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Research Paper

Mulching, farmyard manure and exogenous application of osmo-protectants confer terminal heat tolerance in wheat (*Tritcum aestivum*)

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ABSTRACT

A field experiment was conducted at Ludhiana, Punjab (India) with combinations of 2 sowing dates [timely sowing (10 November) and late sowing (15 December)] and 6 heat-stress-management treatments includes recommended dose of fertilizer (RDF: 150 : 27.3 : 24.8 N, P and K kg/ha), RDF + FYM (10 t/ha farmyard manure), RDF + mulch (rice straw mulch @ 4 t/ha), RDF + FYM + mulch, RDF + FYM + mulch + $ZnSO_4$ (0.5%) and RDF + FYM + mulch + KCl (0.2%) in randomized block design with 3 replications during 2015–16 and 2016–17. The timely sown wheat showed higher emergence count, canopy air temperature difference, normalized difference vegetative index, days to earing/maturity, yield attributes, grain yield and water-use efficiency than the late-sown one. The grain yield recorded in RDF + FYM + mulch + KCl was the highest, which was statistically similar to RDF + 10 t FYM, RDF + Mulch, RDF + FYM + mulch and RDF + FYM + mulch + $ZnSO_4$. The grain yield and water-use efficiency recorded in RDF + FYM + mulch + KCl, RDF + FYM + mulch + $ZnSO_4$ and RDF + FYM + mulch was at par under late sown condition. Under late-sown conditions, RDF + FYM + Mulch + KCl can be used to ameliorate the adverse effect of terminal heat stress on wheat and enhance the grain yield and water use efficiency.

Key words: Farm yard manure, Mulch, Sowing dates, Terminal heat stress, Water-use efficiency

Wheat is the most widely grown cereal crop in the world and the second staple food crop in India after rice. In 2019, wheat was cultivated on an area of 31.0 million ha with 101.2 million ton production in India (AICWBIP 2019). Some areas across the world are available where the temperature in the spring months rises and crops are exposed to terminal heat stress, especially during the grain-filling stage (Rane *et al.,* 2007). Various studies conducted under controlled conditions have confirmed that rise in temperature above a daily average temperature of 15°C during grain-filling period reduced grain yield (Wardlaw, 2002). Thus, heat stress has appeared as a great menace to successful crop production in the world (Lobell and Gourdji, 2012). Song *et al.* (2015) observed a significant reduction in the rate of grain-filling in wheat cultivars at day/night temperature of 32/22°C when compared with that of 25/15°C. Heat stress affects the grain yield of wheat because of limitation of assimilates and less remobilization of nutrients. Most of the areas in North-western Indian conditions fall in timely sown (up to November 15), but some area especially after cotton and *basmati* rice crops, wheat gets delayed. Some of the practices like use of mulching and farmyard manure (FYM) at sowing and application of zinc sulpahte and potassium chloride near anthesis also found beneficial to take care the high temperature stress and increased the grain yield and water-use efficiency. Holik e*t al.* (2018) reported from recent studies that, the combined application of organic manures and mineral fertilizers plays an important role in optimizing soil-nutrient pool, increasing crop yields and the water-use efficiency in wheat. Since heat stress generally increases zinc concentration in grain mostly due to remobilization from the shoot (Dias and Lidon, 2009), Zn has also been proven to be effective in improving the heat tolerance in wheat (Gupta *et al.*, 2016). In general, late sowing of wheat varieties faces severe temperature stress which shortens the heading and maturity duration, ultimately affecting grain yield (Ram *et al.,* 2017). Egilla *et al.* (2001) reported that application of potassium enhances photosynthetic rate, plant growth, grain yield and drought resistance in different crops under abiotic stress conditions. Foliar application of potassium orthophosphate after anthesis could be an alternative technique to increase the heat tolerance of wheat. Potassium orthophosphate causes a delay in the heat stress-induced leaf senescence and enhances grain yield (Dias

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and Lidon, 2010). To increase the wheat tolerance to terminal heat stress, grain yield and water-use efficiency, an experiment was conducted with mulching, FYM along with zinc sulphate and potassium chloride under timely and late-sown conditions.

