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Effect of Different Thermal Regimes and Moisture Levels on the Growth Parameters of Wheat (*Triticum aestivum* L.) Crop Grown under Agro-climatic Conditions of Eastern Uttar Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was carried out at Agrometeorological Research Farm, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.) during rabi season of 2022-23 and 2023-24 to investigate the influence of different thermal regimes and moisture levels on wheat

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growth parameters, including phenophases occurrence, leaf area index (LAI), plant height, and dry matter accumulation at various stages of crop development. The experiment comprised twelve treatment combinations and conducted in split plot design and replicated four times. Treatment consisted of three thermal regimes *viz.* 15th November, 25th November and 5th December with four moisture levels *viz,* I1 at CRI (crown root initiation) , I2- CRI+tillering, I3- CRI+ jointing and milking, I4- CRI+ jointing +anthesis and dough stage. Results reveal that Plant height (cm), dry matter accumulation (gm^{-2}) and leaf area index increased significantly at all the stages of crop growth . Highest values are recorded with the crop thermal regime on 15th November followed by 25th November. Lowest values of all were recorded in 5th December thermal regime. Among the moisture levels, I4- (CRI+ jointing +anthesis and dough stage) took relatively longer duration for maturirty compared to levels I3, I2 and I1.. These findings underscore the importance of carefully managing both temperature and moisture conditions to optimize wheat growth and development. This research contributes to the broader understanding of crop responses to thermal regimes/date of sowing and provides valuable insights for moisture management strategies aimed at improving crop yield and resilience in the face of changing climate conditions.

Keywords: Wheat; phenophases; LAI; plant height; thermal regime; moisture level.

1. INTRODUCTION

Wheat, at present, is one of the most cultivated crops, as well as it is the most consumed one globally. It is now a common meal in many different nations. Global countries are concentrating on raising agricultural yield and production because the demand for wheat is expected to rise by at least 50% by 2050 (FAO Report).

Wheat is very important cereal crop of north India covering whole of Indo-gangetic plains especially Uttar Pradesh by providing more than 50 % of the calories to the population relying on it, wheat contributes significantly to food security of the nation.

Wheat yield under suitable water and nutrient conditions has been demonstrated to be closely associated with the amount of radiation intercepted during the growing season [1]. The primary abiotic variables influencing crop growth, development, and yield are temperature, moisture content, and nutrient availability. These factors could have a significant impact on crop productivity in the future by increasing abiotic and biotic stresses [2,3]. However, by adjusting the sowing period of crop, the negative effects of temperature stress on crop development and yield can be mitigated [4]. Main ecological manipulations that support maintaining existing crop production levels include selecting a variety that meets the best thermal requirements and delaying or advancing the sowing date [5,6]. The unfavorable conditions caused by high temperatures, particularly during the grain filling stage, can be reduced by determining the sowing process to an ideal period for various varieties that are appropriate for early, normal, and late sowing environmental conditions with an assured higher yield. When the sowing date is delayed, wheat growth days decrease and the growth period is extended [7,8]. Planting too early results in weak seedlings with inadequate root systems because of the high temperatures, which eventually reduces crop yield. In order to determine crop performance and get an improved yield, the right sowing time is therefore crucial [9].

Wheat growth is influenced by the time it gets sown and how much irrigation water is used. Sowing time and irrigation control the wheat crop's growth characteristics.

Two key elements that contribute to improved wheat growth are a sufficient amount of irrigation water and an appropriate planting date. Water is necessary for crops to grow through all stages of development, from seed germination to crop maturity, in order to maximize output. Satognon, [10]. Grain yield and irrigation frequency are positively correlated [11]. Having enough moisture available when plants are in critical growth stages enhances the efficiency of the mineral nutrients given to the crop as well as the metabolic activity within each plant cell. Regular irrigations are necessary for increased crop yields, however in times of water scarcity, it is crucial to identify the vital growth stages of crop so that irrigation needs can be avoided without noticeably lowering grain yields. According to Kumar et al., [11], the absence of irrigation during an important growth stage could result to a significant decrease in grain yield because of a reduction in test weight.

