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Efficient irrigation management for enhancing productivity and profitability of wheat under semi-arid inceptisols in Gujarat

Vijendra Shantaram Baviskar, J.B. Patel, S.R. Takale, M.S. Shitap, V.J. Patel and G.R. Maruthi Sankar[1]

Anand Agricultural University, Anand-388110, Gujarat; [1]ICAR-Central Research Institute for Dryland Agriculture, Santoshanagar-500059, Hyderabad.

[1]E-mail: gmsankar2009@gmail.com

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ABSTRACT

Effective irrigation scheduling to manage water requirement of wheat were evaluated with four water application approaches (I_1: Irrigations at crown root initiation (CRI) + tillering + jointing + flowering; I_2: Irrigations at CRI + tillering + jointing + flowering + milking; I_3: Irrigations at CRI + tillering + jointing + flowering + milking + dough; and I_4: Irrigations at 0.8 IW:CPE ratio) in combination with two seeding rates (125 and 150 kg ha^{-1}) and two sowing methods (line sowing at 22.5 cm and broadcasting) at Anand in Gujarat during 2010 and 2011. Observations were recorded on growth, yield attributes grain yield, straw yield, protein content and field water use efficiency (FWUE) in each year. The dry matter of wheat significantly increased with increase in the irrigation frequency. I_4: Irrigation scheduled at 0.8 IW:CPE ratio and irrigations at CRI + tillering + jointing + flowering + milking + dough stage (I_3) gave significantly higher mean grain and straw yields (5.361 and 6.535 t ha^{-1}) compared to irrigation with I_1 or I_2 treatments. However, seed rate @ 150 kg ha^{-1} gave significantly higher plant population with taller plants, grain and straw yield than 125 kg ha^{-1}. Dry matter accumulation/plant increased with a decrease in the seed rate from 150 to 125 kg ha^{-1} at 30 and 45 days after sowing (DAS). Seed rate @ 150 kg ha^{-1} gave significantly higher grain yield (5.673 t ha^{-1}) and straw yield (6.211 t ha^{-1}) compared to 125 kg ha^{-1}. Among sowing methods, line sowing was significantly superior to broadcasting method with regard to improvement in dry matter accumulation/plant. Line sowing gave significantly higher grain yield (5.612 t ha^{-1}) compared to broadcasting method. The grain and straw yield, protein content and FWUE were significantly correlated with different plant traits observed during crop growth period. I_4 + line sowing + seed rate @ 150 kg ha^{-1} was superior with respect to maximum gross returns (₹ 101868 ha^{-1}), net returns (₹ 69253 ha^{-1}) and benefit-cost (B:C) ratio (3.12) compared to other treatments. Based on rank analysis, I_4 + line sowing + seed rate @ 150 kg ha^{-1} was highly efficient for attaining maximum grain and straw yield, protein content, FWUE, besides monetary returns and B:C ratio under semi-arid Inceptisols in Gujarat.

Key words:

Correlation,
Irrigation,
Monetary returns,
Plant traits,
Rank sum,
Seed rate,
Sowing method

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important food grain crop for irrigated perimeters of the arid and semi-arid region of India. Although irrigated area under wheat has been increasing, a static growth of production is observed in the arid zone of Rajasthan. The crop productivity in medium-textured shallow soils of this region is low owing to low water retention, poor inherent fertility, low soil organic carbon and rapid development of mechanical impedance with drying caused by high soil crust strength. High soil temperature during early and later parts in a growing season, in general, is a major production limitation in the north west plain zone (NWPZ) of India. Irrigation would normally optimize plant water use and attain higher crop productivity. Adoption of a suitable irrigation water management practice is necessary to overcome expensive irrigation and eliminate many associated problems. This concept is critically important in the areas of central Gujarat, where deep percolation associated with excess irrigation combined with a saline geographical formation would further contribute to the salinity problem. Therefore, irrigation management would become a crucial element in reducing the deep percolation and improving the water quality downstream.

It is necessary to produce maximum yield per unit area by using available water effectively because irrigation water is rapidly diminishing in most parts of the world. Irrigated agriculture would take place under water scarcity condition not only at present but would increase in the future. Emphasis will shift from production per unit area towards maximizing the production per unit of water consumed, *i.e.* the water productivity. It is essential to develop most suitable irrigation schedule to produce maximum plant yield. Wajid *et al.* (2002) reported that wheat produced the highest grain yield by applying irrigation at all definable growth stages because irrigation is an expensive input, emphasis should be given for maximizing the response of yield to irrigation. In a study by Jamal *et al.* (1996), the authors concluded that grain yield of different wheat cultivars was significantly low due to water stress observed at different critical growth stages. Maximum yield reduction was observed when the water stress existed at the anthesis stage. Thus, deficit irrigation could be defined as the application of water below the full crop water requirements. This is an important tool to achieve the goal of reducing irrigation water use (Fereres and Sariano, 2007).

