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Growth, productivity and rhizospheric behaviour of wheat (*Triticum aestivum*) varieties under delayed planting and zinc application

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ABSTRACT

Field investigation was conducted during *rabi* seasons of 2013-14 and 2014-15 at the Indian Agricultural Research Institute, New Delhi to study growth, productivity and rhizospheric response of wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] varieties under different sowing times and Zn applications. The experiment was laid out in split-plot design, replicated thrice.Treatment consisted of sowing times (normal and very late) and wheat varieties (HD 2967, WR 544 and HD 3059) in main-plots and $ZnSO_4.7H_2O$ application (control, 25 kg ha^{-1} soil application, three foliar sprays @ 0.5% at boot, anthesis and grain filling stage, 25 kg ha^{-1} soil application + one foliar spray @ 0.5% at anthesis) in sub-plots. Wheat growth parameters and grain yield were reduced under very late sowing. Among varieties, WR 544 exhibited higher growth rate, highest grain yield reduction was found with HD 2967.Root growth (RLD, RSA, RV and RWD) lowered at 0−15 cm and improved at 15-30 cm soil depth owing to delayed planting. Higher root growth at 15-30 cm soil depth was noticed with delayed planted HD 3059 which also manifested least yield reduction. Soil application of $ZnSO_4.7H_2O$ @ 25 kg ha^{-1} + one foliar spray of 0.5% $ZnSO_4.7H_2O$ at anthesis recorded higher productivity and root growth of wheat nonetheless was found statistically on par with other Zn levels.

Key words*:* Foliar spray, Root length density, Very late sowing, Wheat varieties, Zinc sulphate

Wheat (*Triticum aestivum* L. emend. Fiori & Paol.) is the most important cereal crop of India. India has largest area under wheat (30.2 Mha) and has a production and productivity of 93.5Mt and 3.09 t/ha, respectively (DES 2016). In Indo-Gangetic Plains (IGP) delayed harvesting of long duration rice and cotton varieties exposes grain filling stage of wheat to high temperature (Singh *et al.* 2017). Heat stress at reproductive phase decreases grain yield due to accelerated development, reduced photosynthesis, increased respiration and decreased starch synthesis in developing grain. Across the globe about 6% yield reduction is expected with each degree increase in temperature. In this situation root system may play important role. Roots absorb water and nutrients from soil and translocate them towards shoot, provide mechanical support and supply hormones that are directly and indirectly useful for diverse physiological and biochemical processes of plants. Therefore root morphology as well as physiology has a close relation with shoot growth and development (Ju *et al* 2015). Delayed planting mediated heat stress enhances soil temperature due to direct heating of soil under lower canopy shading on ground. Moreover, it was seen that high temperature stress becomes more prominent under rising soil temperatures and soil moisture loss (Akter and Islam 2017). Kaspar and Bland (1992) observed improved cell growth and elongation with increasing soil temperature up to 30°C. In winter wheat cultivars (Yangmai-13 and Yannong-19) improvement in roots growth (i.e. root length, surface area and volume) at 0–20, 20–40, and 40–60 cm soil depth was noticed during anthesis under night-warming treatments (Hu *et al.* 2018).

Zinc (Zn) is one, out of 17 essential mineral elements required by plants for their life cycle completion. It is an integral part of antioxidant enzyme Cu-Zn superoxide dismutase that first breakdowns harmful superoxide radical in the cell and thus provides structural and functional integrity of bio-membranes (Marschner 1998). The shoot growth and root morphology of wheat varies according to external Zn supply and Zn use efficiency of individual genotype. Nie *et al.* (2017) observed improvement in root surface area, root length and volume of 14-days old winter wheat seedlings through supply of nitrogen (N) and Zn at 7.5 millimole (mM) and 10 micromole (µM) concentrations, respectively. In light of above facts present investigation was planned to examine the effects of sowing time and zinc application on growth, productivity and root morphological traits of wheat varieties.

MATERIALS AND METHODS

Experimental site and climatic conditions

Field experiment was conducted during *rabi* seasons of

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2013-14 and 2014-15 at the Indian Agricultural Research Institute, New Delhi, India situated at latitude of 28°40′N and longitude of 77°12′E. The experimental soil was sandy clay loam in texture, low in organic C (0.43%) and available N (182.5 kg ha^{-1}), medium in available P (17.3 kg ha^{-1}) and available Zn (1.45 mg kg^{-1}) and high in available K (320.5 kg ha^{-1}). The pH of soil was 7.6.

