Effect of sowing date, seed rate and row spacing on productivity and profitability of barley (*Hordeum vulgare*) in north India

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ABSTRACT

The precise information regarding the date of sowing, seed rate and row spacing is critical for achieving yield targets and better economic returns of barley. Therefore here, we determined the information regarding the optimum date of sowing, seed rate, spacing and economic aspects for barley production. This study was conducted for three years, in north Indian plains. Early sowing date of barley (last week of October) recorded higher yield in comparison to late sown crop (3rd week of November). Moreover, the higher barley production proved more remunerative when sown early in the last week of October to the first week of November as compared to late sown the late sown crop. Furthermore, the enhanced seed rate of 10% then recommended did not affect the grain yield of barley. But, the closer spacing of 20 cm (row to row) produced higher grain yield (5.45 Mg ha^{-1}) than the recommended spacing of 22.5 cm (5.30 Mg ha^{-1}). Likewise, the economical parameters (net returns) were higher with 20 cm row spacing. Overall, this study determines the optimum date of sowing, seed rate and spacing for scoring better returns of barley crop under north Indian conditions.

Keywords: barley; sowing date; seed rate, row spacing, yield

INTRODUCTION

Barley (*Hordeum vulgare*) is a chief cereal crop, and it is believed to be originated in near east fertile crescent (Dai et al., 2012). For the developing world comprising of the countries like India, it has been a crucial component of the human diet (Kumar et al., 2014; Saisho and Purugganan, 2007). Nutritionally barely contains 55.8 % carbohydrates, 3.4% fat, 11% crude protein, vitamins and 3.7 % mineral elements (Fe, K Mg, etc.) (Kumari, 2019). Traditionally, barley in India was relegated to the status of the poor man's bread (Dutta et al., 2018). Moreover, the epidemiological studies have disclosed that regular consumption of barley is competent to reduce the risk of certain diseases, such as chronic heart disease, colonic cancer, high blood pressure, and gallstones. This activity of barley grains is attributed to the presence of phytochemicals (Idehen et al., 2017; Ware, 2018). Globally, occupies an area of 47.0 million ha with a production of 147.4 million tonnes. The global productivity of barley is 3.14 t/ha and in India, barley productivity is only 2.67 t/ha ("FAOSTAT," n.d.).

By the end of the 21st century, the average global temperature rise is expected between 2.4 to 6.4ºC, that is anticipated to cause a remarkable negative influence on agricultural crop production (Council, 2008; Islam and Karim, 2019). The perturbations in weather conditions at any stage from germination to maturity affects the barley crop production (Barnabás et al., 2008). High temperature and limited water availability are significant constraints because of their profound effect on physiological and biochemical processes that result in — reduced photosynthetic activity, altered metabolism and enzymatic activities (Samarah, 2005).

Although high yielding varieties of barley have been developed via plant breeding programs, henceforth the focus of agronomic research is on technologies/practices in consonance with the most important climatic challenges (ARAUS et al., 2002; Ravishankar and Archak, 2000). In the present times, climate change and water management are the most critical constraints to improve and sustain barley productivity. About 40 % of the total area under barley cultivation is dependent on rainfall for the successful production. To combat these challenges, the understanding of the date of sowing, crop geometry (spatial arrangement) with varying seed rate is of vital significance (Hatfield et al., 2011; Högy et al., 2013).

Moreover, the information regarding the agronomical parameters like the optimum date of sowing helps to determine the best time required for germination, crop establishment, canopy development, etc. (Bussmann et al., 2016; Dennett et al., 1999). Whereas, the date of sowing is critical for obtaining appropriate crop yields (Sial et al., 2005). Similarly, the information regarding the row spacing is essential for tillering, canopy development, radiation reception and photosynthetic activities (Moeller et al., 2014; Wei et al., 2014). Therefore, this study was designed to generate valuable information regarding the useful practices, i.e. optimum date of sowing, seed rate and spacing for the cultivation of barley in the northern Indian conditions.

MATERIALS AND METHODS Experimental Site

The experiment was carried out for three consecutive years, i.e. 2015-16, 2016-17 and 2017-18 at CCS Haryana Agricultural University, Regional Research Station, Rewari Haryana, India located at coordinates of 28º4’ N latitude and 76º35’ E longitude, an altitude of 266 m above mean sea level (Arabian Sea). The crop season during each was from October – April.

Climatic conditions and soil characteristics

The climate of Bawal (Rewari), India can be classified as tropical and semiarid with hot and dry winds in summer, severe cold in winter and humid, warm weather during the rainy season. The maximum temperature sometimes exceeds 48^0C in summer while minimum temperature falls to below freezing (0 to -2^0 C) accompanied by frost in winter occasionally. About 80 to 90 per cent of total annual rainfall is received from the south-west monsoon in July to September while remaining 10 to 20 per cent rainfall is received from the northeast monsoon in the winter or spring season. The amount and distribution of rainfall are entirely unpredictable and subjected to vast fluctuations. Total 18.3, 64.3 and 14.2 mm rainfall was received during 2015-16, 2016-17 and 2017-18, respectively. Whereas, the weather parameters during the three different years are presented in Fig. 1. Soil properties were determined based on the methods defined elsewhere (Bandyopadhyay et al., 2012). The soil properties are presented in Table 1. The soil of the experimental field was light-textured loamy sand, slightly alkaline soil in reaction (pH 7.8) and low in organic carbon (0.21 %) and nitrogen (103kg/ha).

Layout and treatments details

The most popular barley crop variety BH 946 was sown in the split-plot design with three replications. The treatments comprised of 4 dates of sowing *viz.,* sowing in last week of October, sowing in 1st week of November, sowing in 2nd week of November and sowing in 3rd week of November. Whereas two seed rates, i.e. recommended seed rate (RSR) (87.5 kg/ha) and 110 % of RSR (96.25 kg/ha). Further, we also tested three different row spacings 17.5 cm, 20.0 cm and 22.5 cm. In layout date of sowing and seed rate combinations constituted the main plot treatments and spacings were kept in subplots. All other recommendations were followed based on the package and practices can be found elsewhere ("Barley," n.d.).

