Growth, phenology, yield, quality and water relations in wheat (*Triticumaestivum* L.) as influenced by moisture regimes and INM modules.

Abstract

A field experimenton wheat (*Triticumaestivum*L.) was carried out during two consecutive *rabi*seasons 2021-22at Crop Research Centre of SardarVallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India. The soil of experimental field was 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. Three moisture regimes in main plots namely, 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 INM modules in sub plots*viz*, 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, N_5: 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 into significantly tallest plants (79.6 cm), more number of physiologically active leaves/pant (5.64) at 50% flowering stage, days taken to 50% flowering (85.9), days taken to maturity (142.1), spike length (11.5 cm), grains weight/spike (2.02 g), grain yield (48.7 q/ha), protein content (11.1 %) in grains and crop water use 541.9mm) over IW/CPE ratio of 0.7. While,the reverse trend was noticed for soil pH (8.47) and electrical conductivity (0.359 dS/m), beingmaximumunder 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 (81.0 cm), more number of days taken to 50% flowering (87.2), days taken to maturity (143.1) and soil pH (8.51) was noticed with N_3 treatment, which was significantly higher over rest of the treatments, except plant height, being *on par* with N_2 and N_6 treatment and soil pH which did not show any significant variationduring both the years. While, maximum number of physiologically active leaves/plant (5.62), grains weight/spike (2.07 g), protein content (11.2%) in grains and electrical conductivity (0.374 dS/m) were recorded under N_5. However, the physiologically active leaves/plant and grain weigh/spikewas significantly superior over control and protein content in grains under N_1 and N_2 both. Moreover, the longest spike (11.4 cm), grain

Comment [Ma1]: Kindly mention the 2nd year of study ?

Comment [Ma2]: Corrrect

yield(51.0 q/ha), crop water use (481.0 mm) and water productivity (6.38 kg/ha-mm) was registered with $N_{6,}$ being significantly superior over the control. Further, thistreatment out yielded control and RDF by 23.7 and 6.3 %, respectively.

Keywords: Wheat, Moisture Regimes, INM Modules, Biofertilizers

1. Introduction

Wheat (*Triticumaestivum*L.)is the second most important food crop of the world as well as India. It is cultivated under various growing conditions of soil and climate and plays a vital role in food and nutritional security of the country. In India, it accounts for about14 percent of global wheat area (30.5 m ha) and 13 percent 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. The excessive irrigation also affect the growth and development adversely and consequently the grain yield. However, maintenance of proper moisture level throughout the growing season is required to secure uninterrupted crop growth and more economic yield. Proper scheduling of irrigation is requiredduring the vegetative and reproductive phases of 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.*(2002) reported that wheat crop produced highest grain yield by applying proper moisture at all the definable growth stages. Wheat is generally grown in intensive cropping system with the excessive use of inorganic fertilizers, especially nitrogenous (Yadav*et al.*, 2019). Increased application of chemical fertilizers can also increase the production, but continuous use of chemical fertilizers led to declining in partial factor productivity, also disturbed the physio-chemical properties of soil, causing adverse effect on environment and impaired the groundwater quality which causes health hazards in changing climate scenario and thus making fertilizer consumption uneconomical (Aulakh and Abhya, 2009).

Comment [Ma3]: physio-chemical or Physico-Chemical

An integrated nutrient management modules to maximising the benefits from all potential sources of plant nutrients in order to keep soil fertility and plant nutrient supply at the optimum level for preserving the desired production (Kumar*et al*., 2023).

Therefore, in recent year's use of organic manure along with biofertilizers gained priority over the inorganic fertilizers alone to meet the demand of essential nutrients to 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 (Hafiz *et* *al.*,2011). Organic manures, such as poultry manure and biofertilizers should be considered as an integral components and aid in the recovery of soil health in cropping systems by improving soil fertility and water holding capacity (Mahajan *et al*., 2009). In the light of above facts, the response of wheat under judicious use of moisture regimes and efficient INM mode was studied in western upcondition.

Comment [Ma4]: Correct to Western UP

2. MATERIALS AND METHODS

Experimental site:

The field experiment was conducted atCrop Research Centre (at a latitude of 29˚ 4' North, longitude of 77˚ 42' East and an elevation of 228 metre above mean sea level) of SardarVallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India during two consecutive *rabi*season 2021-22 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) andavailable potassium (223.0 kg/ha) having pH (8.7) withan electrical conductivity of 0.327. The soil of experimental field was moist, well drained with uniform topography. The rainfall received during the crop period was 173.5 and 155.9 mm in 2021-22 and 2022-23, respectively.