Experimental design and treatments detail

Two sowing times, normal (19 November in 2013-14 and 25 November in 2014-15) and very late (26 December in 2013-14 and 2 January in 2014-15), three wheat varieties (HD 2967, WR 544 and HD 3059) and four levels of $ZnSO_4.7H_2O$ application (control, 25 kg $ZnSO_4.7H_2O$ ha^{-1} soil application, three foliar sprays of $ZnSO_4.7H_2O$ @ 0.5% at boot, anthesis and grain filling stage, 25 kg $ZnSO_4.7H_2O$ ha^{-1} soil application + one foliar spray of $ZnSO_4.7H_2O$ @ 0.5% at anthesis stage) were taken for investigation. There were 24 treatment combinations consisted of sowing time and variety (2×3=6) in main plots and $ZnSO_4.7H_2O$ application (4) in sub-plots. The data were analyzed in split-plot design with three replications.

Crop management

A pre-sowing irrigation was applied to field to ensure adequate soil moisture at crop sowing. The field was cultivated twice with disc harrow followed by rotavator and a fine seed bed was obtained by two operations with cultivator followed by planking. For normal and late sowing seed rate of 100 and 125 kg ha^{-1} was used respectively. The row spacing of 22.5 cm for normal and 18.0 cm for late sown crop was used. The rate of fertilizer applications for normal and late sown crop were150:60:40 kg N: P_2O_5: K_2O ha^{-1} and 120:60:40 kg N: P_2O_5: K_2O ha^{-1}, respectively. The full dose of P_2O_5 and K_2O as well as half N was applied as basal and remaining half N was top dressed during first irrigation. Soil application of $ZnSO_4.7H_2O$ was done as per treatment before crop sowing except in control. Foliar fertilizations of $ZnSO_4.7H_2O$ were done as per treatments using a spray volume of 500 l ha^{-1}. For control plots only spraying of water was done. The plot size of 4.5 m × 3.7 m was kept. The irrigation was applied as per crop requirement and weather conditions. Weeds were controlled by doing one hand weeding 45 days after sowing (DAS).

Crop growth and yield measurement

Wheat plant height (at 60 DAS and maturity) was estimated by averaging height of 10 randomly selected plants from each plot and expressed in cm. For recording total dry matter accumulation (30, 60, 90 DAS and at maturity) plant from 1 m^2 area was manually harvested, sun-dried for 3 to 4 days and then oven-dried at 60°± 2°C till constant weight was obtained. Dry weight of samples was recorded and expressed in g m^{-2}. After harvesting, threshing, cleaning and drying, the grain yield of wheat was estimated at 14% moisture level and final yield was expressed in t ha^{-1}.

Root sampling from field and Image Analysis

After cutting stems, root samples were collected using soil augur (20 cm length and 10 cm diameter) from two soil depths (0–15 and 15–30 cm) during 50% flowering stage. Samples were taken out of core and washed by immersing in a water filled container for removing soil particles. Roots were washed over a sieve (0.5 mm mesh size) to prevent loss of fine roots. The dead roots, foreign plant and other materials were manually separated from sampled roots. Before image analysis, roots were further cleaned by immersing in a water-filled basin and any adhering fine particles were removed by hand. For doing image analysis, roots were floated in water filled acrylic trays on the scanner. The water floating of roots reduces mutual overlapping and crossing of roots thus can reduce bias in measurement. For taking root morphological parameters (root length, root volume and root surface area) each sample was scanned in water with a flatbed scanner (EPSON expression 1640XL, Japan) and after that images obtained were analyzed using WinRHIZO™Reg 2013e (Regent Instruments Inc., Canada) software. Same root samples were then kept in an oven at 70ºC for three days for recording root dry weight.