Plant traits

Seven plant traits were recorded for the different treatments. Plant height was determined from a sample of five randomly selected plants in each plot at the time of harvest. The effective tillers were counted with the help of square of 0.5 m × 0.5 m from the four random sites in each plot at each location and were summed up to calculate tillers/m^2. For the number of grains per spike, twenty spikes were randomly collected from each plot before harvesting. These spikes were threshed and grains were cleaned, counted and weighed to compute 1000-grain weight. For estimating the biological mass crop from 2 m^2 area in the centre of the plot was harvested and weighed after drying (to record biological mass). The grain yield was determined from the threshed and weighed sample of barley crop with the help of portable digital balance. Whereas the harvest index was estimated as the ratio of grain yield to the total biological yield (grain yield + plant biomass).

Economics and statistical analysis

The cost of cultivation was based on the prevailing market rates for all operations and inputs. Cost for additional 10% seed was added in treatment combinations with 110 % of recommended seed rate. Gross returns were determined on the basis prevailing market rates of grain and straw in respective seasons. Net returns were the difference between gross returns and cost of cultivation/ha. Benefit: Cost (B:C) ratio was calculated using the following formula:

$$B{:}C = \text{Gross returns (USD ha}^{-1}) \div \text{Gross cost (USD ha}^{-1})$$

The means were used for the estimation of analysis of variance (ANOVA) in order to estimate the differences among the treatments. The recorded data for 3 years (2015-16 to 2017-18) were tabulated and analysed statistically using the F-test. LSD (Least significant difference) values at p=0.05 were used to explain the significant difference between means of different treatment. All these analyses were performed with the SPSS (11.5 version) software package. Simple regression was also estimated with the help of Stat graphics Centurion XVI software (Stat Point Technologies, Warrenton, VA, USA).

RESULTS

Plant performance and the effect of different years

Plant height decreased significantly with delaying of planting date (Table 2). The crop (barley) attained maximum plant height (115.8 cm) with sowing in last week of October significantly higher than plant height with sowing in 2nd and 3rd week of November (108.0

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and 101.8 cm) and statistically similar to that under sowing in 1st week of November (113.0 cm) (Table 2). No significant variation was determined in plant height with an increase in seed rate. Agronomic management of row spacing brought considerable variation in plant height of barley. Among three-row spacing studied, maximum plant height recorded in 20cm spacing (111.9 cm) followed by that recorded in the recommended spacing of 22.5 cm and significantly higher than height found in 17.5 cm row spacing (Table 2).

Date of sowing had a significant effect on the number of days to 50 % spike emergence and days to maturity of barley (Table 2). Days to 50 % spike emergence dwindled from 86.2 cm with sowing in last week of October to 76.4 cm when the crop is sown in the third week of November. Seed rates did not bring any significant disparity in the number of days needed to 50 % spike emergence and days to maturity of barley. Likewise, variation in row spacing also had no significant effect on days to maturity of barley. Nevertheless, the number of days required for maturity reduced from 143.1 with sowing in the last week of October to 119.4 in sowing in 3rd week of November (Table 2). Grain yield and its attributes of barley *viz.,* effective tillers/m^2, the number of grains/spike and 1000 grain weight were significantly affected by different dates of sowing and spacings but not by an increase in seed rate (Table 2). Earlier sowing of barley, i.e. in last week of October and 1st week of November performed better than later sowings *viz.* in 2nd and 3rd week of November in terms of yield attributes namely effective tillers m^{-2}, the number of grains spike^{-1} and 1000 - grain weight. Sowing of barley in last week of October witnessed 3.6, 7.0 and 7.2 % boost in effective tillers m^{-2}, the number of grains spike^{-1} and 1000-grain weight, respectively than sowing in 2nd last week of November (Table 2). Likewise, higher values of yield attributes were attained by reducing row spacing of barley from recommended of 22.5 cm to 20.0 cm, but more reduction to 17.5

cm gave reverse results. Insignificant variation was recorded in all yield attributing parameters understudy with different seed rates (Table 2).

Among four dates of sowing studied highest yield was recorded when barely was sown in last week of October (5.65 Mg ha^{-1}); nonetheless, it was statistically similar to yield (5.53 Mg ha^{-1}) produced with sowing in the first week of November (Table 2). Sowing of barley in 2nd week of November generated the lowest grain yield (4.82 Mg ha^{-1}) (Table 2). Two levels of seed rate, i.e. recommended (87.5 Kg ha^{-1}) and 110 % of recommended resulted in statistically similar yield. Among three spacings (row to row), significantly higher grain yield (5.45 Mg ha^{-1}) was achieved with the sowing of barley in reduced row spacing of 20 cm than recommended row spacing of 22.5 cm (5.30 Mg ha^{-1}). Closest row spacing of 17.5 cm resulted in significantly lowest grain yield (5.13 Mg ha^{-1}). Significant variation was observed in means of growth (plant height), yield parameters and grain yield of barley among different years of study (Table 3). While phenological characters *viz.* days to 50 % spike emergence and days to maturity were recorded statistically similar during the study (Table 3). The maximum grain yield (5.60 Mg/ha) was recorded during 2017-18 (Table 3).

Functional analysis

The functional analysis results are presented in Table 4 showed a highly significant and positive correlation between grain yield and all the studied variable *viz.* plant height, days to 50% spike emergence, days to maturity, effective tillers/m^2, number of grains/ spike and 1000-grain weight of wheat.