The relationship between yield and crop water use has been investigated by many researchers. Wheat is one of the most important cereal crops grown in the world on account of its wide availability to agro-climatic and soil conditions. In central Gujarat, rice-wheat cropping system is a predominant system, in which wheat is grown after harvest of rice crop. Wheat would require longer days of cold during its tillering period. However, in Gujarat, short winter does not coincide with the tillering stage and the crop is sown late rather than normal sowing particularly in rice lands. Cultivation of high yielding wheat varieties, irrigation would assume a greater importance since during growing season of the crop (October to April), weather would remain relatively dry. The judicious application of water signals for immediate attention. This is possible only by following some scientific basis for water application to the crop. One such scientific approach in water scarcity area is critical growth stage approach for scheduling of irrigation. Suitable sowing method and seed rate are the basic inputs for proper stand and use of available resources for production of wheat. Hence, the method of sowing and seed rate would play an important role for efficient utilization of air, water, solar energy, space and nutrient and improving the crop yield and quality to a great extent.

Hiltbrunner *et al.* (2007) advocated that a rationale increase of the seeding rate with that of sowing time is highly effective to increase the grain yield. From agronomy point of view, a key factor which is reflected in higher wheat production is the well understanding of early crop establishment factors such as time of planting, soil characteristics, seed viability and availability of plant machinery. Therefore, it is important to define the optimal sowing date and seed rate of winter wheat due to the climate-change of habitats, not only from agro-technical factors, but also from economic point of view (Kristo *et al.,* 2006).

Plant density is one of the major factors determining the ability of the crop to capture resources and generate yield. It can be developed by using suitable seeding rate. The growth and yield of wheat are affected by environmental conditions and could be regulated by sowing time and seeding rate (Ozturk *et al.,* 2005). This is important since it is being under fairly close control by the farmers under most wheat based cropping systems. There has been an increased interest among researchers in defining the relationships between density and crop yield quantitatively in order to establish optimum populations and maximum attainable yields under various situations. There is no uniform recommendation by agronomists regarding the seed rate for an unit area. Jaime *et al.* (2004) suggested that the seed rate under irrigation for Mediterranean areas could be higher than the rate used in other wheat-growing areas.

Sharma and Pannu (2008) assessed the effect of limited irrigation on physiological response of wheat. Rahim *et al.* (2010) assessed the effect of P application in combination with irrigation on wheat yield. In a study by Rao *et al.* (2013), the authors assessed the effect of sprinkler irrigation and soil management practices on wheat yield under shallow arid soils. Keeping in view of irrigated environments and number of plants acre^{-1}, the present study was conducted to determine the effect of irrigation schedules in combination with planting methods and seed rates on wheat grain and straw yield and yield contributing parameters under semi-arid Inceptisols in India.

2. MATERIALS AND METHODS

Experimental Details

A field experiment on wheat (GW-496 variety) was conducted during *rabi* 2010-11 and 2011-12 at Regional Research Station, Anand Agricultural University, Anand in central Gujarat. The experimental site had an even topography with moderate slope and good drainage. The climate of this region is semi-arid and sub-tropical with dry and hot summer. Experimental site is situated at 22º35' N latitude and 72º55' E longitude with altitude of 45.1 m above msl. The normal rainfall of Anand is 687 mm from south-eest Monsoon with an average of 40 rainy days. During 2010-11, the maximum temperature ranged between 25.7 to 39^{0}C and minimum between 8.3 to 22.6^{0}C. During 2011-12, the maximum temperature ranged between 25.3 to 36.9^{0}C and minimum between 8.6 to 19.1^{0}C. The normal onset of monsoon is from 3rd week of June and the normal cessation is in the 4th week of September. The soil is Inceptisol in origin and is a representative of the soils of the region. The soil texture was sandy clay, having 0.38% organic carbon and pH of 7.6. It was low in available soil N (232.4 kg ha^{-1}), medium in P (21.0 kg ha^{-1}) and high in K (284.1 kg ha^{-1}). The field experiment was conducted with 3 factors *viz.,* irrigation schedules, sowing methods and seed rates in a Randomized Block Design.

Four irrigation schedules were tested at critical growth stages and IW: CPE ratio *viz.,* I_1: Irrigations at CRI + tillering + jointing + flowering; I_2: Irrigations at CRI + tillering + jointing + flowering + milking; I_3: Irrigations at CRI + tillering + jointing + flowering + milking + dough; and I_4: Irrigations at 0.8 IW: CPE ratio. Similarly, two levels of seed rate *viz.,* 125 and 150 kg ha^{-1} and two sowing methods *viz.,* line sowing at 22.5 cm and broadcasting were adopted in the study. Thus, there were 16 treatment combinations in the study with 4 replications. Nitrogen @ 120 kg ha^{-1} was applied in the form of urea, while phosphorus @ 60 kg ha^{-1} was applied in the form of single super phosphate. Half dose of N and full dose of P were applied as basal dose and the remaining half dose as top dressing after 1st irrigation in each season. The crop was shown on 24th November in 2010 and 21st November in 2011. The irrigation was applied in the field as per treatments. The weeds were removed by two hand weedings done at 20 and 40 DAS. All the growth parameters were observed at 15 days interval. The grain and straw yields were recorded at harvest of the crop. Observations were recorded for different plant traits and yield in each year. The plants were tagged for other phenological observations. The dry matter accumulation was measured at 30, 45, 60 and 75 DAS. The plants uprooted at 30, 45, 60 and 75 DAS were used for dry matter estimation. Leaf and stem were cut into pieces and sun dried and then oven dried at 70^{0}C till constant weight. The dry weight (g) was measured separately for each sample and mean dry matter plant^{-1} was derived.

