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Performance, Phenology and Water relations in wheat (*Triticum aestivum* L.) Concerning Moisture and INM Modules

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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 on wheat (*Triticum aestivum* L.) was carried out during two consecutive *rabi* seasons 2021-22 and 2022-23 at Crop Research Centre of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India. The soil of the experimental field was

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sandy loam in texture, low in organic carbon and available nitrogen, but medium in available phosphorus and available potassium having slightly alkaline pH (8.7) with an electrical conductivity of 0.327. The field experiment allocated three moisture regimes in main plots, I_1: irrigation at IW/CPE ratio of 0.7, I_2: irrigation at IW/CPE ratio of 0.9 and I_3: five irrigations at critical stages (CRI, LT, LJ, F and M) and six integrated nutrient management (INM) modules in sub-plots, N_1: control, N_2: 100 % RDF (150:75:60 kg NPK/ha), N_3: 125 % RDF, N_4: 50% RDF+PM @ 2.5 t/ha, N_5: 50% RDF+PM @ 2.5 t/ha+*Azotobacter*+PSB+KMB, N_6: 50% RDF+PM @ 2.5 t/ha+NPK consortia were tested in split plot design with three replications. On pooled basis of two years experimentation the results showed that, the irrigation applied at critical stages (CRI, LT, LJ, F and M) resulted in significantly ($P<0.05$) tallest plants, more number of physiologically active leaves/plant at 50% flowering stage, days taken to 50% flowering, days taken to maturity, spike length, grains weight/spike, grain yield (48.7 q/ha), protein content (11.1 %) in grains and crop water use (541.9 mm) over IW/CPE ratio of 0.7. While, the reverse trend was noticed for soil pH and electrical conductivity, being maximum under the IW/CPE ratio of 0.7. Moreover, the highest water productivity was obtained with 0.9 ratio followed by 0.7. In respect of INM modules, the tallest plants, more of days taken to 50% flowering, days taken to maturity and soil pH were noticed with N_3 treatment, which was significantly ($P<0.05$) higher over the rest of the treatments, except plant height, being *on par* with N_2 and N_6 and soil pH which did not show any significant variation during both the years. While, the maximum number of physiologically active leaves/plant, grains weight/spike, protein content (11.2%) in grains and electrical conductivity were recorded under N_5. However, the physiologically active leaves/plant and grains weight/spike was significantly ($P<0.05$) superior over control and protein content in grains under N_1 and N_2. Moreover, the longest spike, grain yield (51.0 q/ha), crop water use (481.0 mm) and water productivity (6.38 kg/ha-mm) were registered with N_6, being significantly ($P<0.05$) superior over the control. Further, this treatment out yielded control and RDF by 23.7 and 6.3 %, respectively.

Keywords: Biofertilizers; INM modules; moisture regimes; wheat.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is the second most important food crop in the world as well as India. It is cultivated under various growing conditions of soil and climate and plays a vital role in the food and nutritional security of the country. In India, it accounts for about 14% of the global wheat area (30.5 m ha) and 13% of global wheat production (109.8 million tonnes). Water is considered as one of the most crucial input for agricultural production. Wheat is highly sensitive to water stress during crown root initiation and flowering stage. Excessive irrigation also affect the growth and development adversely and consequently the grain yield. However, maintenance of proper moisture levels throughout the growing season is required to secure uninterrupted crop growth and more economic yield. Proper scheduling of irrigation is required during the vegetative and reproductive phases of the crop to maintain the proper moisture for excellent growth and development of crop in diversified climatic conditions. Irrigation frequency has a significant influence on the growth and yield of wheat. Wajid et al. [1] reported that wheat crop produced the highest grain yield by applying proper moisture at all the definable growth stages. Wheat is generally grown in intensive cropping systems with the excessive use of inorganic fertilizers, especially nitrogenous [2]. Increased application of chemical fertilizers can also increase the production, but continuous use of chemical fertilizers led to declining in partial factor productivity and also disturbed the physico-chemical properties of soil, causing adverse effects on the environment and impairing the groundwater quality which causes health hazards in changing climate scenario and thus making fertilizer consumption uneconomical [3].

An integrated nutrient management modules to maximize the benefits from all potential sources of plant nutrients to keep soil fertility and plant nutrient supply at the optimum level for preserving the desired production [4].

