (*Triticum aestivum* L.) is one of the oldest cereals widely consumed by human being. Wheat cultivation in India started 5000 years ago (Feldman, 2001) [1]. It is an excellent health-building food containing approximately 78% carbohydrates, 12% protein, 2% fat and minerals each and considerable amount of vitamins (Kumar *et al*., 2011) [2]. It is an important crop for India and Uttarakhand which is sown during November-December and is harvested in April. It is a *rabi* season crop and amount of rainfall during this period is mainly received through western disturbances. Hence, the water requirement of the crop is fulfilled by irrigation. Area, production, and productivity of wheat were 3.79 lakh- ha, 8.78 lakh metric tonnes, and 23.16 q ha^{-1}, respectively, in Uttarakhand during 2015-16 (GOI, 2016) [3] which is even lower than the average productivity of wheat in India. Lower productivity of wheat in Indian and Uttarakhand context is due to temperature and soil moisture stress. Wheat is affected by heat in early stage coupled with drought affecting field emergence and subsequent growth in absence of optimum soil moisture also, North Western Plain Zone known as wheat bowl of the country, experiences heat stress affecting the crop at grain filling stage thus one of the most important reasons of low productivity of wheat in India is late sowing with reduced crop duration. Light texture soils (*viz.* sandy loam) having excessive permeability mainly because of their coarse texture, looseness and poor organic matter content, compaction has desirable effects on soil physical conditions. Moisture retention capacities of these soils are very low and more than one third of applied or rain water gets lost by deep percolation (Mann and Singh, 1975) [4]. The fertility status of these soils is also very low. As such these soils are prone to heavy losses of nutrients. The possibility of increasing micro-pores at the expense of macro-pores by compacting soil at optimum moisture creates a barrier of relatively high bulk density was suggested by Ghildyal and Satyanarayana (1965) [5]. The concept put forward by Proctor (1933) [6], though used very extensively by civil engineers has not yet been used by agricultural scientists. Somani (1988) [7] advocated compaction of sandy soil is convenient and economic method of decreasing permeability and nutrient losses. Yadav (1984) [8] and Majumdar (1994) [9] suggested compaction of sandy soils for minimizing percolation losses of nutrients and it improves moisture storage capacity in the soils. Hence, soil compaction can play role in savings the number of irrigations. Since water is a precious commodity, therefore, studies on scheduling of irrigation, water use efficiency (WUE) and moisture depletion pattern in the soil are of direct interest for maximizing crop yields. Keeping all these facts in mind different irrigation schedules, compaction levels and sowing dates treatments were studied to find out their best suited levels and their interactions with the growth and development of wheat crop that majorly determines the yield of wheat crop.

Materials and Methods

The field experiments were conducted in a sandy loam soil with wheat cv. UP-2565 under three compaction levels (C) *viz.* no compaction (C_1), two passes of 500 kg RCC roller (C_2) and four passes of roller (C_3) ; three irrigation schedules (I) *viz*. irrigation at 30 % depletion from available soil moisture (I_1), irrigation at 40 % depletion from available soil moisture (I_2) and irrigation at 50 % depletion from available soil moisture (I_3) at three dates of sowing (D) *viz*. 5 November (D_1), 20 November (D_2) and 5 December (D_3) with three replications during two consecutive *rabi* seasons of 2014-15 and 2015-16 in C_5 plot in sandy loam soil situated at N. E. Borloug Crop Research Centre of the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar. The centre is located at 29^o N latitude, 79^{o}30$'$ E longitude and at an altitude of 243.84 m above the mean sea level. The area lies in the *tarai* belt of Uttarakhand which is 15-18 km wide strip lying immediately south of the *Bhabar* zone, at the foot hills of Shivalik range of the Himalayas. Experiments were conducted in 81 plots each of 4m x 3m size in each season and were laid out in split-split plot design with dates of sowing as main plot treatment, compaction levels as sub plot treatment and irrigation schedules as sub-sub plot treatment. The experimental data were analyzed by using standard procedure for a split-split plot design (Sheoran *et al.*, 1998) [10]. The differences among treatments were compared by applying F test of significance at 5% level of significance or probability. Growth observations *viz*. plant height, leaf area index and root length density and development parameters (*viz*. days to seedling emergence, days to anthesis and days to physiological maturity) were recorded at different intervals during crop period.