Statistical Analysis

The effects of irrigation schedules, sowing methods and seed rates and their interactions were tested based on F-test under analysis of variance procedure. Using the least significant difference (LSD) criteria, pair-wise differences of treatments were compared for significance and superior treatments were identified (Gomez and Gomez, 1984). The importance of plant traits in influencing grain and straw yield, protein content, harvest index and FWUE was assessed based on the estimates of correlation derived. The treatments could be ranked for the mean values of plant traits derived over years. The treatments are assessed based on rank sums and an efficient irrigation treatment in combination with seed rate and sowing method is identified.

3. RESULTS AND DISCUSSION

Effect of Irrigation, Sowing Method and Seed Rate on Dry Matter

The irrigation treatments had significant effect on dry matter at 30, 45, 60 and 75 DAS in 2010 and 2011 and also when pooled over years (Table 1). The two sowing methods differed significantly from each other at all the 30, 45, 60 and 75 DAS in both years except at 30 DAS in 2010. The seed rates also had significant effect on dry matter in both years at 30, 45, 60 and 75 DAS. I_4 gave maximum mean dry matter of 2.99, 6.01, 10.50 and 13.92 g plant^{-1}, while I_1 gave minimum dry matter of 2.52, 5.08, 8.70 and 10.81 g plant^{-1} at 30, 45, 60 and 75 DAS over years, respectively. Line sowing gave maximum mean dry matter of 2.83, 5.69, 9.97 and 12.87 g plant^{-1}, while broadcast sowing gave minimum dry matter of 2.73, 5.37, 9.44 and 11.99 g plant^{-1} at 30, 45, 60 and 75 DAS over years, respectively. Seed rate @ 125 kg ha^{-1} gave maximum mean dry matter of 2.86, 5.78, 10.15 and 13.04 g plant^{-1}, while 150 kg ha^{-1} gave minimum dry matter of 2.70, 5.28, 9.26 and 11.82 g plant^{-1} over years, respectively.

Based on LSD criteria, among irrigation treatments, I_4 gave significantly higher dry matter compared to I_1, I_2 and I_3 at 45 DAS in 2011 and pooled over years; 60 DAS in 2011 and pooled over years; 75 DAS in 2010, 2011 and pooled over years. I_4 was at par with I_3 at 30 DAS in 2010, 2011 and pooled over years; at 45 DAS in 2010. I_3 was superior to I_2 and I_1 at 30 DAS in 2010; 45 DAS in 2011 and pooled over years; 60 DAS in 2011 and pooled over years; 75 DAS in 2011 and pooled over years. I_2 was superior to I_1 at 30 DAS when pooled over years; 45 DAS in 2010 and pooled over years; 60 DAS in 2010 and pooled over years; 75 DAS in 2010, 2011 and pooled over years. Line sowing at 22.5 cm was superior compared to broadcasting method at 30, 45, 60 and 75 DAS in both years except 30 DAS in 2010. The seed rate of 125 kg ha^{-1} was superior compared to 150 kg ha^{-1} at 30, 45, 60 and 75 DAS in both years and when pooled over years.

Our findings are in agreement with those of Pal *et al.* (1996) who observed the effects of irrigation, fertilizer and seeding dates on productivity of wheat. They observed similar

Table: 1
Effect of irrigation, sowing method and seed rate on dry matter in wheat