The functional relationship was established between yield and various growth parameters *viz.* plant height, days to 50% flowering and days to maturity; and grain yield and its attributes *viz.* effective tillers per meter square, number of grains per spikes and one thousand grain

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weight. It was observed that the variable plant height and days to 50% spike emergence explained 97 % variation in yield whereas only 81% variation in the yield was explained by days to maturity. However, the variation in yield by its attributes as described earlier was observed to be 84%, 69% and 71% respectively (Fig. 2). Simple linear regression of yield with plant height and days to 50% spike emergence showed the fitness at R^2 of 0.97 (Fig. 2a and 2b).

Whereas, in the case of the relationship of yield with days to maturity and effective tillers, R^2 values were 0.81 and 0.84, respectively (Fig. 2c and 2d). The regression model of yield with grain per spike and 1000-grain weight showed the R^2 values of 0.69 and 0.71, respectively (Fig. 2e and 2f).

Crop economics

Out of 4 dates of sowing, last week of October proved most remunerative fetching the highest gross (USD 1287 ha^{-1}) and net returns (USD 658 ha^{-1}) as well as B:C (2.04) followed by their counterpart with the first week of November *viz.* USD 1262 ha^{-1}, USD 632 ha^{-1} and 2.00, respectively (Table 5). No additional investment was required for adjustments in the date of sowing as well as row spacing, while USD 4 ha^{-1} needed for 10 % extra seed need in treatment 110 % of recommended seed rate. Among three-row spacings, maximum net returns, 7.4 and 15.2 % higher than 22.5 and 17.5 cm, respectively, were accrued with 20 cm row spacing (Table 5).

DISCUSSION

In this work, the adjustments in the date of sowing and row spacing caused significant variation in average plant height, days to spike emergence, days to maturity, yield and yield attributing parameters of barley. On an average, early sowing of barley *viz.* sowing in last week of October and 1st week of November observed 7.2 and 13.7; and 4.6 and 11.0 per cent increase in plant height than delayed sowing, i.e. in 2nd and 3rd week of November, respectively. This can be because of the shortened vegetative growth period available to the crop plants owing to changes in photoperiod which enhanced the rate of development towards the reproductive phase. The findings are in line with the results of Farid et al.(Farid et al., 1993), Okosunet al. (Okosun et al., 2006), and Ram et al.(Ram et al., 2010). Row spacing of 20 cm found best for barley in respect of growth and yield parameters. Increasing the recommended seed rate by 10 % did not have any impact on the growth and yield of barley.

The various phenological stages of barley *viz.* the number of days required to 50 % spike emergence and days to maturity differed considerably with various sowing dates. A significant difference of 10 and 24 days was recorded in the number of days to 50 % spike emergence and maturity. Moreover, barley is a thermosensitive long-day plant and its spike emergence and maturity stage happens under suitable temperature and sunlight (Bavei et al., 2011). The number of days acquired by barley to arrive at different phenological stages declined significantly with delay in sowing as high temperature hastened phenological development (Anwar et al., 2015; Boonchoo et al., 1998)(Khattak et al., 2016). The significant influence of date of sowing was reflected in terms of higher values of yield in the early sown crop as compared to the late sown crop. Average reductions in the number of spikes/m^2 under delayed sowing (2nd and 3rd week of November) were 1.9 and 3.5; and 2.0 and 2.8 percent. The number of spikes per unit area is of vital significance for maximum yield. The results revealed a strong positive highly significant correlation of the number of effective spikes/m^2 with grain yield.

The crop that was sown on 20 October and 16 November experienced higher temperature than sown on 10 December which favoured the production of more number of tillers. Significantly less number of effective tillers under 10 December sowing might be attributed to its shorter growing period, due to which the late emerged tillers. Early sowing provides a window for utilizing warmer temperature, accommodating crop to produce more tillers (Khattak et al., 2016). The number of spikes/m^2 significantly affected by row spacing also. The number of spikes/ m^2 recorded in 20 cm wide rows than in 22.5 cm, which may be due to increased space between plants in narrow rows than wider rows and consequently more light and radiant energy is received which enhanced number of lateral branches (Mohamadzadeh et al., 2011). Likewise, on an average, 6.9 and 5.1 per cent boost was recorded in the number of grains/spike in the crop sown in the last week of October and 1st week of November as compared to the crop sown in 2nd and 3rd week of November.

Significantly higher 1000 grain weight was obtained in barley sown in last week of October (5.5 and 6.7 per cent) and first week of November (3.9 and 5.1 per cent). The reduction in grain weight in the late sown crops is a consequence of shorter grain filling period and exposure to warmer temperature and more extended photoperiod (long day) accounting for smaller and shrivelled grains (Mani et al., 2006). Among four dates of sowing studied, sowing in last week of October and 1st week of November recorded 8 and 17 and; 6 and 25 per cent more grain yield. This might be because of the higher temperature during the reproductive phase, particularly at the grain filling stage. Abiotic stresses (heat and drought) affect grain filling and reproductive processes (Sehgal et al., 2018). In this direction, the exposure of wheat to short episodes (2–5 days) of heat stress (>24 ^{0}C) at the reproductive stage has resulted in the decreased grain weight and climatic requirements of barley are similar to those of wheat (Prasad and Djanaguiraman, 2014). Moreover, in early sowing greater availability of metabolites (photosynthates) and nutrients to developing reproductive structures seems to have increased all the yield-attributing characters which ultimately improved the yield of the crop (Sehgal et al., 2018) late sown crop matured in a shorter period than the normal sown crop. Whereas, under late sown conditions, lesser numbers of degree days are taken for proper growth and development, leading to diminished yield parameters and finally lessened grain yield (Aslam et al., 2017). Selection of optimum sowing time may be the best option to escape heat stress at anthesis and grain filling stage and to avoid losses and sustain yield levels (Chaudhary et al., 2017).