When describing the impacts of compound heat and water stress and the possibility for irrigation to mitigate heat stress, canopy temperature — which can be some degrees higher than air temperature under water stress—must be taken into account rather than air temperature [12]. Depending on the temperature that a particular organ reaches and the length of the stress, complex and interacting plant physiological processes lead to heat stress and damage. Temperature response in crops is nonlinear (Porter and Gawith, 1999; Sanchez *et al.,* 2014).The objective of this study is to investigate the impact of various thermal regimes and moisture levels on growth parameters, including the occurrence of phenophases, leaf area index (LAI), plant height, and dry matter accumulation at different stages of crop development. Additionally, the study aims to explore whether there is any interaction effect among these factors under the given climatic conditions.

2. MATERIALS AND METHODS

The field experiment was carried out during *rabi* season of 2022-23 and 2023-24 at the Student Instructional Research Farm, Department of Agricultural Meteorology, Acharya Narendra Deva University of Agriculture and Technology Kumarganj Ayodhya (26°.47'N, 82°.12'E and 113 m above mean sea level). Experiment was laid out with three thermal regimes/date of sowings D1-15th November, D2-25th November, D3-5th December along with four moisture levels was applied at different phenophases (I1-CRI, I2-CRI+tillering, I3- CRI+ jointing and milking, I4-CRI+ jointing +anthesis and dough stage) under Split plot design, thermal regimes as main plot treatment and moisture levels as sub plot treatment with four replication at semi-arid climatic condition of eastern plain zone of Uttar Pradesh zone.

The number of days to attain various phenophases was determined from randomly selected five plants in all the plots visually by the number of days taken from the sowing date to attain respective phenophases up to maturity. Daily maximum and minimum temperature, morning and evening relative humidity, bright sunshine hours, rainfall and open pan evaporation were recorded from the meteorological instruments installed at the Agrometeorological Observatory of Department of Agricultural Meteorology, ANDAU&T, Kumarganj Ayodhya.

2.1 Plant Height (cm)

To assess plant height in each plot, five randomly selected plants were marked for measurement, with the initial measurement conducted at 15 days after sowing (DAS). With the use of a meter scale, height was measured from the ground surface to the tip of the top most leaf before heading and up to the base of the ear head after heading at 15, 30, 45, 60, 75, and 90 days after sowing and at harvest stage.

2.2 Leaf Area Index

The leaf area was measured at 30, 60 and 90 DAS for leaf area index. Five plants were selected randomly and leaves were separated out to record their surface area by automatic leaf area meter. All the leaves were grouped into three *viz*., small, medium and large. Five leaves from each group were taken and their surface area was measured. The average areas of five leaves were multiplied with respective leaf number of group and sum of all three gave the total leaf area. The LAI was computed by following formula:

$$LAI = \frac{Leaf\ area\ (cm^2)}{ground\ area (cm^2)}$$

2.3 Dry Matter Accumulation (gm^{-2})

Plants were sampled randomly from 1 meter row length at all crop stages starting from CRI, leaves and roots were separated from stem. These samples were first sun-dried and then put in oven at 65°C for 48 hours to attain constant dry weight. The dried samples were weighed for dry matter accumulation in different plant parts. The fractional weight of stems and leaves were then added to achieve the total weight per plant.

Statistical analysis of varaince (ANOVA) of the experiment was carried out using Excel work sheet.

3. RESULTS AND DISCUSSION

3.1 Crop Phenology

The thermal regimes/dates of sowing differed significantly in all phenophases in both the years (Table 1). Among the thermal regimes/dates of sowing, D1 (15th November) took least time to emergence (6 days) in both crop years followed by D2 (25th November), and maximum in D3 (5th December). Duration of reproductive phase became shorter as the date of sowing delayed in the season. In comparison to Rabi 2022–2023 with differing planting dates, the wheat crop in Rabi 2023–2024 required almost the same number of days to reach crucial reproductive phases such anthesis, milking, and maturity. In comparison to other sowing treatments, the D1 crop sown on November 15th took longer duration to reach heading, anthesis, and physiological maturity. This resulted from delayed sowing, which raised the temperature throughout the middle and late stages and shortened the length of the reproductive phases. These findings are in line with those of Kour et al. [13], Khavse et al. [14], and Murungu and Madanzi [15].