Treatments	Dry matter (g $plant^{-1}$)											
	30 DAS			45 DAS			60 DAS			75 DAS		
	2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled
Irrigation (I)												
I_1	2.61^{c}	2.43^{b}	2.52^{c}	5.36^{c}	4.80^{c}	5.08^{d}	8.77^{b}	8.62^{c}	8.70^{d}	10.8^{c}	10.8^{d}	10.81^{d}
I_2	2.75^{bc}	2.67^{b}	2.71^{b}	5.76^{b}	4.88^{c}	5.32^{c}	10.15^{a}	8.87^{c}	9.51^{c}	12.7^{b}	11.50^{c}	12.13^{c}
I_3	2.87^{ab}	2.91^{a}	2.89^{a}	6.02^{ab}	5.39^{b}	5.71^{b}	10.52^{a}	9.69^{b}	10.11^{b}	13.1^{b}	12.6^{b}	12.86^{b}
I_4	2.95^{a}	3.03^{a}	2.99^{a}	6.22^{a}	5.80^{a}	6.01^{a}	10.58^{a}	10.41^{a}	10.50^{a}	14.1^{a}	13.8^{a}	13.92^{a}
LSD	0.16	0.17	0.13	0.26	0.24	0.18	0.44	0.30	0.26	0.39	0.37	0.26
Sowing method (SM)												
Line sowing	2.83	2.83^{a}	2.83^{a}	5.99^{a}	5.39^{a}	5.69^{a}	10.23^{a}	9.70^{a}	9.97^{a}	13.13^{a}	12.62^{a}	12.87^{a}
Broadcast	2.76	2.69^{b}	2.73^{b}	5.69^{b}	5.04^{b}	5.37^{b}	9.78b	9.10^{b}	9.44^{b}	12.26^{b}	11.71^{b}	11.99^{b}
LSD	NS	0.12	0.09	0.19	0.17	0.13	0.31	0.21	0.19	0.28	0.26	0.19
Seed rate (SR)												
125 kg ha^{-1}	2.89^{a}	2.83^{a}	2.86^{a}	6.16^{a}	5.39^{a}	5.78^{a}	10.59^{a}	9.71^{a}	10.15^{a}	13.47^{a}	12.61^{a}	13.04^{a}
150 kg ha^{-1}	2.71^{b}	2.69^{b}	2.70^{b}	5.52^{b}	5.04^{b}	5.28^{b}	9.42^{b}	9.09^{b}	9.26^{b}	11.92^{b}	11.71^{b}	11.82^{b}
LSD	0.11	0.12	0.09	0.19	0.17	0.13	0.31	0.21	0.19	0.28	0.26	0.19
LSD (I x SM)	0.22	0.25	0.18	0.37	0.34	0.26	0.62	0.42	0.37	NS	NS	NS
LSD (I x SR)	0.22	NS	NS	0.37	0.34	0.26	NS	0.42	0.37	NS	NS	NS
LSD (SM x SR)	0.16	NS	0.13	NS	NS	0.18	0.44	NS	0.26	NS	NS	NS
LSD (I x SM x SR)	0.32	NS	0.25	NS	0.49	0.37	0.88	0.59	0.53	0.78	0.74	0.52

I_1: Irrigations at CRI + Tillering + Jointing + Flowering ; I_2: Irrigations at CRI + Tillering + Jointing + Flowering + Milking ; I_3: Irrigations at CRI + Tillering + Jointing + Flowering + Milking + Dough ; I_4: Irrigations at 0.8 IW: CPE ratio ; LSD : Least significant difference at $p < 0.05$; NS : Non-significant ; DAS : Days after sowing ; Treatments with same letter (a, b, c, d....) indicate that they are at par with each other

findings for management of irrigation. The increase in dry matter accumulation/plant could be attributed to better absorption of plant nutrients, imparted by sufficient air and moisture in the rhizosphere which helped in an increasing expansion of leaf lamina and thereby increased the dry matter accumulation. Our results are in agreement with findings of Pal *et al.* (1996) and Nand *et al.* (2011) who reported that the crop receiving 4 irrigations maintained higher crop growth rate than crop receiving 2 or 3 irrigations. The significant increase in I_4 was due to increased availability of irrigation water which improved the dry matter production. This corroborated with the findings of Sharma *et al.* (1990).

Effect of Irrigation, Sowing Method and Seed Rate on Total and Effective Number of Tillers

The irrigation treatments differed significantly from each other for total and effective number of tillers in both years and also when pooled over years (Table 2). The two sowing methods differed significantly from each other for total tillers and effective tillers in each year and when pooled over years. The seed rates differed significantly from each other in influencing total and effective tillers in 2010 and 2011 and when pooled over years. I_4 gave maximum mean number of total tillers of 541 m^{-2} and effective tillers of 453 m^{-2}. Line sowing gave maximum mean number of total tillers of 520 m^{-2}, while broadcast sowing gave minimum number of effective tillers of 410 m^{-2} over years. Seed rate @ 150 kg ha^{-1} gave maximum mean number of total tillers of 544 m^{-2}, while seed rate @ 125 kg ha^{-1} gave minimum number of effective tillers of 385 m^{-2} over years.

Effect of Irrigation, Sowing Method and Seed Rate on Grain and Straw Yield and Harvest Index

The two sowing methods differed significantly from each other for grain yield in 2010; and straw yield when pooled over years (Table 3). The seed rates differed significantly from each other in both years and when pooled over years for grain and straw yield, while they were significantly different for harvest index in only 2010. I_4 was superior and significantly higher grain yield of 5.861 t ha^{-1} and straw yield of 6.535 t ha^{-1}, while I_1 gave lower yield of 4.794 t ha^{-1} and straw yield of 5.616 t ha^{-1} over years. I_2 gave maximum mean harvest index of 48.3%, while I_1 gave minimum harvest index of 46.0% over years. Line sowing gave maximum mean grain yield of 5.612 t ha^{-1}, straw yield of 6.126 t ha^{-1} and harvest index of 47.6%, while broadcast sowing gave minimum mean grain yield of 5.135 t ha^{-1}, straw yield of 5.897 t ha^{-1} and harvest index of 46.5% over years. Seed rate @ 150 kg ha^{-1} gave maximum mean grain yield of 5.673 t ha^{-1}, straw yield of 6.211 t ha^{-1} and harvest index of 47.6%,