Among three yield parameters studied, productive tillers/ m^2 and grains/ spike are significant contributors towards yield as the regression line showed 86 % variation in yield only by these two parameters. Earlier it was documented that early heading allows long grain filling period during which photosynthetic apparatuses remain green, leading to better grain filling and higher yield because the role of post-anthesis assimilates necessary for grain yield in barley (Bavei et al., 2011). Decreasing row spacing from 22.5 to 20.0 cm produced 3.6 per cent more yield. However, a further decline to 17.5 cm leads to a loss of 3.2 per cent loss of grain yield. Johnson and Hanson (Johnson and Hanson, 2003) observed the consistent distribution of plants and ideal plant canopy where solar radiation reception is better. In contrast, Lafond and Derksen(Lafond and Derksen, 1996) noticed that yield was reduced by increasing row spacing from 11 to 46 cm and found no interaction between row spacing and seed rate (Kirkland, 1993).

No significant effect of seed rate was observed on growth, phenological and yield parameters. However, spike emergence and maturity appeared earlier in higher seed rate than the recommended, while spikes/ m^2, grains/spike and 1000 grain weight reflected the marginal but non - significant increase. The increase in seed rate augmented plant population, which in turn improved spikes per unit area and finally the grain yield. In contrast, O'Donovan et al.(O'Donovan et al., 2011) reported a decline in tillers/ plant and

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grain weight, citing intra row competition and increased seedling mortality as the reason for the same. The profitability of any agricultural research technology is expressed in terms of net returns and B: C ratio. Sowing in last week of October and 1st week of November fetched higher net returns and B:C ratio than sowing in 2nd and 3rd week of November. The higher net returns and B:C ratio was ascribed to more grain and biological yield.

Overall, the alteration in the date of sowing (early sowing) of winter barley has the potential to escape terminal heat stress. Therefore, a shift in the recommended window of sowing is a must to sustain productivity. Three significant recommendations can be generated from the results of the present study *viz.* First - Barley should be sown from last week of October to the first week of November, second – row to row spacing of 20 cm found optimum for achieving a higher yield of barley and third – no change is required in seed rate.

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Table 1. Soil properties of soil of the experimental field.

Component	**Value**
pH	7.8
EC (dsm^{-1})	0.19
Organic Carbon (%)	0.21
Available N ($kg\ ha^{-1}$)	103
Available P ($kg\ ha^{-1}$)	12
Available K ($kg\ ha^{-1}$)	151

Table 2. Effect of date of sowing, seed rate and row spacing on plant height, phenological levels, yield attributes; grain and straw yield of barley (mean of 3 years).

Treatments	**Date of sowing**				**Seed rate**		**Spacing (cm)**		
	Last week of October	**First week of November**	**Second week of November**	**Third week of November**	**RSR**	**110 % RSR**	**17.5**	**20.0**	**22.5**
Plant height (cm)	115.8 a	113.0 a	108.0 b	101.8 c	109.6 a	109.6 a	107.2 b	111.9 a	109.9 a
Days to 50% spike emergence	86.2 a	84.5 a	81.1 b	76.4 c	82.1 a	81.9 a	79.9 c	84.4 a	81.9 b
Days to maturity	143.1 a	139.0 a	131.4 b	119.4 c	133.8 a	132.7 a	132.6 a	133.4 a	133.7 a
Effective tillers/m^2	364.8 a	362.5 a	355.8 b	352.2 c	358.4 a	359.3 a	358.0 b	361.7 a	356.8 b
Number of grains/spike	49.8 a	49.0 a	46.6 b	46.6 b	47.7 a	48.3 a	46.6 c	49.5 a	47.9 b
1000 grain weight (g)	41.6 a	40.9 a	39.3 b	38.8 b	40.3 a	40.3 a	39.3 b	41.7 a	39.9 b
Grain yield (Mg/ha)	5.65 a	5.53 a	5.21 b	4.82 c	5.28 a	5.32 a	5.13 c	5.49 a	5.29 b

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Different letters within rows indicate significant differences within a factor at $p = 0.05$, LSD.

Table 3. Comparison of means of plant height, phenological characters, yield parameters and yield of barley in different years.

Treatments	2015-16	2016-17	2017-18
Plant height (cm)	107.0 ^{b}	110.1 ^{ab}	111.8 ^{a}
Days to 50% spike emergence	83.1 ^{a}	81.1 ^{a}	81.9 ^{a}
Days to maturity	134.3 ^{a}	132.5 ^{a}	132.9 ^{a}
Effective tillers/m^2	389.4 ^{a}	342.3 ^{c}	344.9 ^{b}
Number of grains/spike	46.7 ^{c}	47.8 ^{b}	49.6 ^{a}
1000 grain weight (g)	39.2 ^{b}	40.2 ^{ab}	41.5 ^{a}
Grain yield (Mg/ha)	4.97 ^{c}	5.33 ^{b}	5.60 ^{a}

* Different letters within rows indicate significant differences among different years at $p = 0.05$, LSD.

Table 4. Correlation of grain yield with growth, phenological and yield parameters of barley.