MATERIALS AND METHODS

The field experiment was conducted at research farm of the the Punjab Agricultural University, Ludhiana, India during 2015–16 and 2016–17. The experiment was conducted in randomized complete-block design with 2 dates of sowing [timely sowing (10 November) and late sowing (15 December)] and 6 heat stress-management treatments includes RDF (150 : 27.3 : 24.8 N, P and K kg/ha), RDF + FYM (10 t/ha Farmyard manure), RDF + mulch, RDF + FYM + mulch, RDF + FYM + mulch + $ZnSO_4$ (0.5% at boot leaf stage) and RDF + FYM + mulch + KCl (0.2% at boot leaf and post anthesis) with 3 replications. The rainfall received during the first cropping season was 74 mm for both the dates of sowing. For second year, rainfall of 100.2 mm and 98.2 mm was recorded for timely and late sown respectively. The mean maximum air temperature ranged from 13.0 to 35.1°C in 2015-16 and 16.0 to 36.6°C during 2016–17. The mean minimum air temperature varied from 4.9 to 20.1°C in 2015-16 and 3.5 to 19.3°C during 2016–17. The crop was sown by giving pre-sowing irrigation of 100 mm in both the sowing dates. The half dose of N (60 kg/ha) and full dose of P (27.3 kg P/ha) was applied at the time of sowing and remaining half N was applied at first irrigation. The crop was kept weed-free by application of Atlantis 3.6 WDG (mesosulfuron + iodosulfuron) @ 400 g/ha at 35 days after sowing. The number of irrigations (75 mm of each) applied were 6 and 5 in first and second sowing dates, respectively, in both the years. The data were collected on emergence count, days to 75% earing and days to maturity at 75% appearance of the stage in the plot. Micro-environment parameters, viz. canopy temperature and normalized difference vegetative index (NDVI) were recorded 10 days after the second foliar application of KCl. The data on effective tillers, grains/ear, 1,000-grain weight, grain yield, biological yield were recorded at maturity of the crop. Observations on yield attributes were recorded on 5 random plants from each plot. Data on grain yield and biological yield were collected from net plot of 9.8 m^2. Water use (WU) was assessed from the soil-water content at sowing, soil-water content at harvesting, rainfall (P) and irrigation (I). The runoff, drainage and capillary rise were zero, as the experimental plot was properly leveled and water-table was below 40 m depth. The water-use was calculated by equation given below.

$$WU = P + I + \Delta W$$

where ÄW is the change in soil moisture between sowing minus at harvesting. The soil-moisture samples at sowing and at harvesting were collected up to 120 cm of soil depth. Water-use efficiency (WUE) was calculated by the equation given below

$$WUE = [\text{Grain yield (kg/ha)}/\text{Water use (mm)}]$$

The data obtained for all growth, micro-environment parameters, yield attributes, yield and water-use efficiency were analyzed at P=0.05 using CPCS1 software using randomized complete-block design.

RESULTS AND DISCUSSION

Emergence count, phenology and microenvironment parameters

The emergence count recorded under timely sowing was 18.5 and 10.7% significantly higher than late-sown conditions during 2015–16 and 2016–17 respectively (Table 1). The less emergence count in late sowing might be owing to low temperature at the time of emergence. This was in agreement with findings of Ram *et al.* (2017). Heat-stress management treatment of RDF (150 : 27.3 : 24.8 N, P and K kg/ha) and RDF + FYM (10 t/ha) recorded the maximum emergence count and significantly higher than all the other treatments where mulch was used in both the years. Mulches create the hindrances in the emergence of the wheat crop. Ram *et al.* (2013) also reported lower emergence count under mulched conditions. The days taken to 75% heading and maturity were higher in timely sown conditions. It was due to better environmental conditions for the growth and development of the crop. During 2015–16, days taken to 75% heading and maturity in RDF + FYM + mulch (4 t/ha) was the highest, being significantly higher than the other treatments for days to heading whereas it was at par with all mulched treatments for days to maturity. In 2016–17, RDF + FYM + mulch + KCl (0.2%) took maximum days to heading, which was at par with all mulched treatments. During 2016–17 days to maturity were not significantly influenced. Higher days to heading and maturity under mulched conditions were owing to better environmental conditions available in these treatments which increased the grain-filling duration. Ram *et al.* (2013) and Gupta *et al.* (2016) also recorded 4–6 days delayed heading and maturity under mulched conditions in conventional and no-tilled fields.

