Society for Advancement of Wheat and Barley Research
ICAR-Indian Institute of Wheat & Barley Research
Karnal - 132 001, India

Wheat and Barley Research
10(3): 209-213
Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Research Article

Optimization of sowing time for adaptation to climate change and higher productivity of barley in the mid-Himalayas

Dibakar Mahanta*, Jaideep Kumar Bisht, Lakshmi Kant and Arunava Pattanayak
ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand, India

Article history
Received: 29 Sep., 2018
Revised : 12 Nov., 2018
Accepted: 18 Nov., 2018

Citation
Mahanta D, JK Bisht, L Kant and A Pattanayak. 2018. Optimization of sowing time for adaption to climate change and higher productivity of barley in the mid-Himalayas. *Wheat and Barley Research* **10**(3): 209-213. doi. org/ *10.25174/2249-4065/2018/83644*

****Corresponding author***
Email: *dibakar_mahanta@yahoo.com*

Abstract

Optimization of sowing date of barley was assessed by conducting three years' experiment with different sowing dates and three popular varieties of barley in the mid-Himalayas. With the help of quadratic equation, it was estimated that maximum grain yield of barley could be achieved with sowing on 12th November, which provided 8% higher yield compared to the existing recommended sowing date of 25th October. The present recommendation will help to adapt the climate change situation. Thousand grain weight was the most important yield contributing attribute as found from the principal component analysis and correlation. Grain yield of barley could be modelled through multi-linear regression equation with the help of yield attributes for the mid-Himalayas. The multi-linear regression equation will be highly useful for policy makers to estimate the yield of barley of either a district or a state in the mid-Himalayas.

Keywords: Barley, climate change, modeling for yield prediction, optimum sowing date

1. Introduction

Barley (*Hordeum vulgare* L.) is the fourth most important cereal crop of the world after wheat, rice and maize (Dhillon and Uppal, 2018). It is the second-most important *rabi* season cereal crop of northern hill zone of India, particularly of the marginal and fragile lands as well as in higher hills. It is the staple food crop in the tribal areas of hills. It is used as food, fodder and in other local beverages. It is cultivated with very low inputs by the farmers. During past few years the winters have become warmer in hills and drought is becoming a frequent phenomenon. Therefore, most of the farmers now prefer to grow barley over other crops as it is drought tolerant. Sowing time of barley is one of the most important non-monetary factors that govern the crop phenology and finally the yield. Due to climate change, the sowing time also changes. Hence, it is very important to find out the optimum sowing time to harvest the maximum yield. Hence, it was hypothesized that changing sowing date would provide higher grain yield of barley than the existing sowing date (25th October). To address that hypothesis, the present study was conducted to estimate the optimum sowing date to provide maximum grain yield of barley in the mid-Himalayas, to find out the most important yield attribute contributing to grain yield and to develop the multi-linear regression equation to predict the yield based on yield attributes.

2. Materials and methods

The field experiment was conducted during *rabi* season from 2012 to 2015 for three years at the experimental farm situated in ICAR-*Vivekananda Parvatiya Krishi Anusandhan Sansthan* located in the mid-Himalayan region at Hawalbagh (29^0 36' N and 79^0 40' E and 1,250 m above mean sea level) in the state of Uttarakhand, India. The experiment was conducted in split-plot design with five dates of sowing, *viz.* 25th October, 10th November, 25th November, 10th December and 25th December in main plots and three popular varieties of northern hill zone, *viz.*, BHS 352, VLB 118 and HBL 113 in sub-plots with three replications. The gross plot size was 2.3 m × 3.6 m. The crop was sown with the row spacing of 23 cm. Two life-saving irrigations were applied. The crop was fertilized with 60kg N, 30 kg P_2O_5 and 20 kg K_2O/ha, out of which, ½ N and full dose of P_2O_5 and K_2O were applied as basal dose at the time of sowing. The remaining ½ dose of N was applied at tillering stage of the crop. Weeds were managed by two hand weedings during each crop season. The crops were not infested by any major insect pests or diseases. Generally, the response to date of sowing is quadratic, i.e. yield increases with postponing sowing date up to a certain level. At a particular level, yield approaches a plateau and further postponing the date of sowing decreases the yield. This quadratic response curve can be expressed as a mathematical equation as given below.