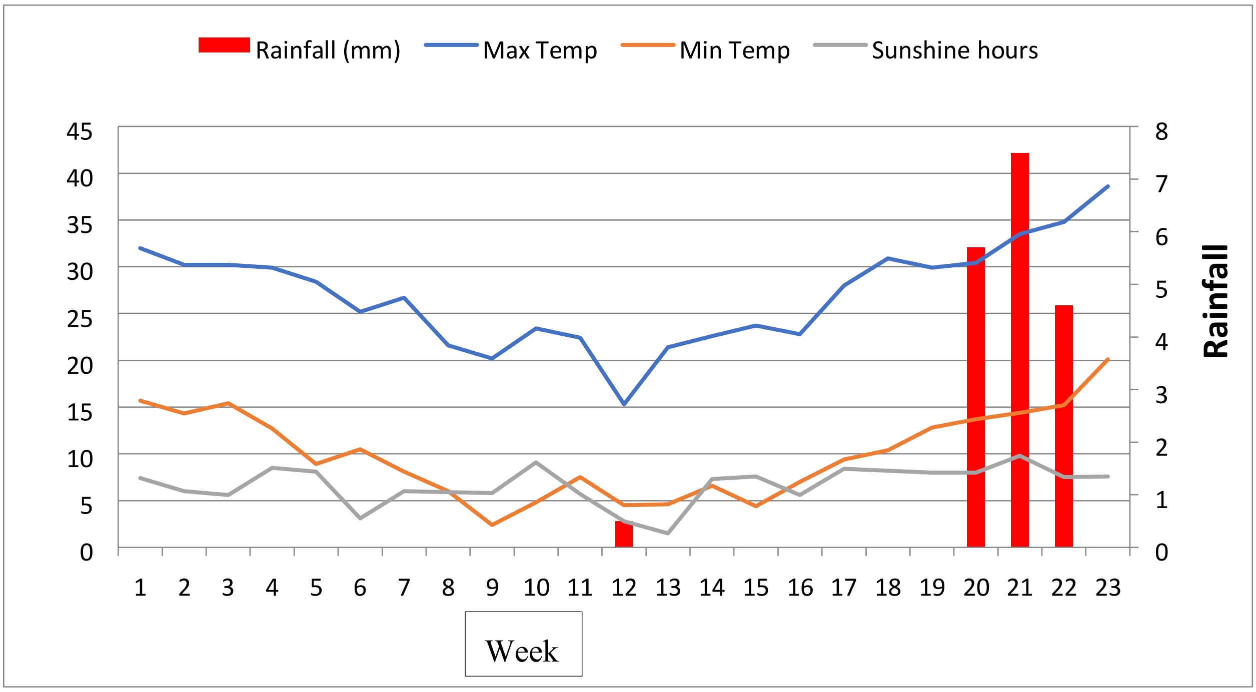
Characteristics	Grain yield
Plant Height	0.987**
Days to 50% spike emergence	0.980**
Days to maturity	0.905**
Effective tillers/m^2	0.917**
Number of grains/spike	0.833**
1000-grain weight	0.846**

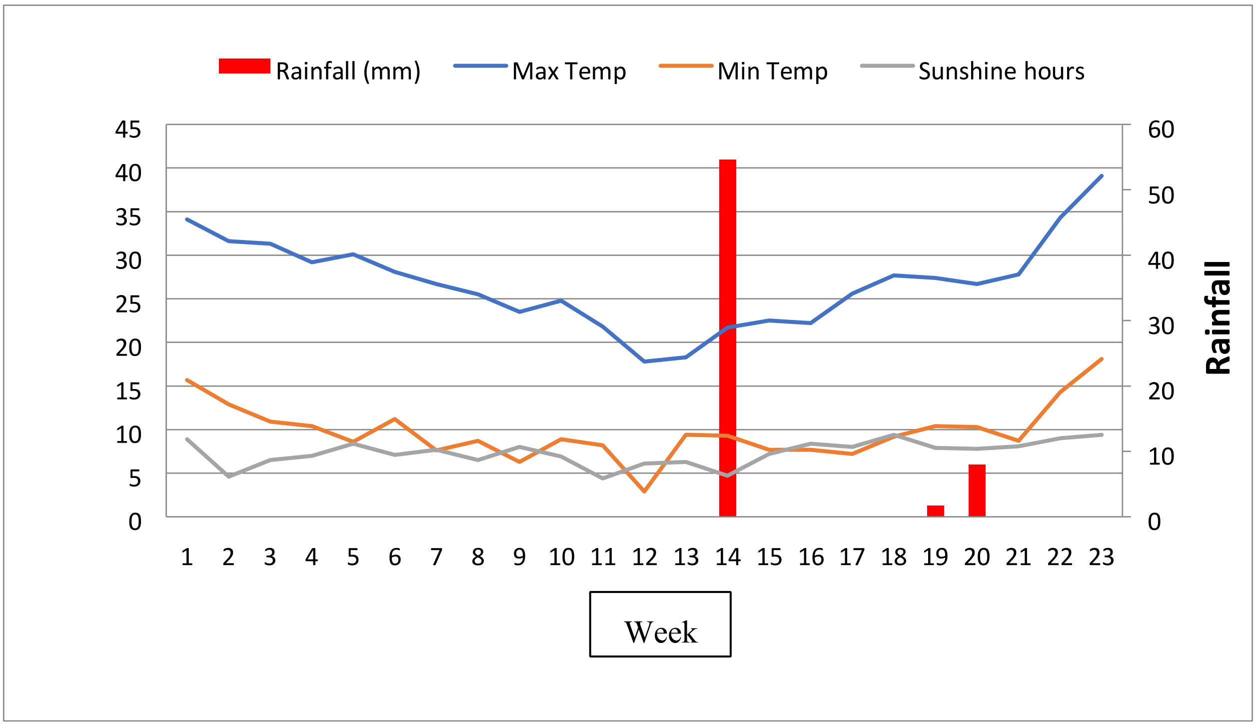
** indícate significance $p < 0.01$.

Table 5: Effect of date of sowing, seed rate and row spacing on the cost of cultivation, gross returns, net returns and B:C of barley (mean of 3 years).