There was significant variance between the four irrigation levels when studied their effects, even with the sowing dates. I1 (CRI) took less days (128 in 2022-23 and 127 in 2023-24) to attain physiological maturity than that of I4 (138, in 2022-23 and 137 in 2023-24). The occurrence of physiological phases was influenced by the irrigation levels used. The occurrence of phenophases in the early stages of vegetative stages was not significantly affected by moisture level treatments; however, in both seasons, moisture level treatments had a significant effect on the reproductive phases. Physiological maturity delayed as the moisture level increased from I1 to I4 level. There was on an average 3 days delay in maturity due to more irrigation application irrespective of date of sowing. Dhaka et al. [16] and Alam et al. [17] have also reported longer crop duration and longer reproductive phase of growth under higher irrigation levels.

3.2 Leaf Area Index

Among the three thermal regimes/dates of sowing, D1 (15th November) crop recorded maximum LAI production during all the phenophases. LAI were recorded at par in D2, lowest under D3 crop. The maximum LAI was recorded at 90 DAS D1 (4.93 & 5.02) and lowest under D3 (4.52 & 4.61) date of sowing in the both the years, respectively (Tables 3 and 4). This may be because D1 sown crops have a longer growing period offered to them than other sown dates. Comparable results are confirmed by Jat et al. [18] and Alam et al. (2013).

Significant difference was found among the moisture levels which produced higher green leaf area during all the phenophases in both years (Tables 3 and 4). In both research years, the highest LAI was achieved with I4 (4.91& 5.01) moisture levels when compared to other moisture level treatments. As a result, it was discovered that LAI is higher at higher moisture levels and gets lower at lower moisture levels. Additionally, as a result of more water being available, more water and nutrients are absorbed from the soil, which may have contributed to the wheat crop's improved growth and development. Fakhr et al. [19], Idnani and Kumar [20], and Ram et al. [21] reported findings that were similar to these.

While studying the interaction effect it is observed that the impact of thermal regimes/ sowing dates on LAI remains consistent regardless of the moisture level, and similarly, the effect of moisture levels on LAI remains consistent regardless of the sowing date. There is no evidence to suggest that the influence of one factor on LAI changes depending on the level of the other factor (Tables 3 and 4).

3.3 Plant Height (cm)

Three different thermal regimes/dates of sowing D1 (15th November), D2 (25th November) and D3 (5th December) had significant influence on plant height attained at different days after sowing over the crop season during both the crop years (Tables 5 and 6). Among all the growing environment treatments, D1 produced taller plants in all the stages followed by D2 and D3. In D1 (15th November) sown wheat, plant height attained a maximum of 98.5 cm at harvest stage in *Rabi* 2022-23, whereas, this length was 100.68 cm in the next year crop. But under late sown (5th December) condition, the maximum height of wheat crop was only 91.05 cm and 92.87 cm in 2022-23 and 2023-24, respectively. This was most likely caused by the early-sown crop having a longer growing season than the later-sown crop. This proved that the wheat plant is responding to the timing of seeding. These results were also corroborated by Tomar et al. [22].

In case of moisture level, all moisture level was not significantly different in respect of plant height at 15 and 30 DAS. Effects of moisture levels statistically differed after 45 DAS till at harvest with highest plant height observed in I4 treatments followed by I3, I2 and I1 irrigation level. This may have also increased in order to promote faster cell expansion and division, which raises the growth rate. Shirazi et al. [23] and Kumar et al. [24] reported similar findings.