Plant height

The height of five randomly selected shoots from one metre square area was recorded at different intervals during crop growth period from the ground level to the top of the longest leaf till anthesis and to the tip of the top most spikelets at maturity.

Leaf area index (LAI)

Leaf area was calculated by selecting small, medium and large leaves in 20 cm row length recorded according to Quarrie and Jones equation *i.e.* Leaf area = Length x Breadth x 0.75 (Aldesuquy *et al.*, 2014) [11] at different intervals during crop growth period Total leaf area was calculated by multiplying the average leaf area with total number of leaves in 20 cm row length. Finally leaf area index was calculated by dividing total leaf area with land area in 20 cm row length as:

$$\text{Leaf area index (LAI)} = \frac{\text{Total leaf area per 20 cm row length (cm}^2)}{460\,(\text{cm}^2)}$$

Where, 460 cm^2 is the covered area of the soil by 20 cm row length.

Days to seedling emergence, anthesis and physiological maturity

The counting of the spikes was done on every day starting from the day when pollens were seen on few spikes till the number of the anthesised spikes became constant. At the end of the dough stage the moisture content of the kernels was determined regularly. The date on which the seeds had 30-35% moisture content was considered the date of physiological maturity and the days from sowing were calculated and recorded as days to physiological maturity.

Results and Discussion

Growth parameters

Plant height

The data pertaining to plant height (cm) of the wheat crop at different intervals an interval of 20 days, as influenced by different dates of sowing, compaction levels and irrigation schedules during *rabi* season of 2014-15 and 2015-16 are given in Table 1. Among the dates of sowing and compaction levels, plant height at 20 DAS was found significantly higher with D_1 (18.68 and 17.07 cm during 2014-15 and 2015-16) and C_2 (18.29 and 16.33 cm during 2014-15 and 2015-16), respectively. Plant height at 20 DAS was higher with treatment I_1 (17.35 cm) during 2014-15 and I_2 (15.61 cm) during 2015-16 over the plant height with other irrigation schedules but could not reach up to the level of significance during both the years. All treatment interactions for plant height at 20 DAS were found non-significant during both the years. Among the dates of sowing and compaction levels, plant height at 40 DAS was found significantly higher with D_1 (38.22 and 38.11 cm during 2014-15 and 2015-16) and C_2 (37.22 and 37.20 cm during 2014-15 and 2015-16), respectively. Plant height at 40 DAS with I_1 treatment (36.24 and 36.66 cm during 2014-15 and 2015-16, respectively) was found higher over the plant height with other irrigation schedules, however, found significant only during 2015-16. All treatment interactions for plant height at 40 DAS were found non-significant during both the years.

Among the dates of sowing and compaction levels, plant height at 60 DAS was found significantly higher with D_1 (74.00 and 74.61 cm during 2014-15 and 2015-16) and C_2 (71.94 and 72.81cm during 2014-15 and 2015-16), respectively. Plant height at 60 DAS with treatment I_1 (69.94 and 71.76 cm during 2014-15 and 2015-16, respectively) was found higher over the plant height with other irrigation schedules but could not reach up to the level of significance during 2014-15. All treatment interactions for plant height at 60 DAS were found non-significant during both the years. Among the dates of sowing and compaction levels, plant height at 80 DAS was found significantly higher with D_1 (92.50 and 93.26 cm in during 2014-15 and 2015-16) and C_2 (89.93 and 91.01 cm under during 2014-15 and 2015-16), respectively. Plant height with I_1 (87.43 cm) treatment during 2014-15 was found non-significantly higher over the plant height with other irrigation schedules while the plant height with same treatment was found significantly higher (89.70 cm) over the plant height with other irrigation schedules during 2015-16. All treatment interactions for plant height at 80 DAS were found non-significant during both the years.

Among the dates of sowing and compaction levels, plant height at 100 DAS was found significantly higher with D_1 (109.92 and 114.38 cm during 2014-15 and 2015-16) and C_2 (105.89 and 110.04 cm during 2014-15 and 2015-16, respectively). Plant height at 100 DAS with I_1 (104.55 and 108.58 cm during 2014-15 and 2015-16, respectively) was higher over the plant height with other irrigation schedules but found significant only during 2015-16. All treatment interactions for plant height at 100 DAS were found non-significant during both the years. Among the dates of sowing and compaction levels, plant height at maturity was found significantly higher with D_1 (107.72 and 110.95 cm during 2014-15 and 2015-16) and C_2 (103.77 and 106.74 cm during 2014-15 and 2015-16), respectively. Plant height at maturity with treatment I_1 (102.46 and 105.32 cm during 2014-15 and 2015-16, respectively) was higher over the plant height with other irrigation schedules but could not reach up to the level of significance during 2014-15. All treatment interactions for plant height at maturity were found non-significant during both the years.