$$Y = a + bD + cD^2 \quad (1)$$

where, Y is the grain yield, D is the date of sowing and a, b and c are constants. Constant 'a' is known as intercept, which indicates the minimum grain yield that can be produced at any sowing date. Constant 'b', otherwise known as slope, provides the response rate. Constant 'c' represents the curvature of the response line, which indirectly indicates the adverse effect of postponing the date of sowing. Generally constant 'c' has a negative sign (Reddy and Reddi, 1995). Each successive increase in date of sowing decreases the successive incremental yield. Ultimately a point comes, when the increase in date of sowing no longer increases the yield of the crop. This point is the yield maximizing date of sowing (D_{max}) and it provides the maximum potential grain yield through date of sowing (Y_{max}). As per Mahanta *et al.* (2015), the date of sowing to provide maximum grain yield can be estimated by the following way. Here the response rate/ slope i.e., the first derivative (dY/dD) is zero. The tangent at this point is parallel to X-axis. This can be written in equation form as follows:

The first derivative of equation

$Y = a + bD + cD^2$ is $(dY/dD) = b + 2cD$

So, $b + 2cD = 0$

Hence, $$D_{max} = -b/2c \quad (2)$$

Putting the value of date of sowing providing maximum grain yield as D_{max}, we can estimate Y_{max}.

$$Y_{max} = a + b\,(D_{max}) + c\,(D_{max}^{\;2}) \quad (3)$$

Multiple linear regression analysis is used to measure the relationship of grain yield with the growth and yield attribute parameters. The function takes the following form:

$$Y = a + bX_1 + cX_2 + dX_3 + eX_4 + fX_5 \quad (4)$$

where, Y is the predicted grain yield (q/ha), a is the intercept point, b, c, d, e and f are regression coefficients associated with effective tiller/m2, grain number/ear head, thousand grain weight (g), plant height (cm) and ear length (cm), respectively. Significant differences ($p < 0.05$) among means of experimental results were evaluated by analysis of variance (ANOVA) and means were compared by Tukey's Honest Significant Difference (HSD) Test, using SAS 9.3 version. Correlations among various parameters were done by using statistical package SPSS (Statistical Package for Social Science, SPSS Inc., Chicago, IL, USA). For multifactorial comparison, principal component analysis (PCA) was used to display the correlation among the various parameters and their relationship with the different dates of sowing. Multifactorial analysis was carried out using the XLSTAT 2010 software (ADDINSOFT, New York, NY 10001, USA).

3. Results and discussion

3.1. Yield attributes and grain yield: The three year pooled analysis of yield attributes (effective tiller/m^2, grains/ear head, 1000-grain weight, plant height and ear length) of barley showed significant difference in different dates of sowing (Table 1). The sowing on 10th November provided significantly higher value of most of the yield attributes compared to sowing on other dates. The sowing on 10th November provided significantly higher effective tiller/ m^2 (417 tiller/m^2) than other dates of sowing, which enhanced 32 number of effective tiller/m^2 compared to recommended sowing date of 25th October (385 tiller/ m^2). Similarly, the sowing on 10th November provided significantly higher 1000-grain weight (45.9 g) than other treatments, which increased 2.3g compared to the recommended sowing date of 25th October (43.6 g). Grain growth takes place entirely during post anthesis period and is determined by the rate and duration of grain filling. Thousand-grain weight is a product of the duration of grain filling period and rate of grain filling. An increase in the rate of grain filling in *rabi* cereals with a rise in temperature above 20 °C is commonly observed (Zahedi *et al.*, 2003). Both the day and night temperatures have a pronounced effect on the duration of grain-filling. The duration of grain-filling is reduced drastically above 30/25°C day/night temperatures. The shortening of the grain filling duration by 0.4 day for each 1°C increase in mean temperature from optimum temperature is observed to escape the heat stress (Modarresi *et al.*, 2010). Brief exposure of plants to high temperatures during grain filling can accelerate senescence, decrease seed weight and reduce yield (Wahid *et al.* 2007). The lower thousand-grain weight with 25th October sowing compared to 10th November might be due to the lower temperature during grain filling than optimum, which reduced the rate of grain filling. The delayed sowing after 10th November shortens the duration of each development phase which ultimately reduces grain filling period and decreased the effective rate of grain filling resulting in lower thousand-grain weight (Sharma-Natu *et al.*, 2006). On the other hand, the sowing on 10th November, the barley crop enjoyed a favourable pre-heading conditions which have had a carry-over effect on grain weight via stem reserves or the setting of potential grain weight soon after anthesis (Ortiz-Monasterio *et al.*, 1994) and further availed better rate of grain filling and higher grain growth duration. The sowing on 10th November might have provided the optimum temperature for emergence, tillering and better growth of barley, which might have been reflected on yield attributes. Significant higher value of effective tiller/m^2, grains/ear head, thousand-grain weight, plant height and ear length was recorded under HBL 113, VLB 118, BHS 352 and HBL 113 varieties, respectively compared to rest of the genotypes. The results of yield attributes reflected in the experiment are the genotypic characters of these varieties. The sowing on 10th November provided significantly higher grain yield (41.8 q/ha), which was 8% higher than 25th October (38.7 q/ha). The higher value of all yield attributes due to sowing on 10th Novemberwas finally reflected for higher grain yield. The very late sown crop completed its life cycle at an accelerated pace, leading to shortening of days taken to earing and maturity ad produced very less yield. It has been reported that 3-4% decrease in grain yield for each 1°C rise in ambient temperature above 25°C during grain filling (Ram and Gupta, 2016).