Table 1. Effect of Thermal Regimes and Moisture Levels on occurrence of different Phenophases (days after sowing) of wheat during 2022-23

Treatment	Ermg	CRI	Tillering	Jointing	Booting	Heading	Anthesis	Milking	Dough	Physiological Maturity
Effect of Thermal Regimes										
D1	6	22	37	66	76.5	87	99	109	119	138
D2	7	21	36	64	74.5	85	98	107	117	136
D3	8	21	34	62	72.5	83	95	103	113	128
SEm±	0.03	0.03	0.04	0.09	0.10	0.11	0.12	0.14	0.15	0.17
CD at 5%	0.09	0.10	0.13	0.30	0.35	0.39	0.43	0.47	0.52	0.59
Test of significance	S	S	S	S	S	S	S	S	S	S
Effect of Moisture Levels										
I1	7	21	33	61	70	82	93	102	110	128
I2	7	21	35	63	74	83	95	105	114	131
I3	7	21	37	65	76	86	98	107	117	136
I4	7	22	38	68	78	90	100	109	121	140
SEm±	0.05	0.16	0.63	0.49	0.57	0.65	0.73	0.80	0.88	1.01
CD at 5%	0.15	0.46	1.84	1.42	1.65	1.88	2.13	2.32	2.55	2.94
Test of significance	NS	S	S	S	S	S	S	S	S	S
Interaction (Main-plot X Sub-plot)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2. Effect of Thermal Regimes and Moisture Levels on occurrence of different Phenophases (days after sowing) of wheat during 2023-24

Treatment	Ermg	CRI	Tillering	Jointing	Booting	Heading	Anthesis	Milking	Dough	Physiological Maturity
Effect of Thermal Regimes										
D1	6	23	38	67	78	89	96	110	119	137
D2	7	22	37	66	76	87	99	108	117	135
D3	8	22	33	64	75	85	94	104	112	127
SEm±	0.07	0.04	0.14	0.10	0.11	0.14	0.33	0.28	0.26	0.35
CD at 5%	0.23	0.14	0.50	0.34	0.38	0.47	1.14	0.96	0.89	1.22
Test of significance	S	S	S	S	S	S	S	S	S	S
Effect of Moisture Levels										
I1	7	22	33	62	71	83	93	103	111	127
I2	7	22	35	64	75	85	95	106	115	131
I3	7	22	36	66	77	88	96	108	117	135
I4	7	22	38	69	80	92	101	110	122	139
SEm±	0.17	0.55	0.62	1.15	1.34	1.54	1.70	1.90	2.05	2.36
CD at 5%	0.50	1.60	1.81	3.34	3.88	4.47	4.93	5.51	5.95	6.86
Test of significance	NS	NS	S	S	S	S	S	NS	S	S
Interaction (Main-plot X Sub-plot)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3. Effect of Thermal Regimes and Moisture Levels on occurrence of different Phenophases (days after sowing) of wheat during 2022-23

Treatment	LAI at 30 DAS	LAI at 60 DAS	LAI at 90 DAS
	Effect of Thermal Regimes		
D1	1.43	4.72	4.93
D2	1.42	4.65	4.86
D3	1.37	4.39	4.52
SEm±	0.01	0.01	0.01
CD at 5%	0.03	0.02	0.02
Test of significance	S	S	S
	Effect of Moisture Levels		
I1	1.38	4.42	4.57
I2	1.39	4.53	4.71
I3	1.41	4.66	4.88
I4	1.43	4.74	4.91
SEm±	0.01	0.03	0.03
CD at 5%	0.03	0.09	0.10
Test of significance	S	S	S
Interaction (Main-plot X Sub-plot)	NS	NS	S

Table 4. Effect of Thermal Regimes and Moisture Levels on occurrence of different Phenophases (days after sowing) of wheat during 2023-24

Treatment	LAI at 30 DAS	LAI at 60 DAS	LAI at 90 DAS
	Effect of Thermal Regimes		
D1	1.46	4.82	5.02
D2	1.45	4.74	4.95
D3	1.39	4.48	4.61
SEm±	0.01	0.01	0.01
CD at 5%	0.03	0.02	0.02
Test of significance	S	S	S
	Effect of Moisture Levels		
I1	1.41	4.51	4.66
I2	1.42	4.62	4.80
I3	1.44	4.75	4.97
I4	1.46	4.83	5.01
SEm±	0.01	0.03	0.03
CD at 5%	0.03	0.10	0.10
Test of significance	S	S	S
Interaction (Main-plot X Sub-plot)	NS	NS	S

Table 5. Effect of Thermal Regimes and Moisture Levels on plant height (cm) of wheat during 2022-23