The canopy air temperature difference (CATD) and normalized difference vegetative index (NDVI) were significantly higher in timely sown conditions in both the years. The cooler canopy and higher NDVI under timely sown conditions were owing to better growth and development of the crop (Jatana *et al*., 2020). Among the heat stress-management treatments, all treatments recorded higher CATD than that recorded in RDF during both the years. The treatment of RDF + FYM + mulch + KCl recorded the highest CATD which was significantly higher than rest of the treatments during 2015–16, but at par with RDF + FYM + mulch + $ZnSO_4$ and RDF + FYM + mulch treatments in 2016–17. In 2015–16, treatment of RDF + FYM + mulch + KCl recorded the highest NDVI which was significantly higher than other treatments. However, during 2016–17, RDF + FYM + mulch and RDF + FYM recorded the highest NDVI value, being significantly higher than RDF, but at par with the other treatments. The higher NDVI in these treatments owing to better growth and high CATD. The interactions effects reveals that during 2015–16 under timely sown conditions, CATD recorded in RDF + FYM + mulch + $ZnSO_4$ was significantly higher than RDF, but statistically at par with rest of the treatments, but in 2016–17, it was statistically at par with RDF + FYM + mulch + KCl and RDF + FYM + mulch only (Table 2). However, under late-sown conditions, CATD recorded in RDF + FYM + mulch + KCl treatment was significantly higher than that recorded in all other treatments. It might be owing the mitigating effect of FYM, mulch and KCl. The NDVI recorded under late-sown conditions during 2015–16 was significantly higher in RDF + FYM + mulch + KCl, RDF + FYM + mulch + $ZnSO_4$ and RDF + FYM + mulch than RDF, RDF + FYM and RDF + mulch but under timely sown conditions, NDVI was not-significantly influenced by any treatment. The results explained the ameliorating effect of combine application of FYM, mulch and $ZnSO_4$/KCl on terminal heat stress under late-sown condition where grain-filling exposed to higher temperature.

Table 1. Effect of sowing dates and heat-stress-management practices on emergence, phenology, canopy temperature difference (CTD) and normalized difference vegetative index (NDVI) of wheat

Treatment	Emergence count (no./m²)		Days to earing		Days to maturity		CTD*(°C)		NDVI*	
	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17
Sowing date										
Timely	179	187	99.9	103.9	144.5	150.6	4.42	5.23	0.77	0.82
Late	151	169	86.9	87.4	121.8	125.1	2.99	3.44	0.57	0.59
SEm±	5.4	2.6	0.15	0.28	0.19	0.35	0.02	0.01	0.004	0.005
CD (P=0.05)	11.2	7.5	0.45	0.82	0.55	1.02	0.05	0.03	0.01	0.01
Heat-stress-management										
RDF	181	190	92.2	94.5	131.8	137.2	3.53	4.18	0.63	0.67
RDF +10 t FYM/ha	181	184	91.5	94.5	131.7	137.2	3.70	4.32	0.66	0.72
RDF + mulch (4t/ha)	155	171	95.0	96.5	134.2	138.2	3.68	4.32	0.66	0.70
RDF + FYM + mulch	161	175	93.7	95.5	133.8	138.2	3.71	4.36	0.67	0.72
RDF + FYM + mulch + $ZnSO_4$ (0.5%)	158	171	94.0	96.3	133.8	139.0	3.70	4.40	0.67	0.71
RDF + FYM + mulch + KCl (0.2%)	154	178	94.0	96.8	133.7	137.5	3.91	4.43	0.71	0.71
SEm±	6.6	4.4	0.26	0.48	0.33	0.60	0.03	0.02	0.006	0.008
CD (P=0.05)	19.4	13.0	0.78	1.42	0.96	NS	0.09	0.05	0.02	0.02
SEm±	9.3	6.3	0.4	0.7	0.5	0.9	0.04	0.03	0.009	0.012
A×B interaction	NS	NS	1.01	NS	NS	NS	0.12	0.08	0.03	NS