Treatments	Date of sowing				Seed rate		Spacing (cm)		
	Last week of October	First week of November	Second week of November	Third week of November	RSR	110 % RSR	17.5	20.0	22.5
Cost of Cultivation (USD ha^{-1})	630	630	630	630	630	634	630	630	630
Gross Returns (USD ha^{-1})	1287	1262	1188	1098	1204	1214	1169	1251	1207
Net Returns (USD ha^{-1})	658	632	558	468	574	580	539	621	578
B:C*	2.04	2.00	1.88	1.74	1.91	1.91	1.85	1.98	1.91

* benefit to cost ratio (B:C)


Rainfall (mm)
Max Temp
Min Temp
Sunshine hours
Rainfall
Week


Rainfall (mm)
Max Temp
Min Temp
Sunshine hours
Rainfall
Week

(B)

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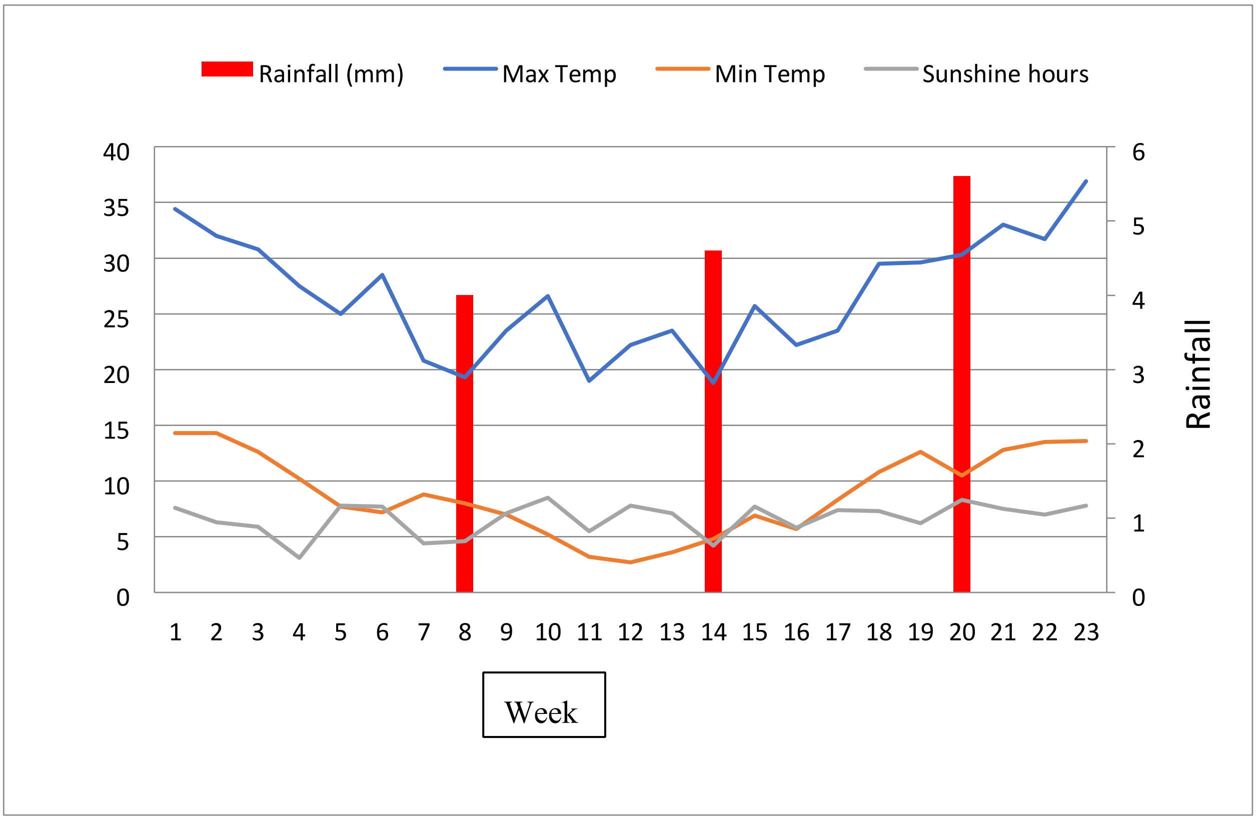
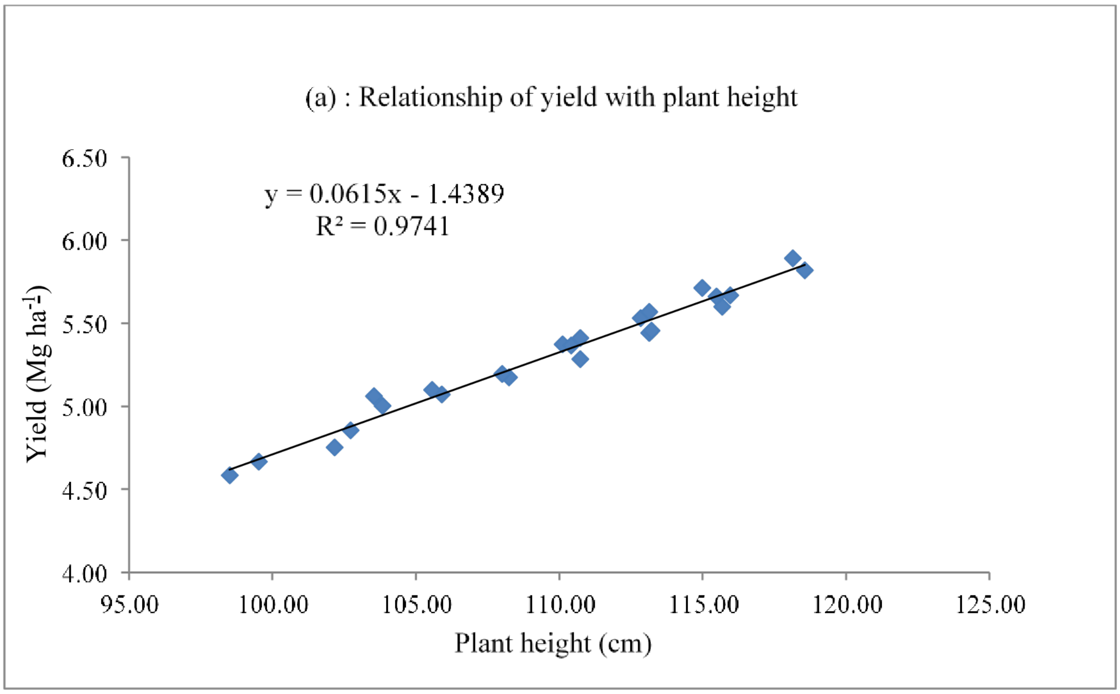
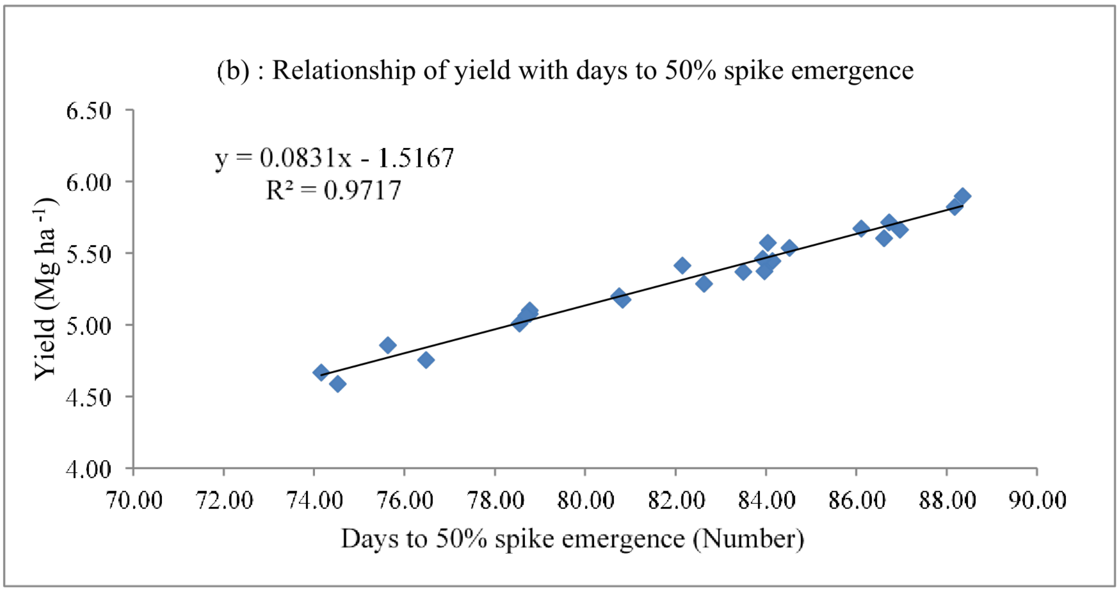