Comment [Ma5]: 2nd Year not mentioned

Treatment description:

The experiment was laid out in 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 plotfactor and six INM modules *viz*, 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, N_5: 50% RDF+PM @ 2.5 t/ha+NPK consortiaas subplot factor.

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 potential yield of 60-65 q/ha.

Scheduling irrigation:

One pre-sowing irrigation (10 cm deep) was uniformly applied for proper germination of wheat crop in entire field. For each irrigation water was applied @ 7 cm depth in IW/CPE ratio of 0.7, when cumulative pen evaporation reading was reached at 100 mm (10 cm) and inI_2i e., IW/CPE ratio of 0.9 when cumulative pen evaporation reached at 77.8 mm (7.78 cm), 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 meteorological observatory of SVPUAT, Meerut during crop growth period in first and second year both. The ofIW/CPE ratio has been worked out as,

Comment [Ma6]: ??

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

Time of irrigation were calculated on the basis of formula (Edward, 2006) given as under,

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

Where,

t = time of application of irrigation (hour)

a = area of plot to be irrigated (m^2)

d = depth of irrigation water (cm)

q = discharge of irrigation water litre/second

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

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 top 15 cm soil depth, before one week of sowing. The quantity of poultry manure was used on the oven dry weight basis. The recommended dose of nitrogen, phosphorus and potassium were applied through urea, NPK (12:32:16) and muriate of potash. The amounts of NPK present in the various sources use in experimentation is given in Table 1.

Table 1: NPK Content present in the various sources of fertilizers

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 @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 jaggery solution. The culture of various bio-fertilizers each @ 20ml/kg seed were mixed in the cooled jiggery slurry. The required quantity of seed was thoroughly mixed with the solution for uniform coating over the seeds; the inoculated seeds were dried in shade and subsequently used for sowing in respective treatments during both the years.

Data recording and their analysis:

Plant height was recorded with the help of meter scale, yield 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 (Richards, 1968) and Crop water use was calculated by adding contribution from different sources, *i.e.* water applied thought 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 total amount of water applied. For the pooled data, mean of two year data was analysed through analysis of variance (ANOVA) technique for split plot design and presented at 5% level of significance (P = 0.05).

Comment [Ma7]: Correct?

Results and Discussion

Growth

Perusal of the pooled data presented in Table-2 clearly indicated that the plant height and physiologically active leaves/plant was significantly 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 superior over I_1 treatment. This might be due to the availability of adequate supply of irrigation water at all the critical growth stages of crop growth, which induced rapid cell division and cell elongation and consequently the higher crop growth. These results are also corroborated with the findings of Carillo*et al*.(2011). Among theINM modules, the highest mean plant height (81.0 cm) was noted under the application of 125% RDF, which was statistically*on par* with treatments N_2 and N_6 but significantly higher over rest of the treatments. This improvementin plant height might be attributed to the fact that higher recommended dose of fertilizers resulted the higher availability of nutrients in the soil forenhanced cell division, cell elongation as well as various metabolic processes which wereultimately responsible for increased plant height. The results have got close conformity with the findings of Krishna *et al*. (2008).

The results showed that the highestpooled physiologically active leaves/plant (5.73) were recorded under the irrigation applied at five critical stages, which was significantly superior over rest of the treatments. 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 andbiofertilizers 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 (2015).

Phenology

Perusal of the mean data presented in Table-2 clearly indicates that the phenology of wheat was significantly influenced by various moisture regimes and INM modules.

Perusal of the mean data showed that in the various moisture regimes, the more (85.8and 143.1) number of days were taken to attainat 50% flowering and maturity under the irrigation applied at critical stages followed by (83.6 and 140.1) under theirrigation applied at IW/CPE ratio of 0.9 and wheat tookminimum (81.6 and 136.3) number of days to attain50% flowering and maturity.This delaying might be due to favourable plant growth conditions owing to better availability of soil moisture, which facilitates better crop growth and delayed its life cycle and alsoavoids forced maturity due to terminal heat (Ranjanna*et al*., 2017).

Among the INM modules, the maximum (87.2 and 143.1) number of days taken to attainat 50 % flowering and maturity was found under the application of 125% RDF followed N_2, N_4, N_6 and N_5 and the minimum (80.2 and 135.1) was recorded under the control. Thismight be due to the more availability of nutrients, particularly nitrogen which promotes the vegetative growth stage of crop and balanced nutrition. Similar finding were also observed by Meena*et al*., (2005).