Statistical analysis

Statistical analysis of data was done using analysis of variance (ANOVA) technique for split-plot design taking two factors (sowing time and variety) in main-plots and four levels of $ZnSO_4.7H_2O$ application in sub-plots. Treatment means were compared using least significant difference (LSD) test at $p \leq 0.05$ (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Biometrical growth parameters of crop

At 60 DAS and at maturity, higher plant height of wheat was recorded under normal planting as compared to very late (Table 1). Wheat's plant height was influenced by sowing time and variety interaction (S×V interaction) at 60 DAS with WR 544 recorded highest plant height followed by HD 3059 and HD 2967 under both sowing times.Dry matter accumulation (DMA) of wheat varied according to crop stage, sowing time, variety and S×V interaction (Table 1). Irrespective of sowing time and variety, DMA increased with concurrent enhancement of crop age. At 60, 90 DAS and at maturity, DMA was reduced under very late sowing. The S×V interaction for DMA was found significant only at 60 DAS with WR 544 recorded highest DMA for either sowing times. However, at 90 DAS, HD 2976 registered highest DMA for both sowing times and years of study. The reduction in plant height and DMA under delayed planting and particular stages may be due to adverse impact of high temperature stress caused by delayed sowing of crop. Gill *et al.* (2013) reported that November sown wheat crop produced higher plant height and dry weight as compared to delayed sown crop in Punjab.The superior growth performance in WR 544 may be due to its higher initial (up to 60 DAS) growth rate.

Table 1 Plant height and dry matter accumulation of wheat as affected by Sowing time × Variety interaction during year 2013-14 and 2014-15

Sowing time	Variety	Plant height (cm)		Dry matter accumulation (g/m^2)			
		60 DAS	At maturity	30 DAS	60 DAS	90 DAS	At maturity
		Sowing time × variety interaction (2013-14)					
Normal	HD 2967	56.7 ±0.72	94.6±0.41	30.4±0.67	316.6±4.13	776.7±1.78	1672.1±25.45
	WR 544	85.4±0.88	86.5±1.23	31.8±0.70	415.1±2.98	891.3±6.75	1548.0±22.55
	HD 3059	65.2±1.16	92.8±0.75	33.7±0.49	340.7±1.62	791.3±2.68	1623.2±8.28
Very late	HD 2967	53.8±0.15	83.2±1.31	31.1±0.55	199.1±3.54	1300.4±8.57	1375.3±17.08
	WR 544	68.1±1.16	86.8±0.63	30.5±0.85	380.5±0.60	1314.2±0.92	1386.8±7.94
	HD 3059	55.4±0.62	82.8±0.41	29.2±0.75	247.1±5.16	1173.6±5.89	1350.1±27.72
	LSD (P=0.05)	4.4	2.8	NS	28.9	NS	NS
		Sowing time × variety interaction (2014-15)					
Normal	HD 2967	56.9±0.90	92.7±0.70	30.9±0.79	308.1±1.14	760.6±1.21	1619.8±19.21
	WR 544	82.4±1.42	93.6±0.41	33.8±0.75	401.6±2.30	871.5±1.66	1514.9±10.78
	HD 3059	62.7±0.36	93.6±1.31	34.7±0.44	324.0±0.29	770.4±2.06	1565.5±8.28
Very late	HD 2967	55.4±0.36	82.5±0.32	33.3±0.55	194.1±3.66	1280.7±8.57	1367.7±18.67
	WR 544	72.7±0.23	84.4±0.58	32.2±0.82	377.1±0.60	1295.2±0.92	1376.9±9.07
	HD 3059	55.8±0.78	82.5±0.29	30.9±0.61	245.1±3.52	1155.9±5.89	1301.6±12.16
	LSD (P=0.05)	4.3	NS	NS	35.2	NS	NS

Root morphology

In both years wheat's root length density (RLD), root surface area (RSA), root volume (RV) and root dry weight (RWD) were affected by sowing time, variety, S×V interaction and soil depth (Table 2 & 3). At 0−15 cm depth, very late sowing reduced RLD, RSA, RV and RWD. The maximum root biomass was confined to top 0−15 cm soil layer and on an average of two soil depths late sown crop showed reduction in root growth. Wang *et al.* (2014) found maximum root weight density around flowering in wheat which was mostly distributed in 0–0.4m soil layer. Improved root growth across two soil depths under normal sowing can be well correlated with higher biomass accumulation by crop. At 15−30 cm soil depth higher root growth of late sown crop might be due to more surface soil drying and evapo-transpirational demand of crop. In plants root absorbed water is used in transpirational cooling that can mitigate ill-effects of thermal stress. Delayed sown wheat

Table 2 Root morphological traits of wheat as affected by Sowing time × Variety interaction during 2013-14

