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Research Paper

Micro-meteorological parameters, growth indices and productivity of barley (*Hordeum vulgare*) cultivars as influenced by clipping and zinc biofortification

BALWINDER SINGH DHILLON[1] AND HARI RAM[2]

Punjab Agricultural University, Ludhiana 141 004

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ABSTRACT

A study was carried out during the winter (*rabi*) season of 2015–16 and 2016–17 at Punjab Agricultural University, Ludhiana, to assess the effect of different barley (*Hordeum vulgare* L.) cultivars (2- and 6-row) on micro-meteorological parameters, growth indices, photosynthetic parameters and productivity of barley (*Hordeum vulgare* L.) in relation to different clippings time along with Zn foliar application. The results indicated that cultivar 'DWRUB 52' intercepted more photosynthetically active radiation (PAR) than 'PL 807' and 'PL 426', whereas, normalized difference vegetative index (NDVI) values of 'DWRUB 52' and PL 807 were statistically similar and significantly better than 'PL 426'. Cultivar 'DWRUB 52' showed the highest absolute growth rate (AGR) and crop-growth rate (CGR), followed by 'PL 807' and 'PL 426' during both the years of study. Cultivar 'DWRUB 52' gave 6.0 and 18.7% higher grain yield than 'PL 807' and 'PL 426' respectively. Foliar application of Zn at anthesis and early milk stages enhanced the PAR and NDVI, AGR, CGR and RGR at 90–120 days after sowing (DAS) and at 120 DAS to maturity. Foliar application of Zn with both clippings, i.e. 50 and 60 DAS resulted in the statistically similar transpiration rates and were significantly higher than the other treatments. There was an increase of 12.6% in grain yield when clipping was done at 50 DAS with foliar application of Zn and an increase of 8.9% in grain yield when clipping was done at 60 DAS with foliar application of Zn than control crop.

Key words: Barley, Clipping, Micro-meteorological, Normalized difference vegetative index. Transpiration rate

Barley (*Hordeum vulgare* L.) is a hardy crop which is grown throughout the temperate and tropical regions of the world. In production, it ranks fourth after rice, maize and wheat and is usually used as food for human beings and feed for animals and poultry. It is an important coarse cereal crop of India, being grown in northern plains as well as in northern hills, mostly under rainfed or limited irrigation conditions on poor to marginal soils (Dhillon and Uppal, 2019). It is mainly grown in Uttar Pradesh, Rajasthan, Punjab, Madhya Pradesh, Haryana, Bihar, Himachal Pradesh, West Bengal and Jammu and Kashmir. In India, representing about 0.609 million ha area with 1.818 million tonnes production and a productivity of 29.9 q/ha (IIWBR, 2021).

Clipping of an annual plant at progressively later stages of growth would also be expected to decrease total production and especially seed production. Clipping at the tillering, does not impede re-growth of barley under semi-arid conditions (El-Shatnawi *et al.,* 1999).

Micronutrient malnutrition is a global health problem affecting more than 3 billion people worldwide (Cakmak *et al.,* 2010). Zinc is an essential micronutrient for plant growth and development (Srivastava and Singh, 2009). Application of the 3 Zn fertilizers on Zn-deficient leaves significantly increased their chlorophyll levels and photosynthetic activities, especially when organosilicone was supplemented. Moreover, better recovery of green and higher chlorophyll levels and photosynthetic activities were observed on $ZnCl_2$- and Zn $(NO_3)_2$. $6H_2O$-treated leaves, indicating that $ZnCl_2$ and Zn $(NO_3)_2$. $6H_2O$ had a more effective correcting effect than $ZnSO_4.7H_2O$ (Fu *et al.*, 2016).

Information on growth indices, photosynthetic parameters (transpiration rate and stomatal conductance) and productivity under variable environmental conditions is essential for identification and overcoming the yield constraints to amplify the crop potential. However, so far little information is available on such aspects of barley under Punjab conditions. Hence, an experiment was conducted to study

[1]**Corresponding author's Email:** dhillonbalwinder@pau.edu
[1]Agronomist, Regional Research Station, Punjab Agricultural University, Ballowal Saunkhri, SBS Nagar, Punjab 144 521; [2]Wheat Agronomist, Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab 141 004

the micro-meteorological parameters, growth indices, photosynthetic parameters and productivity in different barley cultivars in relation to different clipping-management practices.