Treatment	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	At Harvest
Effect of Thermal Regimes							
D1	14.26	26.33	47.50	72.84	94.34	97.46	98.95
D2	13.86	25.48	46.75	70.63	91.39	93.67	94.37
D3	13.46	24.38	43.65	67.88	87.88	89.35	91.05
SEm±	0.15	0.39	0.70	1.07	1.38	1.43	1.45
CD at 5%	0.53	1.33	2.41	3.69	4.79	4.93	5.01
Test of significance	S	S	S	S	S	S	S
Effect of Moisture Levels							
I1	14	25.07	44.51	68.87	88.37	90.20	91.47
I2	13.8	25.25	45.55	69.86	90.23	92.50	93.22
I3	13.6	25.53	46.60	71.10	92.44	94.45	95.98
I4	14.1	25.73	47.20	71.97	93.77	96.82	98.48
SEm±	0.18	0.22	0.40	0.62	0.81	0.83	0.84
CD at 5%	0.53	0.65	1.17	1.81	2.35	2.40	2.45
Test of significance	NS	NS	S	S	S	S	S
Interaction (Main-plot X Sub-plot)	NS	NS	NS	NS	NS	NS	NS

Table 6. Effect of Thermal Regimes and Moisture Levels on plant height (cm) of wheat during 2023-24

Treatment	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	At Harvest
Effect of Thermal Regimes							
D1	14.31	26.39	48.10	74.11	95.99	99.16	100.68
D2	14.12	25.92	47.46	72.04	93.21	95.54	96.25
D3	13.61	24.62	44.36	69.24	89.64	91.14	92.87
SEm±	0.13	0.39	0.68	1.05	1.35	1.39	1.41
CD at 5%	0.47	1.34	2.37	3.64	4.68	4.82	4.89
Test of significance	S	S	S	S	S	S	S
Effect of Moisture Levels							
I1	14.19	25.40	45.17	70.25	90.14	92.01	93.30
I2	13.80	25.29	45.69	71.26	92.03	94.35	95.09
I3	13.78	25.81	47.38	72.28	93.97	96.01	97.57
I4	14.29	26.08	48.31	73.41	95.64	98.75	100.45
SEm±	0.16	0.23	0.44	0.68	0.81	0.82	0.84
CD at 5%	0.46	0.65	1.27	1.98	2.34	2.39	2.43
Test of significance	NS	NS	S	S	S	S	S
Interaction (Main-plot X Sub-plot)	NS	NS	NS	NS	NS	NS	NS

Table 7. Effect of Thermal Regimes and Moisture Levels on dry matter accumulation (g/m^2) of wheat during 2022-23

Treatment	CRI	Tillering	Jointing	Heading	Anthesis	Milking	Dough	Physiological Maturity
Effect of Thermal Regimes								
D1	14.1	34.93	137.80	423.73	570.76	754.97	973.96	990.05
D2	13.2	33.05	129.54	399.39	531.58	743.03	951.47	970.54
D3	12.2	30.65	126.10	384.37	491.25	668.11	854.97	874.15
SEm±	0.13	0.33	1.39	4.22	5.34	7.28	9.27	9.52
CD at 5%	0.46	1.15	4.81	14.60	18.46	25.17	32.06	32.95
Test of significance	S	S	S	S	S	S	S	S
Effect of Moisture Levels								
I1	12.7	31.30	129.57	394.89	514.56	698.70	895.64	917.26
I2	12.9	32.57	130.49	398.30	526.64	719.37	917.03	936.42
I3	13.2	33.37	131.74	405.18	537.94	732.88	939.23	955.04
I4	13.7	34.27	132.78	411.61	545.64	737.19	955.29	970.92
SEm±	0.11	0.28	1.09	3.37	4.43	6.08	7.80	7.95
CD at 5%	0.32	0.80	3.17	9.77	12.84	17.63	22.63	23.06
Test of significance	S	S	NS	S	S	S	S	S
Interaction (Main-plot X Sub-plot)	NS	NS	NS	NS	NS	NS	NS	NS

Table 8. Effect of Thermal Regimes and Moisture Levels on dry matter accumulation (g/m^2) of wheat during 2023-24