The overall data on plant height indicated that at various intervals during crop growth of wheat, plant height was significantly influenced with the dates of sowing and compaction levels during both the years. Irrigation schedules had non-significant effect on plant height during 2014-15 while during 2015-16 significant effect of irrigation schedules was observed except at 20 DAS. Wheat crop receiving more period for its vegetative growth had taller plants under the D_1 compared with D_2 and D_3 during both the years. It may also be due more water use by the crop under D_1 treatment compared with other later sown crop. Kumar and Sharma (2003) [12] also reported a significant effect of dates of sowing on plant height of wheat crop and found that earlier sown crop produced significantly taller plants than the late sown crop. Compaction levels was found to have the significant effect on plant height indicating that with increase in compaction level up to C_2, the plant height increased due to more water availability but, thereafter, decreased due to relatively more compaction. Similar trends of soil compaction on plant height in light textured soils have also been reported by Majumdar and Singh (2000) [13]. Irrigation schedules were found non-significant during 2014-15 because excessive rainfall (187.4 mm) during the crop season attributed to sweep out the effect of irrigation schedules. During 2015-16, plant height at 20 DAS was found non-significantly affected with irrigation schedules because up to 20 DAS no treatment of irrigation schedules was employed. Plant height at later stages during 2015-16 was significantly affected with irrigation schedules. Ali *et al.* (2012) [14] also reported the significant effect of increasing number of irrigations in increasing plant height.

Table 1: Plant height (cm) of wheat crop at various intervals during crop growth as influenced by dates of sowing, compaction levels and irrigation schedules during *rabi* seasons of 2014-15 and 2015-16

Treatments	**20 DAS**		**40 DAS**		**60 DAS**		**80 DAS**		**100 DAS**		**At maturity**	
Dates of sowing	**2014-15**	**2015-16**	**2014-15**	**2015-16**	**2014-15**	**2015-16**	**2014-15**	**2015-16**	**2014-15**	**2015-16**	**2014-15**	**2015-16**
D_1	18.68	17.07	38.22	38.11	74.00	74.61	92.50	93.26	109.92	114.38	107.72	110.95
D_2	18.53	16.68	36.95	37.12	71.41	72.65	89.26	90.82	103.06	106.95	101.00	103.74
D_3	14.51	12.73	33.31	33.53	63.96	65.63	79.95	82.03	98.73	102.21	96.76	99.15
SEm±	0.25	0.21	0.05	0.23	0.68	0.46	0.92	0.57	0.81	1.27	0.80	1.22
CD (P=0.05)	0.98	0.83	0.19	0.91	2.07	1.79	2.85	2.24	3.16	3.94	3.12	3.78
Compaction levels												
C_1	16.00	14.47	35.07	35.39	67.56	69.28	84.45	86.60	102.13	105.86	100.09	102.69
C_2	18.29	16.33	37.22	37.20	71.94	72.81	89.93	91.01	105.89	110.04	103.77	106.74
C_3	17.43	15.67	36.20	36.16	69.86	70.79	87.33	88.49	103.69	107.64	101.62	104.41
SEm±	0.28	0.23	0.32	0.33	0.57	0.41	0.73	0.77	0.84	0.66	0.82	0.75
CD (P=0.05)	0.87	0.70	0.98	1.01	1.75	1.25	2.25	2.35	2.58	2.07	2.54	2.21
Irrigation Schedules												
I_1	17.35	15.39	36.24	36.66	69.94	71.76	87.43	89.70	104.55	108.58	102.46	105.32
I_2	17.21	15.61	36.14	35.99	69.76	70.44	87.20	88.05	104.05	108.03	101.97	104.79
I_3	17.16	15.48	36.10	36.11	69.67	70.68	87.08	88.35	103.11	106.93	101.05	103.72
SEm±	0.13	0.08	0.05	0.14	0.10	0.27	0.13	0.34	0.42	0.13	0.42	0.12
CD (P=0.05)	NS	NS	NS	0.39	NS	0.77	NS	0.96	NS	0.37	NS	0.36
Interactions												
D*C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C*I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D*I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D*C*I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Leaf area index