Table: 2
Effect of irrigation, sowing method and seed rate on total and effective tillers in wheat

Treatments	Total tillers (m^{-2})			Effective tillers (m^{-2})		
	2010	2011	Pooled	2010	2011	Pooled
Irrigation (I)						
I_1	449^c	476^c	463^c	379^b	408^c	394^c
I_2	478^b	509^b	494^b	412^a	438^b	425^b
I_3	504^{ab}	537^{ab}	520^a	427^a	455^{ab}	441^{ab}
I_4	523^a	559^a	541^a	432^a	474^a	453^a
LSD	27	31	21	24	25	18
Sowing method (SM)						
Line sowing	502^a	537^a	520^a	430^a	463^a	446^a
Broadcast	475^b	503^b	489^b	395^b	424^b	410^b
LSD	19	22	15	17	18	13
Seed rate (SR)						
125 kg ha^{-1}	454^b	476^b	465^b	372^b	397^b	385^b
150 kg ha^{-1}	523^a	565^a	544^a	453^a	490^a	472^a
LSD	19	22	15	17	18	13
LSD (I x SM)	NS	NS	NS	NS	NS	26
LSD (I x SR)	NS	NS	NS	NS	NS	NS
LSD (SM x SR)	NS	NS	NS	NS	NS	NS
LSD (I x SM x SR)	NS	NS	NS	NS	NS	NS

I_1: Irrigations at CRI + Tillering + Jointing + Flowering ; I_2: Irrigations at CRI + Tillering + Jointing + Flowering + Milking ; I_3: Irrigations at CRI + Tillering + Jointing + Flowering + Milking + Dough ; I_4: Irrigations at 0.8 IW: CPE ratio ; LSD : Least significant difference at $p < 0.05$; NS : Non-significant ; DAS : Days after sowing ; Treatments with same letter (a, b, c, d....) indicate that they are at par with each other

Table: 3
Effect of irrigation, sowing method and seed rate on wheat grain and straw yield and harvest index

Effect	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})			Harvest index (%)		
	2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled
Irrigation (I)									
I_1	4.640^c	4.953^c	4.794^c	5.215^c	6.017^b	5.616^c	46.9	45.0	46.0
I_2	5.662^a	5.326^b	5.494^b	5.772^b	5.996^b	5.884^b	49.5	47.0	48.3
I_3	5.276^b	5.412^b	5.344^b	5.786^b	6.234^b	6.010^b	47.5	46.3	46.9
I_4	5.820^a	5.903^a	5.861^a	6.343^a	6.728^a	6.535^a	47.7	46.7	47.2
LSD	0.397	0.347	0.271	0.327	0.354	0.254	NS	NS	NS
Sowing method (SM)									
Line sowing	5.567^a	5.656^a	5.612^a	5.888	6.364	6.126^a	48.4	46.9	47.6
Broadcast	5.129^b	5.141^b	5.135^b	5.671	6.123	5.897^b	47.5	45.6	46.5
LSD	0.281	0.245	0.192	NS	NS	0.180	NS	NS	NS
Seed rate (SR)									
125 kg ha^{-1}	5.010^b	5.138^b	5.074^b	5.637^b	5.986^b	5.811^b	46.9^b	46.2	46.5
150 kg ha^{-1}	5.686^a	5.659^a	5.673^a	5.922^a	6.501^a	6.211^a	48.9^a	46.3	47.6
LSD	0.281	0.245	0.192	0.231	0.251	0.180	1.7	NS	NS
LSD (I x SM)	0.561	0.491	0.383	0.463	NS	0.360	NS	NS	NS
LSD (I x SR)	NS	0.491	0.383	NS	NS	0.360	NS	3.0	2.4
LSD (SM x SR)	0.397	0.347	0.271	NS	NS	NS	NS	2.1	1.7
LSD (I x SM x SR)	NS	NS	NS	NS	NS	NS	4.9	NS	3.4

I_1: Irrigations at CRI + Tillering + Jointing + Flowering ; I_2: Irrigations at CRI + Tillering + Jointing + Flowering + Milking ; I_3: Irrigations at CRI + Tillering + Jointing + Flowering + Milking + Dough ; I_4: Irrigations at 0.8 IW: CPE ratio ; LSD : Least significant difference at $p < 0.05$; NS : Non-significant ; DAS : Days after sowing ; Treatments with same letter (a, b, c, d....) indicate that they are at par with each other

while seed rate @ 125 kg ha^{-1} gave minimum mean grain yield of 5.074 t ha^{-1}, straw yield of 5.811 t ha^{-1} and harvest index of 46.5% over years. Similar results were observed based on research work conducted by Singh and Bhan (1998).