Soil depth	Sowing time	Variety	Rhizospheric traits (2013-14)			
			RLD (cm root/ 1000 cm^3 soil)	RSA (cm^2root/ 1000 cm^3 soil)	RVD (cm^3root/ 1000 cm^3 soil)	RWD (mg root/ 1000 cm^3 soil)
0-15 cm	Normal	HD 2967	3745.4±90.98	554.1±12.67	6.96±0.23	1451.3±32.00
		WR 544	4154.9±55.18	592.3±13.50	6.48±0.07	1604.9±21.31
		HD 3059	4006.1±65.34	668.5±5.79	10.03±0.20	1547.4±25.24
	Very late	HD 2967	2939.5±60.67	436.2±10.83	5.04±0.41	1135.4±23.43
		WR 544	2875.3±164.29	387.2±19.43	4.59±0.46	1110.6±63.46
		HD 3059	3246.5±66.08	500.5±21.03	7.25±0.24	1254.0±25.52
		LSD (P=0.05)	266.1	NS	NS	98.7
15-30 cm	Normal	HD 2967	1254.6±19.53	189.3±4.90	1.54±0.04	484.6±7.55
		WR 544	1159.9±7.15	217.4±6.79	1.45±0.11	448.0±2.76
		HD 3059	1238.3±50.55	220.3±1.27	1.51±0.08	478.3±19.52
	Very late	HD 2967	1647.6±34.61	260.9±3.37	1.89±0.06	636.4±13.37
		WR 544	1729.6±36.49	234.9±2.82	1.55±0.06	668.1±14.10
		HD 3059	1967.8±8.99	261.8±2.97	2.15±0.12	760.1±3.47
		LSD (P=0.05)	118.7	18.8	0.18	45.8

RLD: Root length density, RSA: Root surface area, RVD: Root volume density, RWD: Root weight density

Table 3 Root morphological traits of wheat as affected by Sowing time × Variety interaction during 2014-15

Soil depth	Sowing time	Variety	Root morphological traits (2014-15)			
			RLD (cm root/ 1000 cm^3 soil)	RSA (cm^2 root/1000 cm^3 soil)	RVD (cm^3 root/1000 cm^3 soil)	RWD (mg root/ 1000 cm^3 soil)
0-15 cm	Normal	HD 2967	3812.3±88.02	560.4±11.53	9.39±0.24	1472.0±32.20
		WR 544	4159.3±57.19	604.3±10.06	8.80±0.10	1606.5±22.09
		HD 3059	4017.9±49.91	674.2±9.98	12.33±0.31	1552.0±19.28
	Very late	HD 2967	2969.6±53.30	448.4±8.34	7.46±0.41	1147.1±20.59
		WR 544	2871.6±147.48	393.9±14.72	6.91±0.55	1109.2±56.97
		HD 3059	3262.1±59.90	500.2±9.87	9.63±0.24	1260.0±23.14
		LSD (P=0.05)	281.9	44.9	NS	97.2
15-30 cm	Normal	HD 2967	1276.8±14.98	198.0±5.33	1.90±0.07	493.2±5.79
		WR 544	1176.1±7.15	228.3±6.79	1.90±0.08	454.3±2.76
		HD 3059	1255.4±50.95	234.7±3.58	1.89±0.06	484.9±19.68
	Very late	HD 2967	1663.8±34.61	268.5±0.79	2.27±0.08	642.7±13.37
		WR 544	1745.8±36.49	242.9±2.40	1.93±0.08	674.3±14.10
		HD 3059	1960.7±20.08	272.4±3.11	2.39±0.08	757.3±7.76
		LSD (P=0.05)	96.4	20.7	0.24	37.2

RLD: Root length density, RSA: Root surface area, RVD: Root volume density, RWD: Root weight density

Table 4 Root morphological traits of wheat as affected by Sowing time × $ZnSO_4.7H_2O$ interaction during 2013-14