Recently the use of organic manure along with biofertilizers gained priority over inorganic fertilizers alone to meet the demand for essential nutrients in the wheat crop. Whereas, integration of organic sources, bio-fertilizers and chemical fertilizers not only supply essential nutrients to the crop but also have some positive interactions leading to increased efficiency, restoration of soil health and quality food production [5]. Organic manures, such as poultry manure and biofertilizers should be considered as integral components and aid in the recovery of soil health in cropping systems by improving soil fertility and water holding capacity [6]. We investigated, the response of wheat under judicious use of moisture regimes and efficient INM mode was studied in western Uttar Pradesh conditions.

2. MATERIALS AND METHODS

2.1 Experimental Site

The field experiment was conducted at the Crop Research Centre (at a latitude of 29˚ 4' North, a longitude of 77˚ 42' East and an elevation of 228 m above mean sea level) of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India during two consecutive *rabi* season 2021-22 and 2022-23 on sandy loam soil. The soil was low in organic carbon (0.34%) and available nitrogen (203.3 kg/ha), but medium in available phosphorus (20.8 kg/ha) and available potassium (223.0 kg/ha) having pH (8.7) with an electrical conductivity of 0.327. The soil of the experimental field was moist, well- drained with uniform topography. The rainfall received during the crop period was 162.5 and 155.9 mm in 2021-22 and 2022-23, respectively.

2.2 Treatment Description

The experiment was laid out in a split plot design with three replications and 18 treatment combinations. The treatment comprised of three moisture regimes *viz,* I_1: irrigation at IW/CPE ratio of 0.7, I_2: irrigation at IW/CPE ratio of 0.9 and I_3: five irrigation at critical stages (Crown root initiation, Late tillering, Late jointing, Flowering and milking stage) as main plot factor and six INM modules, N_1: control, N_2: 100% RDF (150:75:60 kg NPK/ha), N_3: 125% RDF, N_4: 50% RDF+PM @ 2.5 t/ha, N_5: 50% RDF+PM @ 2.5 t/ha + *Azotobacter*+PSB+KMB, N_6: 50% RDF+PM @ 2.5 t/ha+NPK consortia as subplot factor.

2.3 Variety Description

The variety, DBW-187 (Karan Vandana) was taken for experimentation. This Variety was developed by ICAR- Indian Institute of Wheat and Barley Research Karnal, Haryana. It was notified in 2019 and recommended for commercial cultivation in NEPZ, mainly under irrigated timely sown conditions. It has an average maturity period of about 140-145 days and a potential yield of 60-65 q/ha.

2.4 Scheduling Irrigation

One pre-sowing irrigation (10 cm deep) was uniformly applied for proper germination of wheat crop in the entire field. For each irrigation water was applied upto7 cm depth, as per treatment as in IW/CPE ratio of 0.7, when the cumulative pan evaporation reading was reached at 100 mm (10 cm) and in I_2 i e., IW/CPE ratio of 0.9 when cumulative pan evaporation reached at 77.8 mm, while in treatment I_3, irrigation water was applied at five critical stages (above 20-25 days intervals). The daily pan evaporation was recorded at the meteorological observatory of SVPUAT, Meerut during the crop growth period in first and second years. The IW/CPE ratio has been worked out as,

$$\mathrm{IW/CPE} = \frac{\text{Irrigarion water (mm)}}{\text{cumulative pen evaporation (mm)}}$$

The time of irrigation was calculated based on the of formula (Edward, 2006) given as under,

$$t = \frac{a \times d}{q}$$

Where,

t = time of application of irrigation (minute)
a = area of the plot to be irrigated (m^2)
d = depth of irrigation water (mm)
q = discharge of irrigation water liter/minute

The discharge of irrigation water was measured with the help of a 90˚ V notch, which was installed in the irrigation channel.

2.5 Description of Manures and Fertilizers

The experimental soil was fertilized as per treatments, after laying out of the experimental field, poultry manure @ 2.5 t/ha was thoroughly mixed up to the top 15 cm soil depth, before one week of sowing. The quantity of poultry manure was used on the oven dry weight basis. The nitrogen, phosphorus and potassium recommend doses were applied through urea, NPK (12:32:16), and muriate of potash. The amounts of NPK present in the various sources used in experimentation is given in Table 1.