*Data recorded at 10 days after foliar application of $ZnSO_4$ and KCl

Table 2. Interactive effect of sowing dates and heat-stress-management practices on CTD of wheat

Heat-stress-management	Canopy temperature difference			
	2015–16		2016–17	
	Timely	*Late*	*Timely*	*Late*
RDF	4.30	2.77	5.13	3.22
RDF + 10 t FYM/ha	4.41	2.98	5.17	3.47
RDF + mulch (4t/ha)	4.45	2.91	5.15	3.48
RDF + FYM + mulch	4.42	3.00	5.29	3.43
RDF + FYM + mulch + $ZnSO_4$ (0.5%)	4.48	2.92	5.33	3.47
RDF + FYM + mulch + KCl (0.25)	4.43	3.38	5.30	3.57
SEm±	0.04		0.03	
CD (P=0.05)	0.12		0.08	

Details of treatments are given under Materials and Methods

Yield attributes and yields

The yield attributes like effective tillers, grains/eard and 1,000-grain weight recorded under timely sown conditions was significantly higher than under late-sown conditions except grains/ear during 2016–17 (Table 3). The effective tillers recorded in timely sown were 16.2 and 5.8% higher than late-sown conditions during 2015–16 and 2016–17 respectively. The bolder grains were recorded under timely sown conditions during both the years. The higher effective tillers, more grains/ear and higher 1,000-grain weight under timely sown conditions might be owing to congenial environmental condition (more CATD and NDVI), more numbers of days to maturity and higher growing degree-days than late-sown conditions. Egilla *et al.* (2001) and Ram *et al.* (2017) also observed similar observations. Among the heat-stress-management treatments, the highest effective tillers were recorded in RDF + FYM + much + KCl which was significantly higher than RDF and RDF + FYM but statistically at par with the rest of the treatments in 2015–16, but the effect of heat-stress-treatments on effective tillers was non-significant during 2016–17. Better environmental conditions helped to produce more productive tillers. The grains/ears were not-significantly influenced by the heat-stress treatments. The 1,000-grain weight recorded in RDF + FYM + much + KCl was the highest during 2015–16 which was significantly higher than rest of the treatments. During 2016–17, all the treatments recorded significantly higher 1,000-grain weight than RDF. The highest 1,000-grain weight was recorded in RDF + mulch treatment in the second year was significantly higher than RDF and RDF + FYM + much + KCl. It was owing to more number of days taken by the crop for heading and maturity. So, more the grain filling period higher will be the grain yield owing to increased translocation of photosynthates to the developing grains (Song *et al.*, 2015). Interaction effect on 1,000-grain weight revealed that, RDF + FYM + mulch + $ZnSO_4$/KCl recorded similar 1000-grain weight under timely sown conditions in both years (Table 4). But under late-sown conditions, RDF + FYM and RDF + mulch recorded significantly higher 1000-grain weight than RDF and the other treatments. Eisvand *et al.* (2018) also reported bolder grains in zinc + boron foliar application in wheat crop owing to longer grain-filling period. The higher effective tillers and 1000-grain weight recorded in mulching along with FYM, $ZnSO_4$ and KCl was owing to better micro-environment and more days taken to maturity recorded under these conditions. The higher canopy air temperature difference and NDVI under these treatments depicted better micro-environmental conditions (Table 1).