Yieldattributes, yield and protein content

The results obtained from the present investigation on yield attributes, protein and yield of wheat (on pooled basis) significantly influenced by various moisture regimes and INM modules. The data presented in the table indicated that the highest spike length (11.5 cm), grains weight/spike (2.02 g) and grain yield (48.7 q/ha) were recorded under the I_3

treatment which received irrigation at critical stages and statistically *on par* with I_2,but significantly superior over the I_1 (0.7 IW/CPE) treatment. The increase in yield attributes and yield of wheat in present investigation might be due to adequate availability of moisture gained by application of more number of irrigations throughout the growing season which inturn increased the plant biomass and proper development of sink along with better translocation of photosynthates towards sink. Similar finding was observed by Thakur *et al*., (2000) and Niwas*et al*., (2019). The same trend was also noticed for protein content (%) in grains.

Comment [Ma8]: correct

Among the INM modules, the longest spike (11.4 cm) and grain yield (51.0 q/ha) was noticed under application of 50 % RDF + PM @ 2.5 t/ha + NPK consortia. The spike length was statistically *on par* with treatments N_2, N_3, N_4 and N_5 but significantly superior over control,while grains yield, being *on par* with treatments N_3, N_4 and $N_5$and significantly superior over N_1 and N_2treatments. The more grains weight/spike (2.07 g) was registered under the treatment N_5, being *on per* with N_2, N_3, N_4 and N_6,but significantly higher over the control. This increase might be due to the fact that, integration of poultry manure and biofertilizers with 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 period of time, which increased the photosynthetic activities and translocated more photosnthatesin reproductive stage of crop growth, thereby enhance the yield attributes and yield of wheat. Similar results were also reported by Yadav*et al.* (2018). 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 overrest of the treatments. This is might be due to the fact that integration of poultry manure and biofertilizersalong with chemical fertilizer which resulted that poultry manure and biofertilizers increase the nitrogen content in grains consequently enhanced the protein content in grains.

Soil studies

Comment [Ma9]: Change to Soil Characteristics

Perusal of the mean data in the 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 (8.33) and electrical conductivity (0.336 dS/m) was 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 (8.47) and electrical conductivity (0.359 dS/m) was recoded under the irrigation of IW/CPE ratio of 0.7. Thismight be due to that frequent irrigations at critical stages, slightly reduces the soil pH and electrical conductivity. These finding are supported by Bhattacharyaya*et al.* (2008) and Pal *et al.* (2022). Among the INM modules, minimum mean soil pH was recoded under the application of 50% RDF+PM @ 2.5 t/ha+NPK consortia treatment. This is might due to owing the formation of organic acids during decomposition of poultry manure. Our results are in lines those of Kumara *et al*. (2013) and Singh (2019).

Crop water use

The total crop water use was calculated by adding contribution from different sources ofwater, *i.e.* water applied thought the irrigation, difference in moisture content at sowing and harvesting and effective rainfall. It was directly related to number of irrigation applied to relative treatments. The maximum amount ofcrop water use (541.9 mm) was recorded under the treatment? 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_3had received 26.8 % more water compared to the I_1 treatment. This was mainly due to thefact that more frequent irrigation applied under I_3(at critical stages) maintains the optimum soil moisture throughout the growth period of crop. Singh *et al.* (2015) and Niwas*et al.* (2023) also made similar observations in wheat atHisar (H.) and Kanpur (U.P.), respectively. Among the INM modules, application of 50 % RDF + PM @ 2.5 t/ha + *Azotobacter*+ PBS + KMB in wheat showed the highest crop water use (482.5 mm) and it was higher (1.8%) compared to control.

Comment [Ma10]: Which treatment?

Water productivity

Thewater productivity was calculated as the production of economic yield per unit of total amount of water used. In the moisture regimes, the maximum mean water productivity (5.94 kg/ha-mm) 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 minimum of 5.46 kg/ha-mm with irrigation at critical stages. This is might be due to fact that better grain yield obtained with minimum amount of water applied resulted more water productivity. Similar finding was noted by Rajanna*et al*. (2017). Among the INM modules, the maximum water productivity (6.38 kg/ha-mm) was observed under the application of 50 % RDF + PM @ 2.5 t/ha + NPK consortia being *on par* with N_2, N_3, N_4 and N_5 but significantly 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 water use. The similar results were reported by Liu *et al*. (2018).

Table 2: Effect of various moisture regimes and INM modules on growth, 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

4. CONCLUSION

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

Comment [Ma11]: Kindly add more scientific context in the conclusion part to make it more realistic

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