Soil depth	Sowing time	$ZnSO_4.7H_2O$ application	Root morphological traits (2013-14)			
			RLD (cm root/ 1000 cm^3 soil)	RSA (cm^2 root/1000 cm^3 soil)	RVD (cm^3 root/1000 cm^3 soil)	RWD (mg root/ 1000 cm^3 soil)
0-15 cm	Normal	Control	3907.8±193.73	592.4±39.73	7.5±1.08	1515.6±69.17
		SA 25 kg/ha	4035.7±66.84	611.8±42.92	7.9±0.93	1558.8±25.82
		3FS*	3889.5±69.64	593.9±32.67	7.9±1.24	1502.4±26.90
		SA 25 kg/ha + 1FS**	4042.2±178.05	621.7±22.15	8.0±1.23	1561.3±68.77
	Very late	Control	2949.7±87.63	408.2±38.18	5.8±0.51	1139.4±33.85
		SA 25 kg/ha	2977.7±212.10	450.7±53.77	5.3±0.98	1150.2±81.92
		3FS*	3135.2±114.55	451.8±14.01	5.7±0.81	1211.0±44.24
		SA 25 kg/ha + 1FS**	3019.1±216.27	454.6±29.93	5.7±1.28	1166.2±83.54
		LSD (P=0.05)	NS	NS	NS	NS
15-30 cm	Normal	Control	1190.9±36.52	205.2±8.79	1.3±0.09	460.0±14.11
		SA 25 kg/ha	1199.2±51.92	213.4±8.72	1.5±0.09	463.2±20.06
		3FS*	1249.4±51.93	209.9±10.12	1.5±0.05	482.6±20.06
		SA 25 kg/ha + 1FS**	1230.8±39.39	207.6±16.15	1.7±0.04	475.4±15.22
	Very late	Control	1747.7±119.83	254.8±12.55	1.8±0.04	675.1±46.29
		SA 25 kg/ha	1797.3±109.25	248.2±9.05	1.8±0.18	694.2±42.20
		3FS*	1771.9±100.51	251.5±5.82	2.0±0.29	684.4±38.82
		SA 25 kg/ha + 1FS**	1809.8±67.47	255.6±8.80	1.9±0.20	699.0±26.06
		LSD (P=0.05)	NS	NS	NS	NS

SA: Soil application, 3FS*: Three foliar sprays @ 0.5% at boot, anthesis and grain filling stage, 1FS**: One foliar spray @ 0.5% at anthesis, RLD: Root length density, RSA: Root surface area, RVD: Root volume density, RWD: Root weight density experiences rapid soil drying due to direct heating of soil under high temperature. Moreover, reduction in canopy area of late sown crop further decreases shading of soil by leaves thus accentuates soil drying. Under concurrent heat and drought stress in field roots of surface layer produces drought signals (ABA) that triggers more root growth in lower soil layers.

On an average of two sowing times, HD 3059 recorded highest RLD, RSA, RV and RWD for both studied soil depths as well as years. At 0–15 cm soil depth, highest RLD and RWD under normal and late sowing were produced by WR 544 and HD 3059, respectively. The highest RLD and RWD at 15–30 cm soil depth under normal and very late sowing was recorded with HD 2967 and HD 3059 varieties, respectively in both years. Significantly highest RSA and RV at 15–30 cm soil depth were found with HD 3059 followed by HD 2967 under very late sowing. Gupta *et al.* (2013) exposed seedling stage of 10 wheat cultivars to heat stress (45 $^{\circ}$C temperature for 2 hours) and observed reduction in seedling root dry weight of all tested cultivars. The genotypes PBW 550 and PBW 502 showed highest and Raj 4037, a heat tolerant genotype showed lowest reduction in root dry weight. In our study HD 3059 recorded higher root growth under stressed condition and lower grain yield reduction. This might be due to its heat tolerant nature owing to which it produced and maintained higher root as well as shoot growth. Due to slightly more surface soil drying under higher atmospheric demand for water it may have produced somewhat more root biomass downward. Non-significant effect of $ZnSO_4$ was found on root morphological traits of wheat (Table 4 and 5). This might be due to optimum availability of soil Zn to plant roots.

Wheat yield

Very late sowing reduced wheat grain yield as compared to normal sowing in both the years (data not shown here). The S×V interaction was found significant for wheat grain yield (Table 6). Under normal sowing, HD 2967 recorded highest grain yield followed by HD 3059 and least was attained with WR 544. The highest grain yield reduction was found in HD 2967, though WR 544 and HD 3059 also exhibited yield reductions due to late planting. Owing to extended growing period timely sown crop not only gives higher grain, straw and biological yields but also completes its life span before advance of later season abiotic (heat and drought) and biotic stresses (Gill *et al.* 2013). Moreover, reduction in grain yield under late sowing may be ascribed to heat stress during grain growth phase. Dwivedi *et al.* (2015) conducted an experiment with 10 wheat varieties (HI 1563, HD 2987, Kundan, Raj 4238, GW 273, HD 2967 NW 1012, DBW 14, Halna and HD 2733) at Eastern Indo-Gangetic Plains and found 30% reduction in grain yield due