Treatment	CRI	Tillering	Jointing	Heading	Anthesis	Milking	Dough	Physiological Maturity
Effect of Thermal Regimes								
D1	14.19	35.62	139.18	427.96	576.47	763.77	983.70	999.95
D2	13.28	33.71	130.83	403.38	536.90	750.46	960.98	980.24
D3	12.32	31.26	127.36	388.22	496.16	674.79	863.51	882.89
SEm±	0.02	0.05	0.20	0.61	0.93	1.04	1.40	1.38
CD at 5%	0.08	0.18	0.70	2.10	3.23	3.60	4.83	4.78
Test of significance	S	S	S	S	S	S	S	S
Effect of Moisture Levels								
I1	12.83	31.93	130.87	398.84	519.70	707.35	904.60	926.44
I2	13.03	33.22	131.79	402.29	531.91	723.61	926.20	945.78
I3	13.33	34.03	133.06	409.23	543.32	735.39	948.62	964.59
I4	13.87	34.95	134.11	415.73	551.10	752.34	964.84	980.63
SEm±	0.10	0.25	0.99	3.05	4.04	5.49	7.05	7.17
CD at 5%	0.29	0.74	2.87	8.85	11.73	15.92	20.46	20.80
Test of significance	S	S	NS	S	S	S	S	S
Interaction (Main-plot X Sub-plot)	NS	NS	NS	NS	NS	NS	NS	NS

There was no significant interaction observed between the main factors (thermal regimes and moisture levels) at any of the observed growth stages or at harvest. This indicates that the effect of thermal regimes on growth and yield parameters did not depend on the moisture level, and vice versa (Tables 5 and 6).

3.4 Dry Matter Accumulation (g m^{-2})

The most crucial factor in determining how much potential the crop has for final yield is its periodic dry matter accumulation. Evidently, dry matter accumulation was more in early sowing D1 (15th November) followed by D2 (25th November), and late D3 (5th December) sowing during both the years, respectively (Tables 7 and 8).

Three thermal regimes differ significantly in producing dry matter at all the phenophases. Consequently, the maximum dry matter (g m^{-2}) was recorded at physiological maturity during both the years. The highest dry matter was obtained in treatment D1 (990.05 and 999.95g m^{-2}) followed by D2 (970.54 and 980.24) while the lowest in D3 (874.15 and 882.89g m^{-2}) during the year 2022-23 and 2023-24, respectively. However, during 2023-24 accumulated dry matter was more as compared to 2022-23 in all the phenophases. Higher temperatures during the D1 crop (sown on November 15) caused early germination, which increased the number of plants and, additionally, ensured increased production of dry matter. These results are further supported by the findings of Dalirie et al. [25], Reddy et al., [26] and Vashisth et al., (2020). Additionally, Schwarte et al. [27] verified that delayed sowing lowers the generation of dry matter.

Among the various moisture levels evaluated, I4 consistently exhibited the highest dry matter accumulation across all phenophases compared to I3, I2, and the lowest observed in I1 treatments during both growing years. Specifically, I4 consistently produced the highest dry matter, with values of 970.92 and 980.63 gm-2, while I1 treatments yielded the lowest dry matter accumulation, with values of 917.26 and 926.44 gm-2 in the respective years. The reduced dry matter accumulation observed in the I1 treatments may be attributed to inadequate moisture levels, leading to diminished plant height and subsequently reduced photosynthetic activity. These factors collectively contribute to the lower dry matter accumulation observed in the I1 treatments compared to the other moisture levels. These results with response of moisture regimes was also reported by Shirazi et al. [23] Kumar et al. [24] and Dhaliwal et al*.,* [28]. The absence of significant interaction suggests that the effects of these factors on dry matter accumulation at different phenophases are relatively independent of each other.

4. CONCLUSION

In conclusion, both thermal regimes and moisture levels significantly influence wheat growth parameters, with thermal regime D1 and moisture level I4 generally resulting in longer durations for growth stages. However, there is no evidence of an interaction effect between these factors, indicating that their effects on wheat growth parameters operate independently of each other. These findings highlight the importance of carefully managing both temperature through optimum date of sowing and moisture conditions to optimize wheat growth and development.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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