Leaf area index (LAI) of wheat crop at an interval of 20 days, as influenced by different dates of sowing, compaction levels and irrigation schedules during *rabi* season of 2014-15 and 2015-16 has been presented in Table 2. Among the dates of sowing and compaction levels, leaf area index at 20 DAS was found significantly higher with D_1 (1.08 and 1.07 during 2014-15 and 2015-16) and C_2 (0.92 and 0.92 during 2014-15 and 2015-16), respectively. LAI at 20 DAS with treatment I_1 (0.87 and 0.88 during 2014-15 and 2015-16, respectively) was higher than LAI with other irrigation schedules but could not reach up to the level of significance during both the years. All treatment interactions for LAI at 20 DAS were found non-significant during both the years. Among the dates of sowing and compaction levels, LAI at 40 DAS was found significantly higher with D_1 (2.07 and 2.04 during 2014-15 and 2015-16) and C_2 (1.78 and 1.83 during 2014-15 and 2015-16), respectively. LAI at 40 DAS with treatment I_2 (1.73) during 2014-15 was found non-significantly higher over LAI with other irrigation schedules. However, LAI with treatment I_1 (1.75) was found significantly higher over the LAI with other irrigation schedules during 2015-16. All treatment interactions for LAI at 40 DAS were non-significant during both the years.

Among the dates of sowing and compaction levels, LAI at 60 DAS was found significantly higher with D_1 (3.76 and 3.80 during 2014-15 and 2015-16) and C_2 (3.36 and 3.40 during 2014-15 and 2015-16), respectively. LAI at 60 DAS with I_1 (3.25) during 2014-15 was found non-significantly higher while LAI with I_1 (3.27) was found significantly higher over the LAI with other irrigation schedules during 2015-16. All treatment interactions for LAI at 60 DAS were found non-significant during both the years. Among the dates of sowing and compaction levels, LAI at 80 DAS was found significantly higher with D_1 (3.89 and 4.02 during 2014-15 and 2015-16) and C_2 (3.57 and 3.59 during 2014-15 and 2015-16), respectively. LAI at 80 DAS with treatment I_1 (3.46) was found to be higher over the LAI with other irrigation schedules during 2014-15 but could not reach up to the level of significance. However, LAI at 80 DAS with treatment I_1 (3.46) during 2015-16 was found significantly higher over the LAI with other irrigation schedules. All treatment interactions for LAI at 80 DAS were found non-significant during both the years.

Among the dates of sowing and compaction levels, LAI at 100 DAS was found significantly higher with D_1 (3.56 and 3.51 during 2014-15 and 2015-16) and C_2 (3.07 and 3.15 during 2014-15 and 2015-16), respectively. LAI at 100 DAS with I_2 (2.98) during 2014-15 was found non-significantly higher while LAI with treatment I_1 (3.02) was found significantly higher over the LAI with other irrigation schedules during 2015-16. All treatment interactions for LAI at 100 DAS were found non-significant during both the years.

Among the dates of sowing and compaction levels, LAI at maturity was found significantly higher with D_1 (2.20 and 2.23 during 2014-15 and 2015-16) and C_2 (1.89 and 1.82 during 2014-15 and 2015-16), respectively. LAI at maturity with treatment I_1 (1.79) during 2014-15 was non-significantly higher over the LAI with other irrigation schedules. However, LAI at maturity with treatment I_1 (1.69) was found significantly higher over the LAI with other irrigation schedules during 2015-16. All treatment interactions for LAI at maturity were found non-significant during both the years.

The results indicate that at various intervals during crop growth of wheat, leaf area index of wheat was significantly influenced with the dates of sowing and compaction levels during 2014-15 and 2015-16. Irrigation schedules during 2014-15 was found to have non-significant effect on leaf area index while during 2015-16, irrigation schedules was found to have significant effect over leaf area index of wheat except at 20 DAS. Higher leaf area index obtained under the treatment D_1 during both the years, was due to increased length of vegetative growth period. Lower LAI in late sown crop indicates that crop did not receive optimum temperature and time for its vegetative development. Also, total water use under treatment D_1 is higher than the other treatments within dates of sowing. Yadav and Somani (1990) [15] reported that compaction in light texture soil, increases moisture storage capacity and decreases nutrient losses which might be the reason behind significant effect of compaction in increasing LAI with increase in compaction level up to C_2 but thereafter decreased due to excessive compaction. Significant effects of irrigation schedules on LAI during 2015-16 are in conformity with the findings of Ali *et al.* (2012) [14] who have reported that LAI of wheat crop was maximum with five irrigations over rainfed, two, three and four irrigations.