Effect of Irrigation, Sowing Method and Seed Rate on Plant Population, Protein Content and Field Water Use Efficiency (FWUE)

The two sowing methods differed significantly from each other for protein content in 2010 and when pooled

Table: 4
Effect of irrigation, sowing method and seed rate on plant population, protein content and field water use efficiency in wheat

Effect	Plant population (m^{-2})			Protein content (%)			FWUE (kg ha^{-1} mm^{-1})		
	2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled
Irrigation (I)									
I_1	249	233^b	242	10.7^c	11.1	10.9^c	12.3^a	14.9^a	13.6^a
I_2	254	245^{ab}	250	11.5^b	11.3	11.4^{bc}	10.7^b	12.6^b	11.7^b
I_3	257	258^a	258	12.1^{ab}	12.1	12.1^a	8.9^c	12.8^b	10.8^c
I_4	264	260^a	262	12.5^a	11.9	12.2^a	8.2^c	12.9^b	10.6^c
LSD	NS	15.5	NS	0.7	NS	0.6	1.2	0.9	0.8
Sowing method (SM)									
Line sowing	261	250	256	11.4^b	11.4	11.4^b	9.8	14.1^a	11.9
Broadcast	250	248	249	12.0^a	11.8	11.9^a	10.3	12.5^b	11.4
LSD	NS	NS	NS	0.5	NS	0.4	NS	0.7	NS
Seed rate (SR)									
125 kg ha^{-1}	237^b	234^b	236^b	12.0	11.4	11.7	9.5^b	11.3^b	10.4^b
150 kg ha^{-1}	275^a	264^a	270^a	11.6	11.7	11.6	10.5^a	15.3^a	12.9^a
LSD	12.4	10.9	16.6	NS	NS	NS	0.8	0.7	0.6
LSD (I x SM)	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD (I x SR)	NS	NS	NS	NS	NS	NS	1.7	NS	1.1
LSD (SM x SR)	NS	NS	NS	NS	NS	NS	1.2	NS	NS
LSD (I x SM x SR)	NS	NS	NS	NS	NS	NS	NS	NS	NS

I_1: Irrigations at CRI + Tillering + Jointing + Flowering ; I_2: Irrigations at CRI + Tillering + Jointing + Flowering + Milking ; I_3: Irrigations at CRI + Tillering + Jointing + Flowering + Milking + Dough ; I_4: Irrigations at 0.8 IW: CPE ratio ; LSD : Least significant difference at $p < 0.05$; NS : Non-significant ; DAS : Days after sowing ; Treatments with same letter (a, b, c, d....) indicate that they are at par with each other

over years; while they differed in 2011 for FWUE (Table 4). The seed rates were at par for protein content, while they differed significantly for plant population and FWUE in both years and when pooled over years. I_4 gave maximum mean plant population of 261.9 m^{-2} and protein content of 12.2%, while I_1 gave minimum mean plant population of 241.6 m^{-2} and protein content of 10.9% over years. I_1 gave maximum mean FWUE of 13.6 kg ha^{-1} mm^{-1}, while I_4 gave minimum mean FWUE of 10.6 kg ha^{-1} mm^{-1} over years. Line sowing gave maximum mean plant population of 256 m^{-2} and FWUE of 11.9 kg ha^{-1} mm^{-1}, while broadcast sowing gave minimum mean plant population of 249.5 m^{-2} and FWUE of 11.4 kg ha^{-1} mm^{-1} over years. However, broadcast sowing gave maximum mean protein content of 11.9%, while line sowing gave minimum mean protein content of 11.4% over years. Seed rate @ 150 kg ha^{-1} gave maximum mean plant population of 269.6 m^{-2} and FWUE of 12.9 kg ha^{-1} mm^{-1}, while seed rate @ 125 kg ha^{-1} gave minimum mean plant population of 235.9 m^{-2} and FWUE of 10.4 kg ha^{-1} mm^{-1} over years. However, seed rate @ 125 kg ha^{-1} gave maximum mean protein content of 11.7%, while seed rate @ 150 kg ha^{-1} gave minimum mean protein content of 11.6% over years. Our findings are in convergence with the results of Kharrou *et al.* (2011) who studied effects of irrigation on water use efficiency (WUE) and yield of wheat. Similarly, our results corroborated with those of Nasseri and Fallahi (2007) who assessed WUE of wheat under limited irrigation.

Effect of Seed Rates on Plant Traits

The seed rate @ 150 kg ha^{-1} gave maximum total and effective tillers in both years and when pooled over years. It was superior for attaining maximum plant population and FWUE, while it was at par with 125 kg ha^{-1} for protein content in both years and when pooled over years. This was due to a higher plant population under higher seed rate which resulted in better utilization of natural resources particularly nutrients, moisture, carbon dioxides and radiant energy. Chen *et al.* (2008) and Iqbal *et al.* (2012) found similar observations in their study.

The seed rate of 125 kg ha^{-1} gave maximum dry matter at 30, 45, 60 and 75 DAS in both years and when pooled over years. It was superior for attaining significantly higher grain and straw yield in both years and pooled over years and harvest index in 2010. The dry matter accumulation (g $plant^{-1}$) increased significantly with a decrease in seed rate. As a result, the dry weight of whole plant increased linearly with a decreasing seed rate. It was also due to the accelerated leaf area/plant under a lower seed rate to which most of the photosynthates were diverted to the increasing sink. Said *et al.* (2012) and Anwar *et al.* (2015) reported that grain yield increased as seed rate increased from 50 to 150 kg ha^{-1}.