Table 1. NPK content present in the various sources of fertilizers/manure

S. No.	Source	N (%)	P_2O_5 (%)	K_2O (%)
1.	Poultry Manure	3.0	2.6	1.4
2.	Urea	46	-	-
3.	NPK	12	32	16
4.	MOP	-	-	60

The wheat seeds at 100 kg/ha used for sowing receiving bio-fertilizers treatment were inoculated with *Azotobacter,* phosphorus solubilizing bacteria (PSB), potassium mobilizing bacteria (KMB) and NPK consortia, as per treatments. For the inoculation of bio-fertilizers, 10 % jaggery slurry was prepared by boiling the jaggery solution. The culture of various bio-fertilizers each @ 20ml/kg seeds was mixed in the cooled jaggery slurry. The required quantity of seeds was thoroughly mixed with the solution for uniform coating over the seeds; the inoculated seeds were dried the in shade and subsequently used for sowing in respective treatments during both the years.

2.6 Data Recording and their Analysis

Plant height was recorded with the help of a meter scale, the yield was recorded in kg/plot and then converted into q/ha, protein content in grains as determined by modified- Kjeldahl method was multiplied by 5.73 to get total protein content, soil pH and EC was determined with the help of glass electrode pH and EC meter in 1:2.5 soil: water suspension method [7] and Crop water use were calculated by adding contribution from different sources, *i.e.* water applied by the irrigation, difference in moisture content at sowing and harvesting and effective rainfall and water productivity was calculated as the production of economic yield per unit of the total amount of water applied. For the pooled data, the mean the of two year data was analyzed through Analysis of Variance (ANOVA) technique for split-plot design and presented at 5% level of significance (P = 0.05) .

3. RESULTS AND DISCUSSION

3.1 Growth

A Perusal of the pooled data presented in Table 2 indicated that the plant height and physiologically active leaves/plant were significantly (P<0.05) affected by various moisture regimes and INM Modules.

The result showed that the highest mean plant height (79.6 cm) was recorded under the irrigation applied at critical stages, being statistically *on par* with I_2 and significantly (P<0.05) superior to the I_1 treatment. This might be due to the availability of an adequate supply of irrigation water at all the critical growth stages of crop growth, which induced rapid cell division and cell elongation and consequently higher crop growth. These results are corroborated by those of Carillo et al. [8]. Among the INM modules, the highest mean plant height was noted under the application of 125 % RDF, which was statistically *on par* with treatments N_2 and N_6 but significantly (P<0.05) higher over rest of the treatments. This improvement in plant height might be attributed to the fact that a higher recommended dose of fertilizers resulted in the higher availability of nutrients in the soil for enhanced cell division, cell elongation, as well as various metabolic processes which were ultimately responsible for increased plant height. The results have got close conformity with the findings of Krishna et al. [9].

The results showed that the highest pooled physiologically active leaves/plant (5.73) were recorded under the irrigation applied at five critical stages, which was significantly (P<0.05) superior over rest. This might be due to the proper moisture supply that increased the chlorophyll content in leaves and consequently increased the rate of photosynthesis.

Among the INM modules, the mean maximum physiologically active leaves/plant (5.62) were recorded in treatment N_5 which was *on par* with other treatments, except control. This might be attributed to better integration of chemical fertilizers with poultry manure and biofertilizers, however poultry manure and biofertilizers enhances the uptake of N and P for the plants which results in more synthesis of chlorophyll in the leaves. Similar results were also reported by Jan and Boswal [10].

3.2 Phenology

The mean data presented in Table 2 indicates that the phenology of wheat was significantly (P<0.05) influenced by various moisture regimes and INM modules.

The mean data showed that in the various moisture regimes, more days were taken to attain at 50% flowering and maturity under the irrigation applied at critical stages followed by (83.6 and 140.1) under the irrigation applied at IW/CPE ratio of 0.9 and wheat took a minimum (81.6 and 136.3) number of days to attain 50% flowering and maturity. This delay might be due to favorable plant growth conditions owing to better availability of soil moisture, which facilitates better crop growth and delayed its life cycle and also avoids forced maturity due to terminal heat [11].