Table 2: Leaf area index of wheat at various intervals during crop growth as influenced by dates of sowing, compaction levels and irrigation schedules during *rabi* seasons of 2014-15 and 2015-16

Treatments	20 DAS		40 DAS		60 DAS		80 DAS		100 DAS		At maturity	
Dates of sowing	**2014-15**	**2015-16**	**2014-15**	**2015-16**	**2014-15**	**2015-16**	**2014-15**	**2015-16**	**2014-15**	**2015-16**	**2014-15**	**2015-16**
D_1	1.08	1.07	2.07	2.04	3.76	3.80	3.89	4.02	3.56	3.51	2.20	2.23
D_2	0.85	0.83	1.70	1.72	3.20	3.17	3.42	3.31	2.93	2.96	1.75	1.56
D_3	0.63	0.63	1.39	1.40	2.73	2.64	3.00	2.81	2.40	2.41	1.35	1.08
SEm±	0.03	0.04	0.03	0.08	0.06	0.12	0.07	0.15	0.06	0.11	0.06	0.10
CD (P=0.05)	0.10	0.14	0.13	0.25	0.22	0.39	0.25	0.46	0.23	0.35	0.24	0.31
Compaction levels												
C_1	0.79	0.77	1.63	1.60	3.09	3.01	3.30	3.20	2.82	2.76	1.64	1.45
C_2	0.92	0.92	1.78	1.83	3.36	3.40	3.57	3.59	3.07	3.15	1.89	1.82
C_3	0.86	0.84	1.74	1.72	3.25	3.20	3.44	3.36	3.00	2.97	1.76	1.6
SEm±	0.03	0.03	0.03	0.03	0.05	0.05	0.06	0.06	0.05	0.04	0.06	0.05
CD (P=0.05)	0.08	0.08	0.08	0.10	0.15	0.17	0.18	0.21	0.14	0.12	0.17	0.18
Irrigation Schedules												
I_1	0.87	0.88	1.72	1.75	3.25	3.27	3.46	3.46	2.97	3.02	1.79	1.69
I_2	0.85	0.83	1.73	1.72	3.24	3.20	3.44	3.38	2.98	2.96	1.77	1.62
I_3	0.84	0.82	1.71	1.68	3.21	3.14	3.41	3.31	2.94	2.90	1.74	1.56
SEm±	0.01	0.02	0.01	0.01	0.03	0.01	0.05	0.01	0.01	0.01	0.04	0.01
CD (P=0.05)	NS	NS	NS	0.03	NS	0.05	NS	0.05	NS	0.03	NS	0.05
Interactions												

D*C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C*I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D*I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D*C*I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Root length density

Root length density (RLD) of wheat crop at different soil depths as influenced by different dates of sowing, compaction levels and irrigation schedules during *rabi* season of 2014-15 and 2015-16 has been presented in Table 3. Data indicated that among the dates of sowing and compaction levels, RLD at 0-15 cm depth was significantly higher under D_1 (1.27 and 1.13 cm cm^{-3} of soil during 2014-15 and 2015-16) and C_2 (1.18 and 1.03 cm cm^{-3} of soil during 2014-15 and 2015-16), respectively. RLD at 0-15 cm depth was found higher with I_1 (1.16 and 1.0 cm cm^{-3} of soil during 2014-15 and 2015-16, respectively) over the RLD with other irrigation schedules, during both the years but could not reach up the level of significance during 2014-15. All treatment interactions for root length density at 0-15 cm depth were found non-significant during both the years of experiment.