MATERIALS AND METHODS

A field experiment was conducted at students' research farm, Punjab Agricultural University, Ludhiana, on loamy sand soil during the winter (*rabi)* season of 2015–16 and 2016–17. The experimental soil site had *p*H 7.4 and 7.3, containing 0.37 and 0.39% organic carbon, 179.2 and 192.8 kg/ha available N, 28.5 and 31.3 kg/ha available P and 143.9 and 137.1 kg/ha available K during growing season of 2015–16 and 2016–17 respectively. Total rainfall received was 80.4 and 100.3 mm during growing season of 2015–16 and 2016–17 respectively. The field experiment was laid out in split-plot design with 15 treatment combinations, consisting of 3 varieties ('DWRUB 52', 'PL 807' and 'PL 426') in main plots and 5 clipping management, viz. [control, clipping at 50 days after sowing (DAS), clipping at 60 DAS, clipping at 50 DAS + 0.5% Zn foliar application at anthesis and early milk stage [Zn (f)] and clipping at 60 DAS + 0.5% Zn foliar application at anthesis and early milk stage [Zn (f)] in subplots. Recommended dose of nutrients to barley was applied at 62.5 kg N/ha, 30 kg P_2O_5 and 15 kg K_2O through urea (46% N), single superphosphate (16% P_2O_5) and muriate of potash (60% K_2O), respectively, at the time of sowing. The site was a under sunhemp (*Crotalaria juncea* L.)–wheat (*Triticum aestivum* L.) cropping system for 3 years before the establishment of the experiment. Crop was sown at 5 cm depth with a seed drill at row spacing of 22.5 cm on November 17 and October 25 during crop season of 2015–16 and 2016–17 respectively. The uniform seed rate was 87.5 kg/ha for sowing. Clipping was done with hedge trimmer as per treatments by 10–15 cm and leaving plant for further regeneration. The crop was harvested on 7 April 2016 and 31 March 2017 and threshed with the help of a thresher.

Photosynthetically active radiation interception was measured between 12:30 and 1:30 PM, on clear sunny day at monthly interval with LI-COR-LINE Quantum Sensor Photometer. Incoming and outgoing solar radiations on top of the canopy and radiation penetration at the ground surface below the crop canopy were measured. Observations were taken at random from 2 places in each plot. The intercepted PAR (%) was calculated as:

$$\text{PARI (\%)} = \frac{\text{PAR(I)} - \text{PAR(T)} - \text{PAR(R)}}{\text{PAR(I)}} \times 100$$

where, PAR (I), PAR (T) and PAR (R) are the incident, transmitted and reflected photosynthetically active radiations (W/m^2), respectively.

Normalized difference vegetative index (NDVI) was measured at 30, 60, 90 and 120 DAS using green seeker. Green seeker was revolved over the crop canopy in each plot and mean value given by instrument at the end was recorded for final presentation. The NDVI was calculated from reflectance measurements in the red and near infrared (NIR) portion of the spectrum as:

$$\text{NDVI} = \frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red}}$$

where, R_{NIR} is the reflectance of near-infrared radiation and R_{Red} is the reflectance of visible red radiation.

Absolute growth rate (AGR), crop-growth rate (CGR) and relative growth rate (RGR) were calculated as per Radford (1967). Photosynthetic parameters, viz. transpiration rate and stomatal conductance, were measured at 90 DAS from fully expanded apical leaves, using a portable LCi photosynthesis system (ADC Bio-Scientific Limited). The grain yield was recorded as the total weight and weight of threshed grains obtained from net plot area of each experimental unit respectively and expressed as kg/ha. Data were subjected to analysis of variance (ANOVA) using statistical analysis software (SAS 9.4) to evaluate differences between treatments. Maximum, minimum and a mean temperatures and rainfall were measured at agro–meteorological observatory of PAU, Ludhiana and data are presented in Table 1.