Among the INM modules, the maximum number of days taken to attain 50% flowering and maturity was found under the application of 125% RDF followed by N_2, N_4, N_6 and N_5 and the minimum was recorded under the control. This might be due to the more availability of nutrients, particularly nitrogen which promotes the vegetative growth stage of crops and balanced nutrition. Similar findings were observed by Meena et al., [12].

3.3 Yield Attributes, Yield and protein Content

The yield attributes, protein and yield of wheat (on pooled basis) were significantly ($P<0.05$) influenced by various moisture regimes and INM modules. The highest spike length, grains weight/spike and grain yield (48.7 q/ha) were recorded under the I_3 treatment which received irrigation at critical stages and was statistically *on par* with I_2, but significantly ($P<0.05$) superior over the I_1. The increase in yield attributes and yield of wheat in the present investigation might be due to adequate availability of moisture gained by the application of more irrigations throughout the growing season which inturn increased the plant biomass and proper development of sink along with better translocation of photosynthates towards sink. A similar finding was observed by Niwas et al., [13]. The same trend was also noticed for protein content (%) in grains.

Among the INM modules, the longest spike (11.4 cm) and grain yield (51.0 q/ha) was noticed under application of N_6. The spike length was statistically *on par* with treatments N_2, N_3, N_4 and N_5 but significantly ($P<0.05$) superior over control, while grains yield, being *on par* with treatments N_3, N_4 and N_5 and significantly ($P<0.05$) superior over N_1 and N_2. The more grains weight/spike was registered under the treatment N_5, being *on par* with N_2, N_3, N_4 and N_6, but significantly ($P<0.05$) higher over the control. This increase might be because, the integration of poultry manure and biofertilizers with a half dose of chemical fertilizers supplied the plant nutrients in adequate proportion at all the crop growth stages and increases nutrient use efficiency and water holding capacity for longer periods, which increased the photosynthetic activities and translocated more photosynthate in the reproductive stage of crop growth, thereby enhance the yield attributes and yield of wheat. Similar results were also reported by Yadav et al. [14]. The maximum mean protein content (11.2%) in grains was recorded under the treatment of N_5 which was statistically *on par* with N_3 and N_6 and significantly higher over rest of the treatments. This is might be because of the integration of poultry manure and biofertilizers along with chemical fertilizer which resulted that poultry manure and biofertilizers increasing the nitrogen content in grains consequently enhancing the protein content in grains.

3.4 Soil Analysis

The data in Table-4 indicated that the electrical conductivity (dS/m) was slightly affected by various moisture regimes and INM modules. Under the various moisture regimes, the soil pH and electrical conductivity were slightly reduced under the irrigation applied at critical stages followed by irrigation applied at IW/CPE ratio of 0.9 and 0.7. However, the maximum mean soil pH and electrical conductivity were recorded under the irrigation of the IW/CPE ratio of 0.7. This might be due to those frequent irrigations at critical stages, which slightly reduces the soil pH and electrical conductivity. These finding are supported by Bhattacharyay et al. [15] and Pal et al. [16]. Among the INM modules, the minimum mean soil pH was recorded under the application of N_6 treatment. This is might due to owing the formation of organic acids during the decomposition of poultry manure. Our results are in lines with those of Kumara et al. [17] and Singh [18].

3.5 Crop Water Use

The total crop water use was calculated by adding contributions from different sources of water, *i.e.* water applied through the irrigation, the difference in moisture content at sowing and harvesting and effective rainfall. It was directly related to the number of irrigation applied to relative treatments. The maximum amount of crop water use (541.9 mm) was recorded under the I_3 which received irrigation at critical stages followed by I_2 and minimum water use was observed under I_1 treatment (Table 4). The treatment I_3 received 26.8% more water compared to the I_1 treatment. This was mainly because more frequent irrigation applied under I_3 (at critical stages) maintains the optimum soil moisture throughout the growth period of the crop. Singh et al. [19] and Niwas et al. [13] also made similar observations in wheat at Hisar (H.) and Kanpur (U.P.), respectively. Among the INM modules, the application of N_6 in wheat showed the highest crop water use (482.5 mm) and it was higher (1.8%) compared to the control.