Among the dates of sowing and compaction levels, RLD at 15-30 cm depth was significantly higher under D_1 (0.74 and 0.85 cm cm^{-3} of soil during 2014-15 and 2015-16) and C_2 (0.70 and 0.82 cm cm^{-3} of soil during 2014-15 and 2015-16), respectively. RLD at 15-30 cm depth was found to be more with I_3 (0.67 and 0.78 cm cm^{-3} of soil during 2014-15 and 2015-16, respectively) over the RLD with other irrigation schedules but was significant only during *rabi* season of 2015-16. All treatment interactions for root length density at 15-30 cm depth were non-significant during both the years. Among the dates of sowing and compaction levels, RLD at 30-45 cm depth was significantly higher with D_1 (0.43 and 0.46 cm cm^{-3} of soil during 2014-15 and 2015-16) and C_2 (0.38 and 0.40 cm cm^{-3} of soil during 2014-15 and 2015-16), respectively. RLD at 30-45 cm depth was found more with treatment I_3 (0.36 and 0.38 cm cm^{-3} of soil during 2014-15 and 2015-16, respectively) over the RLD with other irrigation schedules but was significant only during 2015-16. All treatment interactions for root length density at 30-45 cm depth were non-significant during both the years. It is evident from the data that RLD at different depths was significantly affected with the dates of sowing and compaction levels during 2014-15 and 2015-16. However, Irrigation schedules had significant effect on RLD only during 2015-16. More number of irrigations and prolonged period for growth under D_1 might be reason for higher root length density among dates of sowing during both the years. Favorable soil physical condition *viz*. proper aeration and higher availability of moisture with C_2, led to increase RLD among compaction levels. Merotto and Mundstock (1999) [16] also reported increase in root growth with increase in the soil compaction from 1.29 to 1.67 kg dm^{-3}. RLD with I_1 have higher values but only up to 30 cm from surface while at depth more than 30 cm, higher values of RLD was found with I_3. Quanqi *et al*. (2010) [17] also reported higher RLD with increasing availability of soil moisture while in 30 cm deep soil profile, RLD was more with less number of irrigations. Tripathi (1986) [18] also reported that in sandy loam soil under moderate to deep water table conditions under well watered situation, RLD at surface layers was not only greater but also more uniformly distributed.

Table 3: Root length density (RLD) (cm cm^{-3} of soil) of wheat crop as influenced by dates of sowing, compaction levels and irrigation schedules during *rabi* seasons of 2014-15 and 2015-16

Treatments	**0-15 cm**		**15-30 cm**		**30-45 cm**	
Dates of sowing	**2014-15**	**2015-16**	**2014-15**	**2015-16**	**2014-15**	**2015-16**
D_1	1.27	1.13	0.74	0.85	0.43	0.46
D_2	1.15	0.98	0.68	0.82	0.37	0.37
D_3	0.97	0.83	0.55	0.64	0.28	0.29
SEm±	0.03	0.02	0.01	0.01	0.01	0.02
CD (P=0.05)	0.10	0.10	0.03	0.02	0.05	0.06
Compaction levels						
C_1	1.06	0.92	0.61	0.72	0.34	0.35
C_2	1.18	1.03	0.70	0.82	0.38	0.40
C_3	1.14	0.98	0.66	0.77	0.36	0.37
SEm±	0.02	0.01	0.01	0.01	0.01	0.01
CD (P=0.05)	0.06	0.04	0.05	0.04	0.02	0.02
Irrigation Schedules						
I_1	1.16	1.00	0.66	0.76	0.35	0.37
I_2	1.14	0.98	0.66	0.77	0.34	0.37
I_3	1.09	0.95	0.67	0.78	0.36	0.38
SEm±	0.02	0.01	0.02	0.00	0.02	0.00
CD (P=0.05)	NS	0.02	NS	0.01	NS	0.01
Interactions						
D*C	NS	NS	NS	NS	NS	NS
C*I	NS	NS	NS	NS	NS	NS
D*I	NS	NS	NS	NS	NS	NS
D*C*I	NS	NS	NS	NS	NS	NS

Developmental parameters

Developmental parameters *viz.* days to seedling emergence, days to anthesis and days to physiological maturity of wheat crop as influenced by different dates of sowing and compaction levels during *rabi* season of 2014-15 and 2015-16 have been presented in Table 4.

Table 4: Days to seedling emergence, days to anthesis and days to physiological maturity of wheat crop as influenced by dates of sowing, compaction levels and irrigation schedules during *rabi* seasons of 2014-15 and 2015-16