The timely sown wheat yielded 40.1% and 43.75% higher than late-sown one in the first and second year respectively (Table 3). The grain yield recorded in the second year was also higher than the first year. The higher grain yield under timely sown conditions was owing to better microenvironment, more days take to heading and maturity, more CATD, higher NDVI and increase in yield attributes. The higher grain yield under optimum conditions owing to better environmental conditions was also recorded by Ram *et al.* (2017) and Song *et al.* (2015). As far as the heat-stress-management concerns, all the treatments recorded

Table 3. Effect of sowing dates and heat-stress-management practices on yield attributes, grain yield and biological yield of wheat

Treatment	Effective tillers (no./m²)		Grains/ear		1,000-grain weight (g)		Grain yield (t/ha)		Biological yield (t/ha)	
	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17
Sowing date										
Timely	316	404	43.2	41.4	44.9	43.8	6.03	7.29	15.75	17.52
Late	272	382	38.0	41.8	42.0	32.0	4.30	5.07	10.80	14.26
SEm±	1.3	3.1	1.1	1.0	0.3	0.3	0.04	0.04	0.11	0.13
CD (P=0.05)	3.9	9.0	3.16	NS	0.96	0.85	0.12	0.11	0.31	0.38
Heat-stress-management										
RDF	284	380	38.8	45.2	44.2	34.2	4.93	5.91	12.73	15.14
RDF + 10t FYM/ha	285	395	42.2	40.7	42.5	38.9	5.16	6.25	13.18	16.16
RDF + mulch (4t/ha)	295	396	41.1	39.3	42.2	39.8	5.14	6.17	13.27	15.65
RDF + FYM + mulch	300	398	41.2	41.9	43.2	37.8	5.23	6.29	13.57	16.34
RDF + FYM + mulch + $ZnSO_4$ (0.5%)	299	395	40.8	41.2	42.7	38.5	5.18	6.21	13.40	16.02
RDF + FYM + mulch + KCl (0.2%)	300	396	39.3	41.4	46.0	38.2	5.36	6.23	13.51	16.02
SEm±	2.3	5.3	1.9	1.7	0.6	0.5	0.07	0.07	0.18	0.22
CD (P=0.05)	6.8	NS	NS	NS	1.66	1.47	0.21	0.20	0.54	0.66
SEm±	3.3	7.5	2.6	2.4	0.8	0.7	0.10	0.10	0.26	0.32
A×B interaction	9.6	NS	NS	NS	2.35	2.08	0.29	NS	0.77	NS

Details of treatments are given under Materials and Methods

significantly higher grain yield than RDF alone treatment during 2015–16 and 2016–17. The grain yield recorded in RDF + FYM + mulch + KCl was significantly higher than RDF but statistically at par with the other treatments in both the years. Although RDF + FYM + mulch + KCl and RDF + FYM + mulch during 2015–16 were statistically similar, but RDF + FYM + mulch + KCl recorded 5.3% higher grain yield than RDF + FYM + mulch, which might be owing to higher temperature conditions prevailed during this year. But these types of results were not obtained during 2016–17. Egilla *et al.* (2001) found foliar application of potassium promising for ameliorating terminal heat-stress in different crops including wheat. Application of $ZnSO_4$ was not found suitable for terminal heat stress management during both the years. However, in contrary to our finding Dias and Lidon (2009) and Gupta *et al.* (2016) reported that zinc can be used to mitigate the effect of heat stress at grain-filling stage. Interaction effects during 2015–16 indicated that, the grain yield recorded in heat-stress-management treatments under timely sown was statistically at par with each other but under late-sown conditions, the grain yield recorded in RDF + FYM + much + KCl and RDF + FYM + much was statistically at par but better than rest of the treatments. Under late-sown conditions, RDF + FYM + much + KCl recorded 5.7% higher grain yield than RDF + FYM + mulch. So, the effect of KCl was visible only under late-sown conditions during 2015–16. Holik *et al.* (2018), Ram *et al.* (2013) and Egilla *et al.* (2001) also reported beneficial effect of FYM, mulch and KCl.

The biological yield recorded in timely-sown conditions was significantly higher than late-sown conditions in during the years. It might be owing to more days take to maturity and better micro-environmental conditions prevailed in timely sown conditions. The highest biological yield

Table 4. Interactive effect of sowing dates and heat-stress-management practices on 1,000-grain weight of wheat