Table 1. Mean monthly meteorological data during *rabi* seasons of 2015–16 and 2016–17

Months	Max Temp (°C)		Min Temp (°C)		Mean Temp (°C)		Rainfall (mm)	
	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17
October	31.3	32.7	19.0	19.0	25.1	25.9	16.4	0
November	26.9	27.7	12.6	12.0	19.8	19.9	0	2.0
December	21.3	22.2	7.3	8.6	14.3	15.4	1.7	0
January	17.2	18.2	7.4	7.6	12.3	12.9	19.4	46.1
February	23.0	23.1	9.0	9.3	16.0	16.2	8.8	5.2
March	28.0	27.2	14.6	12.5	21.3	19.9	41.1	40.8
April	36.6	36.9	19.6	20.0	28.1	28.5	3.0	14.8

Max Temp, Maximum temperature; Min Temp, minimum temperature

RESULTS AND DISCUSSION

Weather data

Maximum air temperature varied from 17.2 to 36.6°C and 18.2 to 36.9°C, minimum from 7.3 to 19.6°C and 7.6 to 20.0°C, with mean temperature variation from 14.3 to 28.1°C and 12.9 to 28.5°C during 2015–16 and 2016–17, respectively. Total rainfall of 90.4 and 108.9 mm was received during the respective crop seasons of 2015–16 and 2016–17. Overall, both seasons were normal but rainfall during the crop season of 2016–17 was reasonably distributed and 18.5 mm higher than during 2015–16. Consequently, to meet the water requirement of crop, more number of irrigations was given during the first year than the second year.

Micro-meteorological parameters

Photosynthetically active radiation interception: Photosynthetically active radiation (PAR) interception and its distribution within the crop canopy is important determinant of photosynthetic activity of the crop. Intercepted PAR by the canopy influences the leaf photosynthesis efficiency, which in turn effects the dry matter production and grain yield. The ultimate capacity of a plant community to produce dry-matter depends on the degree of exploitation of solar radiation. Cultivars did not show any significant difference in PAR interception at 30 DAS (Fig. 1). However, cultivar 'DWRUB 52' (80.2, 94.9 and 87.9% during 1st year and 76.2, 91.4 and 84.4% during 2 year) intercepted significantly higher PAR interception than PL 807 (76.6, 93.2 and 85.1% during 1st year and 74.6, 87.7 and 79.6% during 2nd year) and 'PL 426' (73.7, 90.6 and 81.2% during 1st year and 70.6, 83.4 and 74.7% during 2nd year) at 60, 90 and 120 DAS, respectively, during both the years of study, except 60 DAS during 2nd year, where 'DWRUB 52' was statistically at par with 'PL 807'. Higher PAR interception of 'DWRUB 52' cultivar was attributed to higher leaf area recorded under this cultivar. Cultivar differences in intercepted PAR might be differences in the leaves dry matter of these cultivars. Kaur (2007) also reported varietal differences for PAR interception.

Clipping management showed non-significant difference in PAR interception at 30 DAS during both the years (Fig. 2). However, at 60 DAS the PAR interception of the control, clipping at 60 DAS and clipping at 60 DAS + Zn (f) treatment was statistically at par among each other, but significantly higher than clipping at 50 DAS and clipping at 50 DAS + Zn (f) treatments. Significantly lower PAR interception was recorded when clipping was done at 50 DAS and clipping at 50 DAS + Zn (f) treatments, because of minimum leaf-area index at 60 DAS which might be due to removing vegetation by clipping reduced leaf-area