Treatments	Days to seedling emergence		Days to anthesis		Days to physiological maturity	
Dates of sowing	**2014-15**	**2015-16**	**2014-15**	**2015-16**	**2014-15**	**2015-16**
D_1	5.21	5.23	91.49	81.94	135.39	125.45
D_2	6.25	6.42	89.02	75.37	129.95	116.58
D_3	7.92	8.11	82.35	70.02	122.39	109.46
SEm±	0.06	0.15	0.58	1.77	1.62	1.89
CD (P=0.05)	0.23	0.58	2.26	5.35	4.95	5.69
Compaction levels						
C_1	5.30	5.35	84.82	75.65	126.50	114.20
C_2	6.48	6.72	87.92	75.93	129.39	117.11
C_3	7.60	7.69	90.12	76.16	131.85	120.19
SEm±	0.32	0.33	0.48	0.46	0.68	0.42
CD (P=0.05)	0.98	1.03	1.49	NS	2.12	1.29
Irrigation Schedules						
I_1	6.41	6.72	87.96	79.17	129.37	119.00
I_2	6.53	6.48	87.53	75.71	129.28	117.02
I_3	6.44	6.55	87.37	72.47	129.06	115.48
SEm±	0.06	0.06	0.20	0.80	0.23	0.39
CD (P=0.05)	NS	NS	NS	2.48	NS	1.20
Interactions						
D*C	NS	NS	NS	NS	NS	NS
C*I	NS	NS	NS	NS	NS	NS
D*I	NS	NS	NS	NS	NS	NS
D*C*I	NS	NS	NS	NS	NS	NS

Days to seedling emergence

It is apparent from the data that among the dates of sowing, days to seedling emergence was significantly more with D_3 (7.92 and 8.11 during 2014-15 and 2015-16, respectively). During 2014-15, days to seedling emergence was more with C_3 (7.60 and 7.69 during 2014-15 and 2015-16, respectively) over the days to seedling with other compaction levels but reached up to level of significance during 2015-16 only. Days to seedling emergence during 2014-15 and 2015-16 were non-significantly more with treatment I_2 (6.53) and I_1 (6.72), respectively over the days to seedling emergence with other irrigation schedules. All treatment interactions were found non-significant during both the years. Number of days to seedling emergence with delay in sowing increased significantly, which is in conformity with the findings of Ejaz *et al.* (2003) [19], who have reported that with delay in sowing of wheat crop, number of days to seedling emergence increased significantly. Increased bulk density and penetration resistance in compacted soil, attributed to increase in days to seedling emergence. Ramzan *et al.* (2014) [20] also reported that days to seedling emergence of wheat (11.18 days) with four tractor passes were more than the days to seedling emergence (10.98 days) with zero tractor passes.

Days to anthesis

It is apparent from the data that among the dates of sowing, days to anthesis were significantly more with D_1 (91.49 and 81.94 during 2014-15 and 2015-16, respectively). Days to anthesis were more with C_3 (90.12 and 76.16 during 2014-15 and 2015-16, respectively) over the days to anthesis with other compaction levels but reached up to level of significance only during 2014-15. Days to anthesis during both the years were found to be more in I_1 (87.96 and 79.17 during 2014-15 and 2015-16, respectively) over the days to anthesis with other irrigation schedules but were significant only during 2015-16. All treatment interactions were found non-significant during both the years. Panelia *et al.* (1993) [21] reported that time taken to anthesis was reduced due to delay in sowing which was in conformity with the results observed with dates of sowing during both the years. More number of irrigations might be the reason for delay in anthesis with I_1. Ngwako and Mashiqa (2013) [22] also reported delay in anthesis with increased number of irrigations.

Days to physiological maturity

Among the dates of sowing and compaction levels, days to physiological maturity were significantly more in D_1 (135.39 and 125.45 during 2014-15 and 2015-16) and C_3 (131.85 and 120.19 during 2014-15 and 2015-16), respectively. Days taken to physiological maturity were more in I_1 (129.37 and 119.00 during 2014-15 and 2015-16, respectively) over the days to physiological maturity with other irrigation schedules but reached up to the level of significance during 2015-16 only. All treatment interactions were found non-significant during both the years. Panelia *et al.* (1993) [21] also reported that time taken to maturity was reduced due to delay in sowing which is in conformity the results observed during both the years. More number of irrigations might be the reason for delay in physiological maturity with I_1. Ngwako and Mashiqa (2013) [22] also reported delay in physiological maturity with increased number of irrigations.

Conclusion

Wheat crop study under the effect of different dates of sowing, compaction levels and irrigation schedules concludes the significant effect of dates of sowing and compaction levels on all the studied growth and developmental parameters while there was significant effect of irrigation schedules on wheat growth and development during 2015-16, only. Irrigation scheduled at 30 % depletion from available soil moisture supplemented with excess rainfall (187.4 mm) during the crop period might be the reason for non-significant effect of irrigation schedules on growth and development during 2014-15.

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