Heat-stress management	1,000-grain weight (g)			
	2015–16		2016–17	
	Timely	Late	Timely	Late
RDF	44.33	44.00	37.93	30.38
RDF + 10 t FYM/ha	43.67	41.33	43.83	33.93
RDF + mulch (4 t/ha)	43.00	41.33	46.37	33.31
RDF + FYM + mulch	46.00	40.33	44.20	31.36
RDF + FYM + mulch + $ZnSO_4$ (0.5%)	45.00	40.33	45.13	31.86
RDF + FYM + mulch + KCl (0.2%)	47.33	44.67	45.60	30.89
SEm±	0.8	0.7		
CD (P=0.05)	2.35	2.05		

Details of treatments are given under Materials and Methods

Table 5. Effect of sowing dates and heat stress management practices on water use and water use efficiency of wheat

Treatment	Water-use (mm)		Water-use efficiency(kg/ha-mm)	
	2015–16	2016–17	2015–16	2016–17
Sowing date				
Timely	700.7	723.2	8.61	10.08
Late	624.6	644.7	6.89	7.86
SEm±	–	–	0.06	0.06
CD (P=0.05)	–	–	0.17	0.16
Heat-stress-management				
RDF	670.7	690.0	7.30	8.50
RDF + 10 t FYM/ha	670.3	688.5	7.64	9.02
RDF + Mulch (4 t/ha)	659.5	681.6	7.74	8.99
RDF + FYM + mulch	658.5	680.9	7.90	9.18
RDF + FYM + mulch + $ZnSO_4$ (0.5%)	658.7	681.3	7.81	9.05
RDF + FYM + mulch + KCl (0.2%)	658.4	681.4	8.11	9.09
SEm±	–	–	0.10	0.10
CD (P=0.05)	–	–	0.30	0.20
SEm±	–	–	0.15	0.14
A×B interaction	–	–	0.43	NS

Details of treatments are given under Materials and Methods

recorded with RDF + FYM + much was significantly higher than RDF but statistically similar to rest of the treatments. It might be owing more days taken to heading and maturity which helped to accumulate higher dry matter. Interaction effect indicated that all mulched treatments under timely-sown conditions, recorded significantly higher biological than RDF and RDF + FYM, but this types of effect was absent under late-sown conditions.

Water use and water use efficiency

The water use recorded under timely sown conditions was 12.2% higher than late-sown conditions (Table 5). It might be owing to application of 1 less irrigation water applied to the late-sown crop due to lesser crop duration. Dar *et al.* (2019) also reported that, timely sown wheat uses more water. Among the heat-stress-management treatments, mulched treatments recorded about 10 mm less water use as compared to unmulched treatments irrespective of sowing dates. The higher water-use efficiency recorded in timely sown conditions was significantly higher (25.7–28.4%) than late-sown conditions. It was owing to better environmental conditions and higher grain yield recorded under timely sown conditions. Duchemin *et al.* (2015) also recorded that earlier the sowing date more will be the water used and water use efficiency. Among the heat-stress-treatments, the water-use efficiency recorded during 2015–16 under RDF + FYM + much + KCl was the highest which was statistically at par with RDF + FYM + much + $ZnSO_4$ and RDF + FYM + much treatments, but significantly higher than rest of the treatments. In the second year, the water-use efficiency recorded in RDF + FYM + much was significantly higher than RDF but statistically at par with rest of the treatments. Interaction effects during 2015–16 revealed that under timely sown conditions, the water use efficiency recorded in RDF + FYM + mulch + $ZnSO_4$ was significantly higher than RDF but statistically at par with rest of the treatments. However, under late-sown conditions, the water-use efficiency recorded in RDF + FYM + mulch + KCl, RDF + FYM + mulch + $ZnSO_4$ and RDF + FYM + mulch was statistically at par but significantly higher than the other treatments. The higher water-use efficiency recorded in mulched and KCl/$ZnSO_4$ treatments might be to less water used and more grain yield recorded in these treatments. Ram *et al.* (2013) also reported higher water-use efficiency under mulched conditions.

It can be concluded from 2 years studies that, timely-sown crop (up to 10 November) helped escape the crop from terminal heat. Under late-sown conditions, application KCl along with FYM and mulching will help to confer tolerance to terminal heat stress in wheat. The effect of various osmo-protentants under different climatic conditions should be studied, especially in the areas where terminal heat-stress causing considerable yield loss of wheat.

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