3.6 Water Productivity

The water productivity was calculated as the production of economic yield per unit of the total amount of water used. In the moisture regimes, the maximum mean water productivity was recorded under the irrigation applied at IW/CPE ratio of 0.9 followed by 5.62 kg/ha-mm under the IW/CPE ratio of 0.7 and a minimum of 5.46 kg/ha-mm with irrigation at critical stages. This might because better grain yield obtained with a

Table 2. Effect of various moisture regimes and INM modules on growth and phonology of wheat (pooled mean of 2021-22 and 2022-23)

Treatment	At 50 % flowering		Days taken to	
	Plant height (cm)	Physiologically active leaves/plant	50 % flowering	Maturity
Moisture regimes				
I_1	73.2	5.20	81.6	136.3
I_2	76.3	5.39	83.6	140.1
I_3	79.6	5.73	85.8	143.1
S.Em.±	0.8	0.03	0.5	1.1
C.D. (P= 0.05)	3.6	0.13	2.4	5.1
INM modules				
N_1	65.5	5.02	80.2	135.1
N_2	78.9	5.47	85.2	141.2
N_3	81.0	5.56	87.2	143.1
N_4	77.1	5.43	83.5	139.7
N_5	77.5	5.62	82.5	138.7
N_6	78.4	5.54	83.2	139.1
S.Em.±	1.0	0.07	0.5	1.1
C.D. (P= 0.05)	2.8	0.20	1.6	3.2

Table 3. Effect of various moisture regimes and INM modules on yield attributes, protein content and yield of wheat (pooled mean 2021-22 and 2022-23)

Treatment	Spike length (cm)	Grains weight/spike (g)	Grain yield (q/ha)	Grains protein content (%)
Moisture regimes				
I_1	10.5	1.83	42.2	10.5
I_2	10.7	1.94	44.9	10.7
I_3	11.5	2.02	48.7	11.1
S.Em.±	0.2	0.03	0.87	0.11
C.D. (P= 0.05)	0.9	0.13	3.90	0.50
INM modules				
N_1	9.4	1.46	22.8	10.0
N_2	11.0	1.98	48.0	10.8
N_3	11.2	2.03	50.3	11.0
N_4	11.1	2.01	48.9	10.8
N_5	11.3	2.07	50.6	11.2
N_6	11.4	2.04	51.0	11.0
S.Em.±	0.2	0.03	0.85	0.12
C.D. (P= 0.05)	0.6	0.09	2.45	0.35

Table 4. Effect of various moisture regimes and INM modules on soil pH, electric conductivity (dS/m), physiological efficiency, crop water use and water productivity of wheat (pooled mean 2021-22 and 2022-23)

Treatment	Soil pH	Electrical conductivity (dS/m)	Crop water use (mm)	Water Productivity (kg/ha-mm)
Moisture regimes				
I_1	8.47	0.359	427.3	5.62
I_2	8.41	0.354	467.1	5.94
I_3	8.33	0.336	541.9	5.46
S.Em.±	0.08	0.003	1.5	0.11
C.D. (P= 0.05)	NS	0.013	6.6	NS
INM modules				
N_1	8.39	0.297	474.0	2.90
N_2	8.50	0.345	475.5	6.06
N_3	8.51	0.357	479.6	6.29
N_4	8.43	0.364	480.0	6.11
N_5	8.34	0.374	482.5	6.31
N_6	8.25	0.362	481.0	6.38
S.Em.±	0.12	0.005	2.2	0.11
C.D. (P= 0.05)	NS	0.013	6.5	0.33

minimum amount of water applied resulted in more water productivity. A similar finding was noted by Rajanna et al. [11]. Among the INM modules, the maximum water productivity (6.38 kg/ha-mm) was observed under the application of N_6 being *on par* with N_2, N_3, N_4 and N_5 but significantly ($P<0.05$) higher than control. This is might be due to the fact that integration of poultry manure and biofertilizers along with chemical fertilizer produce more yield per unit of water use. Similar results were reported by Liu et al. [20].

4. CONCLUSION

On the basis of two years experimentation, it may be concluded that the irrigation applied at critical stages along with 50% RDF through chemical fertilizers and the rest through organic manures along with biofertilizers in wheat seems to be best as they improved the growth, phenology, yield attributes, yield and protein, content and crop water use, with a slight reduction in soil pH and electrical conductivity than rest of the treatment combinations. Although, the highest water productivity was achieved under the irrigation applied ats IW/CPE ratio of 0.9.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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