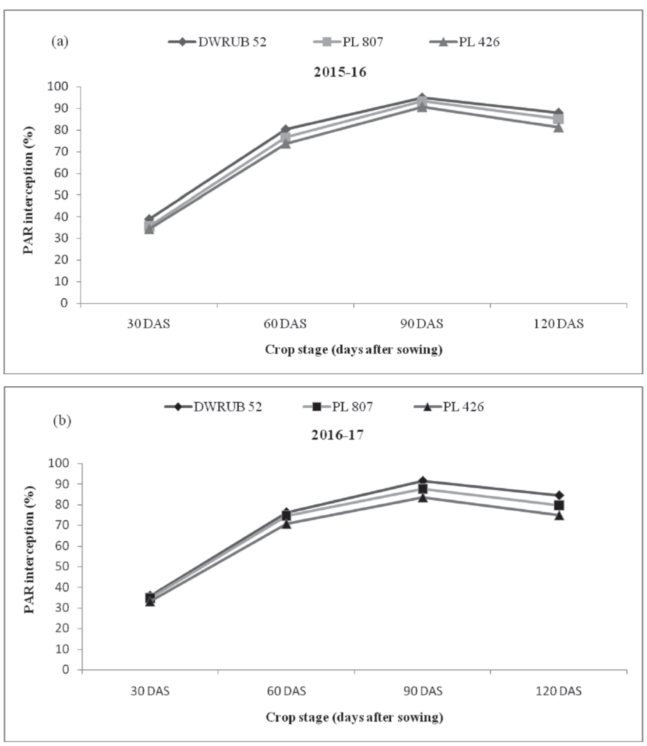

Fig. 1. Effect of different barley cultivars on periodic photosynthetically active radiation (PAR) interception (%) during (a) 2015–16 and (b) 2016–17 (DAS, days after sowing)

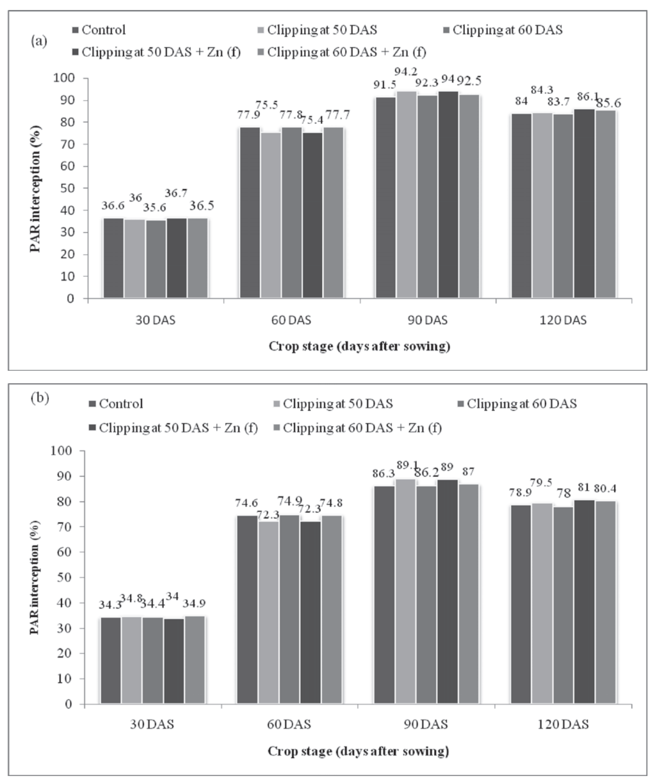

Fig. 2. Effect of clipping management on periodic photosynthetically active radiation (PAR) interception (%) in barley during (a) 2015–16 and (b) 2016–17 (DAS, days after sowing)

index. At 90 DAS, PAR interception of both clipping times, i.e. 50 and 60 DAS with and without Zn foliar application and PAR interception of clipping at 50 DAS with and without Zn foliar application (89.1%) was statistically at par among each other during 1st and 2nd year. At 120 DAS, the highest PAR interception was recorded in clipping at 50 DAS + Zn (f) treatment and it was statistically at par with clipping at 50 DAS and clipping at 60 DAS + Zn (f) treatment but significantly higher than the control and clipping at 50 DAS treatments during 1st and 2nd year. This might be because of the fact that, foliar application of Zn caused higher photosynthetic activities which leads to more leaf area at 120 DAS. Fu *et al*., (2016) also reported that application of Zn foliar spray significantly chlorophyll levels and photosynthetic activity in plants.

Normalized difference vegetative index: Cultivars did not show any significant difference in NDVI at 30 DAS (Fig. 3). However, 'DWRUB 52' recorded significantly higher NDVI than 'PL 426' and but it was statistically at par with 'PL 807'. Cultivar 'DWRUB 52' exhibited 9.1, 8.4 and 11.2% higher during 1st year and 5.4, 6.3 and 9.1% higher during 2nd year of study, higher NDVI at 60, 90 and 120 DAS, respectively, than 'PL 426'.