Table 5 Root morphological traits of wheat as affected by Sowing time × $ZnSO_4.7H_2O$ interaction during 2014-15

Soil depth	Sowing time	$ZnSO_4.7H_2O$ application	Root morphological traits (2014-15)			
			RLD (cm root/ 1000 cm^3 soil)	RSA (cm^2 root/1000 cm^3 soil)	RVD (cm^3 root/1000 cm^3 soil)	RWD (mg root/ 1000 cm^3 soil)
0-15 cm	Normal	Control	3946.4±193.57	611.2±41.71	9.6±1.00	1525.5±73.69
		SA 25 kg/ha	4034.7±42.03	619.3±42.29	10.2±0.88	1556.5±16.90
		3FS*	3910.8±69.64	597.6±29.66	10.3±1.23	1510.6±26.90
		SA 25 kg/ha + 1FS**	4094.1±114.43	623.9±21.26	10.5±1.26	1581.4±44.20
	Very late	Control	2994.1±82.34	432.1±36.47	8.2±0.51	1156.5±31.80
		SA 25 kg/ha	2984.6±197.30	442.7±36.88	7.7±0.93	1152.8±76.21
		3FS*	3123.2±95.00	460.6±13.03	8.1±0.81	1206.3±36.69
		SA 25 kg/ha + 1FS**	3035.9±225.11	454.4±37.87	8.0±1.41	1172.6±86.95
		LSD (P=0.05)	NS	NS	NS	NS
15-30 cm	Normal	Control	1206.1±35.53	215.3±10.78	1.8±0.02	465.9±13.73
		SA 25 kg/ha	1215.4±51.92	224.3±8.72	1.9±0.09	469.5±20.06
		3FS*	1265.6±51.93	220.7±10.12	1.9±0.06	488.9±20.06
		SA 25 kg/ha + 1FS**	1257.2±39.02	221.1±19.30	2.0±0.02	485.6±15.07
	Very late	Control	1763.9±119.83	262.9±11.74	2.1±0.05	681.3±46.29
		SA 25 kg/ha	1813.5±109.25	259.4±9.05	2.2±0.18	700.5±42.20
		3FS*	1768.4±81.04	260.1±10.48	2.2±0.22	683.1±31.30
		SA 25 kg/ha + 1FS**	1814.6±56.39	262.6±6.36	2.2±0.15	700.9±21.78
		LSD (P=0.05)	NS	NS	NS	NS

SA: Soil application, 3FS*: Three foliar sprays @ 0.5% at boot, anthesis and grain filling stage, 1FS**: One foliar spray @ 0.5% at anthesis, RLD: Root length density, RSA: Root surface area, RVD: Root volume density, RWD: Root weight density

Table 6 Interaction effect between sowing time and variety on grain yield of wheat during 2013-14 and 2014-15

Variety	Grain yield (t ha^{-1})			
	2013-14		2014-15	
	Normal	Very late	Normal	Very late
HD 2967	5.05±0.08	4.26±0.09	4.92±0.09	4.01±0.05
WR 544	3.75±0.03	3.60±0.08	3.61±0.07	3.43±0.16
HD 3059	4.42±0.04	4.29±0.06	4.27±0.04	4.04±0.07
LSD (P=0.05)	0.36		0.37	

to delayed sowing across studied genotypes.

In conclusion it can be stated that very late sowing mediated high heat environment has adverse effects on growth and grain yield of wheat. Contrasting responses were obtained from tested genotypes with WR 544 exhibited higher growth rates upto 60 days period owing to its earliness. Under delayed planting HD 3059 showed lowest yield loss, highest being with HD 2967.Root growth (RLD, RSA, RV and RWD) lowered due to very late sowing at 0–15 cm soil depth and improved at 15-30 cm soil layer. Higher root growth at 15–30 cm soil depth was noticed with delayed planted HD 3059 which also manifested least yield reduction. Soil application of $ZnSO_4$ @ 25 kg ha^{-1} + one foliar spray of 0.5% $ZnSO_4$ at anthesis recorded numerically higher grain yield and root growth however was found statistically on par with other Zn levels.

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