(C)

Fig 1. Weather parameters during first (**A**) second (**B**), and third **(C)** year. (A) 1st week started from 22nd October in each year


(a) : Relationship of yield with plant height
y = 0.0615x - 1.4389
R² = 0.9741
Yield (Mg ha-1)
6.50
6.00
5.50
5.00
4.50
4.00
95.00
100.00
105.00
110.00
115.00
120.00
125.00
Plant height (cm)


(b) : Relationship of yield with days to 50% spike emergence
y = 0.0831x - 1.5167
R² = 0.9717
Yield (Mg ha-1)
6.50
6.00
5.50
5.00
4.50
4.00
70.00
72.00
74.00
76.00
78.00
80.00
82.00
84.00
86.00
88.00
90.00
Days to 50% spike emergence (Number)

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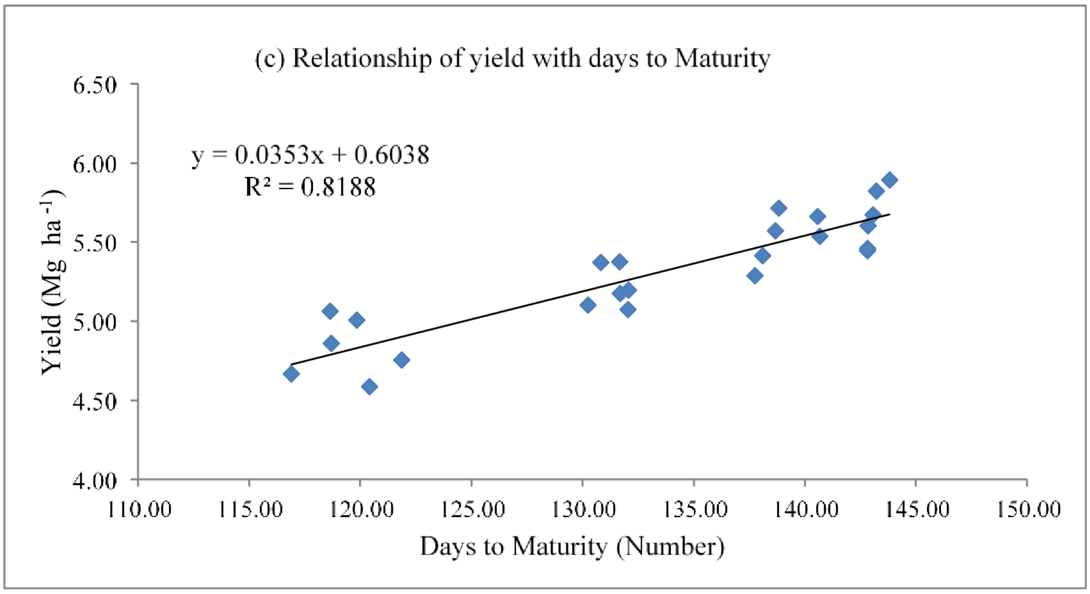