Table 1. Effect of date of sowing and varieties on yield and yield attributes of barley

Treatment	Effective tiller/m^2	Grains/ earhead	1000-grain weight (g)	Plant height (cm)	Ear length (cm)	Grain yield (q/ha)
Date of sowing						
October 25	385$^{B\mu}$	44.8^{AB}	43.6^{B}	107^{A}	9.07^{A}	38.7^{B}
November 10	417^{A}	45.5^{A}	45.9^{A}	109^{A}	9.04^{A}	41.8^{A}
November 25	407^{A}	43.3^{BC}	44.1^{B}	104^{AB}	8.66^{B}	39.4^{AB}
December 10	386^{B}	41.5^{C}	43.4^{B}	101^{B}	8.40^{BC}	35.7^{C}
December 25	328^{C}	39.6^{D}	42.4^{C}	89^{C}	8.19^{C}	30.3^{D}
Variety						
BHS 352	351^{C}	48.7^{B}	39.4^{C}	111^{A}	8.54^{B}	31.3^{C}
VLB 118	378^{B}	51.0^{A}	48.6^{A}	102^{B}	7.93^{C}	42.8^{A}
HBL 113	424^{A}	29.0^{C}	43.6^{B}	93^{C}	9.54^{A}	37.4^{B}

μ Means in the same column with different letters are significantly (P < 0.05) different

3.2. Optimization of sowing date: The experiment was conducted with different dates of sowing of 15 days interval. Hence, the optimum date of sowing to harvest the potential yield cannot be informed from the result of the experiment. That's why the optimum sowing date was estimated. Based on the yield data of three years, the response to date of sowing was quadratic (R^2 = 0.987, Fig. 1). From the quadratic response equation, it was estimated that the date of sowing (D_{max}) that could provide maximum potential grain yield (Y_{max}) was 316th day of the year (November 12). The sowing of barley on November 12 will adapt to climate change in a better way than the previously recommended sowing date for barley (25th October) and the maximum potential of the crop can be harvested.

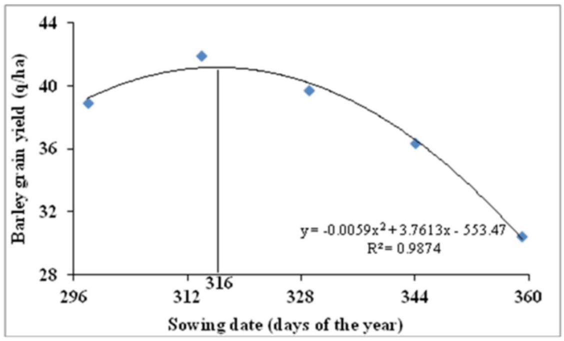

Fig. 1 Response of barley grain yield to sowing dates

3.3 Correlation and regression of grain yield with yield attributes: The positive relationships of effective tiller/m^2 and thousand grain weight with grain yield indicate that yield was highly dependent upon these parameters (Table 2) and these were very good indicators (P<0.05) of grain yield. The result of the regression analysis presented in Table 3 showed the effect of various yield attributes on grain yield of barley. The R^2 value was 0.945; indicating 94.5% of the variation in the grain yield had been explained by the variables included in the model. According to the results, F values were found significant at <0.001% level of significance, which showed that the grain yield could be well predicted from the model using the equation 5 for barley with the help of the variables, *viz*, effective tiller/m^2, grains per ear head, thousand grain weight, plant height and ear length. Hence, the grain yield of barley could be estimated with the help of the above mentioned parameters and the equation as developed from regression analysis as follows:

$$GY = -58.35 + 0.02X_1 - 0.15 X_2 + 1.51X_3 + 0.27X_4 - 0.04X_5$$

where, GY = Grain yield (q ha^{-1})