Effect of Sowing Methods on Plant Traits

Line sowing was superior for maximum dry matter at 30, 45, 60 and 75 DAS in both years except 30 DAS in 2010.

Significantly higher total and effective tillers were attained by line sowing in both years and when pooled over years. Line sowing was superior for grain yield in both years, while it was superior for grain and straw yield when pooled over years; and FWUE in 2011.These findings are in conformity with the findings of Jat and Singh (2003), Pandey and Kumar (2005), Shivamurthy *et al.* (2009). Broadcast sowing was superior for protein content in 2010 and pooled over years.

Correlation Among Different Plant Traits

The grain yield had a significant positive correlation with dry matter at 30, 60 and 75 DAS; plant population, total tillers and effective tillers over years (Table 5). This indicated that grain yield increased with increase in dry matter, plant population, total and effective tillers. The straw yield had a significant positive correlation with dry matter at 30, 45, 60 and 75 DAS; plant population, total tillers and effective tillers. This indicated that straw yield increased with increase in dry matter, plant population, total and effective tillers. The protein content had a significant positive correlation with dry matter at 60 and 75 DAS. This indicated that protein content increased with dry matter. The FWUE had a significant negative correlation with plant population and effective tillers over years. This indicated that FWUE decreased with increase in dry matter, plant population and effective tillers. These results are in conformity with the findings of Pandey *et al.* (1999).

Table: 5
Correlation between yield and different plant traits in wheat

Variable	Estimate of correlation with				
	Grain yield	Straw yield	Harvest index	Protein content	Field WUE
Dry matter (g plant^{-1}) accumulation at 30 DAS	0.33*	0.28*	0.16	0.12	-0.52**
Dry matter (g plant^{-1}) accumulation at 45 DAS	0.13	0.36**	-0.19	0.24	-0.46**
Dry matter (g plant^{-1}) accumulation at 60 DAS	0.25*	0.29*	0.04	0.37**	-0.58**
Dry matter (g plant^{-1}) accumulation at 75 DAS	0.32*	0.41**	0.02	0.36**	-0.61**
Plant population (m^2)	0.39**	0.48**	0.11	0.02	0.26*
Total number of tillers	0.55**	0.64**	0.14	0.24	0.17
Number of effective tillers	0.55**	0.59**	0.17	0.14	0.25*

* and ** indicate significance at $p < 0.05$ and $p < 0.01$ level, respectively ; DAS : Days after sowing

Monetary Returns Attained from Irrigation, Seeding Method and Seed Rate Treatments

I_1 + 125 kg ha^{-1} + line sowing incurred the lowest cost of cultivation (₹ 29,757 ha^{-1}), while I_4 + 150 kg ha^{-1} + broadcasting incurred highest cost of cultivation (₹ 33,781 ha^{-1}). I_4 + 150 kg ha^{-1} + line sowing gave maximum net returns. I_1 + 125 kg ha^{-1} + broadcasting gave minimum B:C ratio of 2.03, while I_3 + 150 kg ha^{-1} + line sowing gave maximum B:C ratio of 3.14 over years. The treatments had a coefficient of variation of 3.4% for cost of cultivation, 13.9% for gross returns, 22.2% for net returns and 13.1% for B:C ratio over years (Table 6).

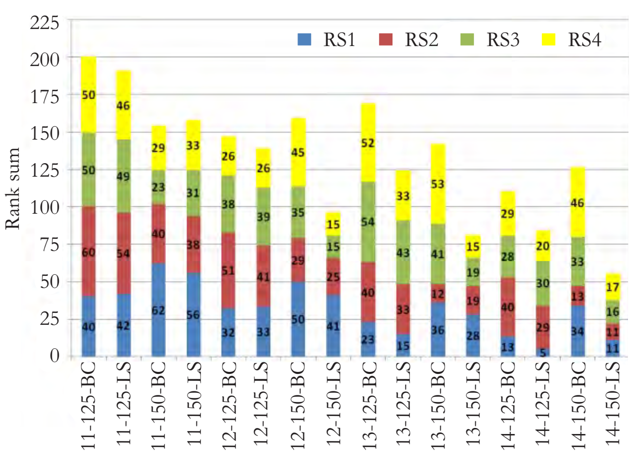
Table: 6
Monetary returns and benefit-cost ratio from irrigation, seed rate and sowing methods in wheat