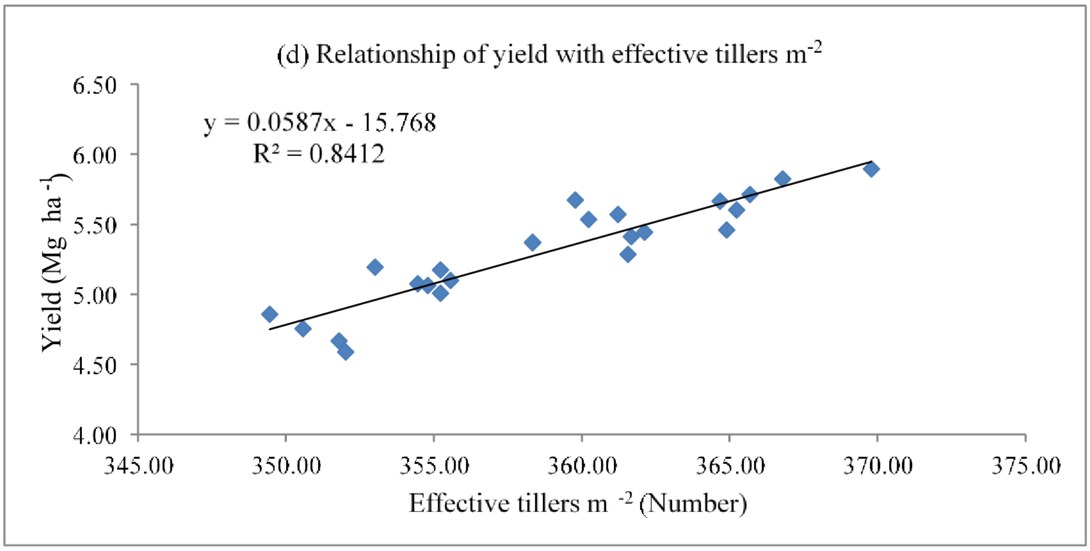

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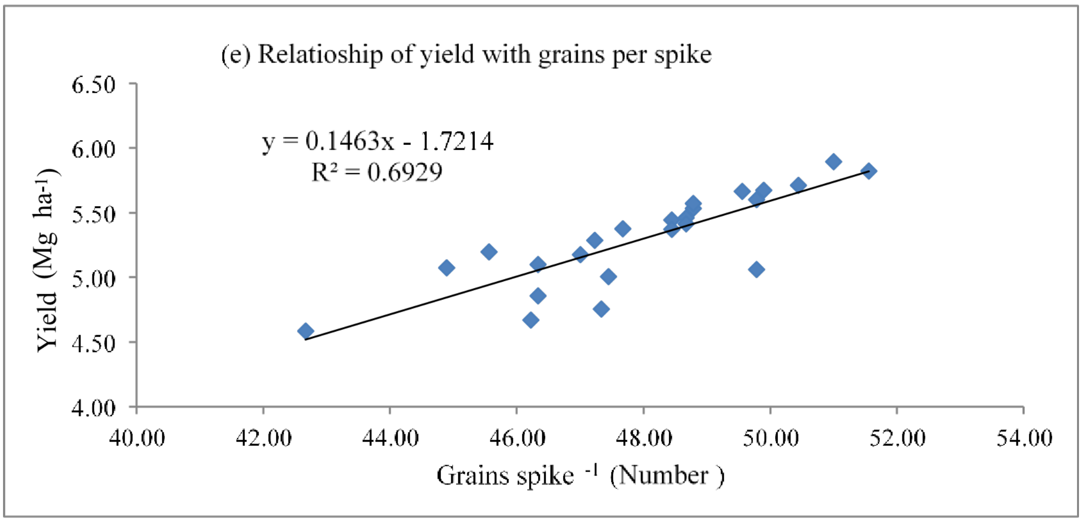

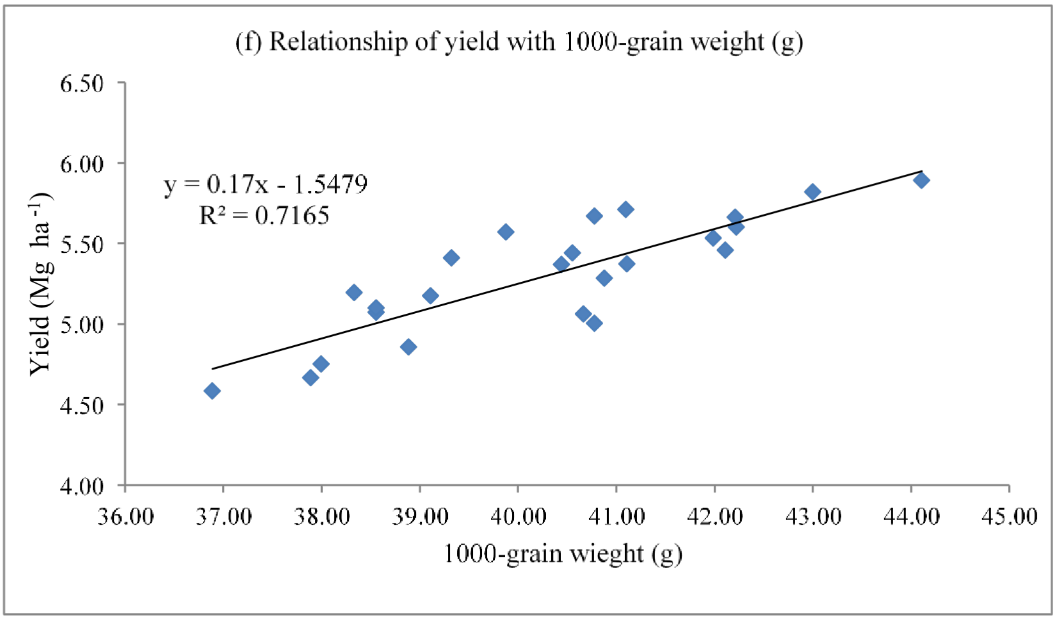

Fig 2. Relationship between grain yield and (a): Plant height, (b) : Days to 50 % spike emergence, (c) : Days to maturity, (d) : Effective tillers/m^2, (e) : Grains/spike and (f) : 1000 - Grain weight.