X_1 = Effective tiller/m^2

X_2 = Grains/ear-head

X_3 = Thousand-grain weight (g)

X_4 = Plant height (cm)

X_5 = Ear length (cm)

Table 2. Correlation between yield and yield attributes

	Grain yield	ET†	GE	TW	PH	EL
Grain yield	1.000	0.620*	0.161	0.885***	0.109	0.005
ET		1.000	-0.469	0.376	-0.011	0.637*
GE			1.000	0.182	0.688**	-0.709**
TW				1.000	-0.172	-0.243
PH					1.000	-0.079
EL						1.000

***p<0.001; ** p<0.01; *p<0.05

†ET = Effective tiller/m^2
GE = Grains/earhead
TW = Thousand-grain weight (g)
PH =Plant height (cm)
PL = Ear length (cm)

Table 3. Yield attribute coefficients with respect to grain yield of barley

Variables	Coefficients
Intercept	-58.35
Effective tiller m^{-2}	0.02
Grains per ear head	-0.15
Thousand grain weight	1.51
Plant height	0.27
Ear length	-0.04
R^2	0.945
Degree of freedom	5
F value	30.9

3.4. Principal component analysis: Principal component analysis (PCA) is a useful statistical technique which had found application in reduction of the original variables in a smaller number of underlying variables (principal component) in order to reveal the inter relationships between the different variables and to find the optimum number of extracted principal components (Mahanta *et al.*, 2018). The date of sowing with different varieties and grain yield attribute parameters were superimposed in a single biplot of PCA with four zones of ordinate and were depicted in Fig. 2. The PCA comprising two principal components (1 and 2) accounted for 97.6% of variance for grain yield. But, the component 1 comprised of 90.1% variance. So, the PCA was interpreted on the basis of component 1 only. Most of the parameters were occupied on the right side of the biplot and were very close to each other, except grain per earhead. Thousand-grain weight is very close to grain yield followed by effective tiller/m^2. This suggested again that thousand-grain weight and tiller/m^2 were having strong positive correlation with grain yield. The PCA revealed that November 10 (D_2) sowing was positively correlated with component 1, which was away from the origin and closer to yield attribute parameter lines in the same direction. The second group constituted of 25th October and 25th November sowing and was positively correlated with component 1, which was close to origin point. The third group (constituted of December 10 (D_4) and December 25 (D_5)) was negatively correlated with component 1 and was in opposite direction of yield attribute variables.

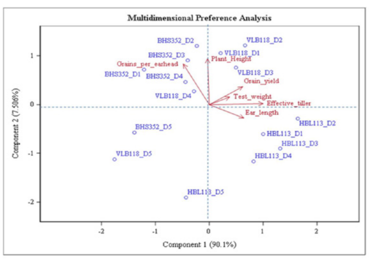

Fig. 2 Multi-factorial comparison of the yield attributes with date of sowing and varieties using principal component analysis

The longer the line, the higher is the variance. The cosine of the angle between the lines approximates the correlation between the variables they represent. The closer the angle is to 90 or 270 degrees, the smaller the correlation. An angle of 0 or 180 degrees reflects a correlation of 1 or -1, respectively (Kohler and Luniack, 2005). The biplot in Fig. 2 showed a strong positive relationship between the grain yield and thousand grain weight. The cut point of a perpendicular from a treatment point to a variable line approximates the value of that observation on the variable that the line represents. If the cut point falls on the origin, the value of the observation is approximately the average of the respective variable. Cut points far off in the direction of the variable line indicate high values, while cut points far off on the variable line, which has been extended through the origin, represent low values (Mahanta *et al.*, 2015). Superimposition of date of sowing with varieties and yield attributes showed that 10th November (D_2) sowing provided higher thousand grain weight and effective tiller/m^2 and grain yield is positively correlated with these parameters. Therefore, November 10th stood out with the highest yield attributing parameters as well as grain yield. The results obtained from three years' experimentation provide us with major findings on optimization of date of sowing. It was estimated from the quadratic equation that sowing on November 12 could provide maximum potential grain yield of barley in the mid-Himalayas. Thousand grain weight was the most important yield attribute contributing to grain yield. With the help of the developed multi-linear regression equation the yield can be predicted based on yield attributes. The multi-linear regression equation will be highly useful for policy makers to estimate the yield of barley of either a district or a state in the mid-Himalayas.

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