Irrigation	Seed rate (kg ha^{-1})	Sowing method	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	Benefit-cost ratio
I_1	125	Line sowing	29,757	61,990	32,233	2.08
I_1	125	Broadcasting	30,923	62,892	31,969	2.03
I_1	150	Line sowing	30,617	78,402	47,785	2.56
I_1	150	Broadcasting	31,783	82,780	50,997	2.60
I_2	125	Line sowing	30,423	79,214	48,791	2.60
I_2	125	Broadcasting	31,589	82,743	51,154	2.62
I_2	150	Line sowing	31,283	91,002	5,718	2.91
I_2	150	Broadcasting	32,449	78,442	45,992	2.42
I_3	125	Line sowing	31,089	78,886	47,797	2.54
I_3	125	Broadcasting	32,255	68,565	36,310	2.13
I_3	150	Line sowing	31,949	1,00,182	68,233	3.14
I_3	150	Broadcasting	33,115	74,372	41,257	2.25
I_4	125	Line sowing	31,755	87,233	55,478	2.75
I_4	125	Broadcasting	32,921	87,180	54,259	2.65
I_4	150	Line sowing	32,615	1,01,868	69,253	3.12
I_4	150	Broadcasting	33,781	79,911	46,129	2.37
Min			29,757	61,990	31,969	2.03
Max			33,781	1,01,868	69,253	3.14
Mean			31,769	80,979	49,210	2.55
SD			1,073	11,245	10,909	0.33
CV (%)			3.4	13.9	22.2	13.1

I_1: Irrigations at CRI + Tillering + Jointing + Flowering ; I_2: Irrigations at CRI + Tillering + Jointing + Flowering + Milking ; I_3: Irrigations at CRI + Tillering + Jointing + Flowering + Milking + Dough ; I_4: Irrigations at 0.8 IW: CPE ratio

Ranking of Irrigation, Seeding Method and Seed Rate Treatments for Superiority

Ranks were assigned to each treatment based on the performance of different plant traits over years and rank sums were derived. The rank sums of treatments ranged from 55 for the treatment of I_4 + line sowing + 150 kg ha^{-1} to 200 for I_1 + broadcasting + 125 kg ha^{-1}. I_4 + line sowing + 125 kg ha^{-1} was superior for dry matter at 30, 45, 60 and 75 DAS with rank sum of 5. I_4 + line sowing + 150 kg ha^{-1} was superior for total and effect number of tillers, plant population and protein content with rank sum of 11. I_2 + line sowing + 150 kg ha^{-1} was superior for grain yield, straw yield, harvest index and FWUE with rank sum of 15. I_2 + line sowing + 150 kg ha^{-1} and I_3 + line sowing + 150 kg ha^{-1} were superior for attaining maximum monetary returns and B:C ratio with rank sum of 15. However, I_3 + line sowing + 150 kg ha^{-1} was the 2nd best with rank sum of 81 and I_4 + line sowing + 125 kg ha^{-1} was the 3rd best treatment with rank sum of 84. The rank sum of each treatment for different plant traits is depicted in Fig. 1. The interactive effect of irrigation schedules, seed rates and sowing methods was significant on grain yield. Significantly higher grain yield was attained under the treatment combination of 0.8 IW: CPE ratio + seed rate @ 150 kg ha^{-1} + line sowing at 22.5 cm than other treatments together with seed rate @ 150 kg ha^{-1} and line sowing. Similar results were reported by Mehmood *et al.* (2002); Singh *et al.* (2016) and Jat *et al.* (2012). We recommend I_4 + line sowing + seed rate @ 150 kg ha^{-1} for attaining maximum grain and straw yield of wheat, monetary returns, apart from dry matter, total tillers, effective tillers, harvest index, plant population, protein content and FWUE under semi-arid Inceptisols.



RS1 : Rank sum of dry matter at 30, 45, 60 and 75 DAS ; RS2 : Rank sum of plant population, harvest index, protein content and field WUE ; RS3 : Rank sum of grain and straw yield ; RS4 : Rank sum of cost of cultivation, gross returns, net returns and B:C ratio ; I_1: Irrigations at CRI + Tillering + Jointing + Flowering ; I_2: Irrigations at CRI + Tillering + Jointing + Flowering + Milking ; I_3: Irrigations at CRI + Tillering + Jointing + Flowering + Milking + Dough ; I_4: Irrigations at 0.8 IW : CPE ratio ; LS : Line sowing ; BC : Broadcast sowing

Fig. 1. Superiority of treatments of irrigation, seed rate and sowing method based on rank sum of wheat yield and different plant traits

4. CONCLUSIONS

The study indicated that use of seed rate of 150 kg ha^{-1} with line sowing and irrigate the crop on the basis of 0.8 IW: CPE ratio (8 irrigations with one common irrigation of 50 mm immediately after dry sowing) could be adopted for attaining significantly higher yield of wheat. This should be followed by 1st irrigation of 50 mm at 17 DAS, 2nd and 3rd irrigation at an interval of 21 DAS and 4th irrigation at 16 days after 3rd irrigation. Based on ranking of treatments, irrigations at 0.8 IW: CPE ratio (I4) + line sowing + 150 kg ha^{-1} was most efficient for enhancing grain and straw yield of wheat, protein content, FWUE, apart from maximum monetary returns. The remaining 3 irrigations have to be given at an interval of 10 to 14 days. The farmers could attain maximum grain and straw yield, FWUE, protein content and harvest index by adopting the efficient treatment of irrigation, seed rate and sowing method identified based on the study under semi-arid Inceptisols in Gujarat.

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