Clipping management showed non-significant difference on NDVI at 30 DAS during both the years of study (Fig. 4). However, at 60 DAS NDVI values of the control, clipping at 60 DAS and clipping at 60 DAS + Zn (f) treatment were statistically at par among each other, but significantly higher than clipping at 50 DAS and clipping at 50 DAS + Zn (f) treatment during 1st and 2nd year respectively. At 90 DAS, NDVI of clipping at 50 DAS and clipping at 50 DAS + Zn (f) treatment was statistically at par among each other during 1st and 2nd year respectively. At 120 DAS, the highest NDVI was recorded in clipping at 50 DAS + Zn (f) treatment and it was statistically at par with clipping at 50 DAS and clipping at 60 DAS + Zn (f) treatment, but significantly higher than control and clipping at 60 DAS during 1st and 2nd year respectively.

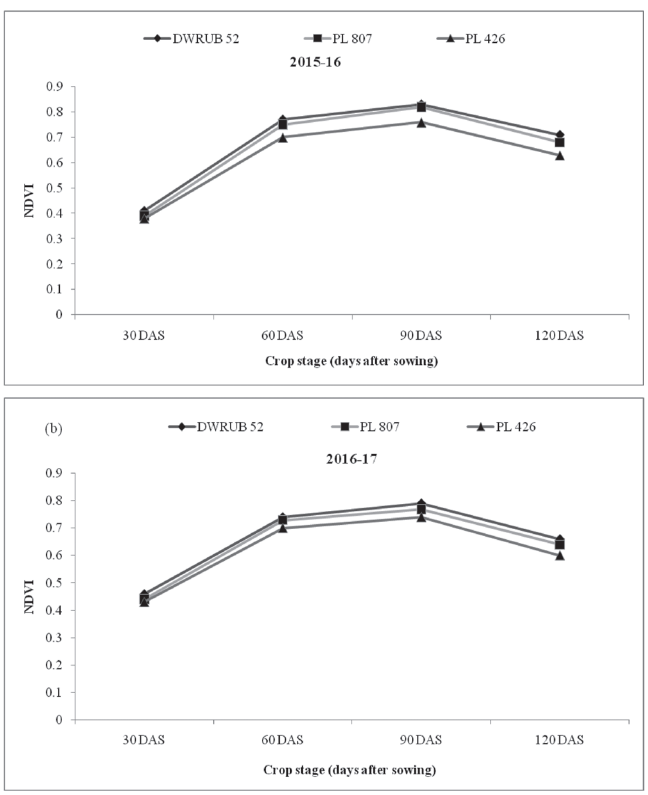

Fig. 3. Effect of different barley cultivars on periodic normalized difference vegetative index (NDVI) during (a) 2015–16 and (b) 2016–17

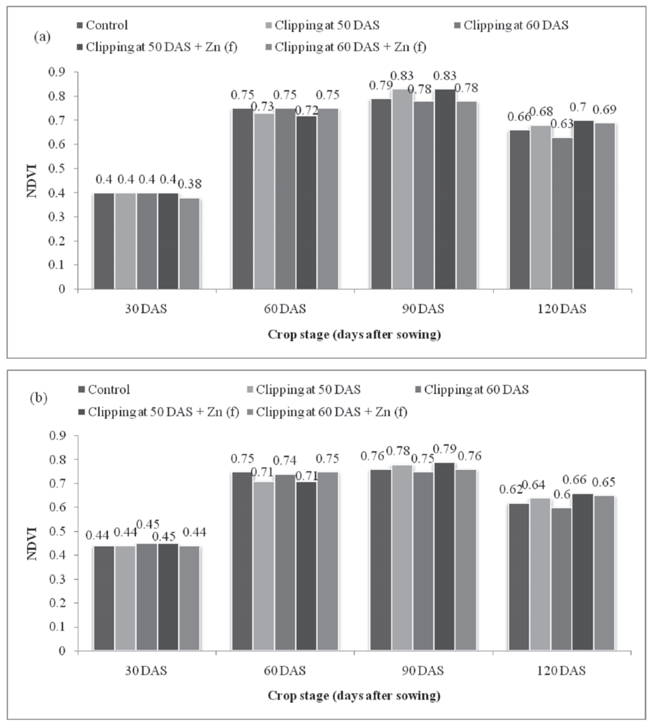

Fig. 4. Effect of clipping management on periodic normalized difference vegetative index (NDVI) in barley cultivars during (a) 2015–16 and (b) 2016–17

Growth indices

Absolute growth rate (g/m row length/day)

The data pertaining to absolute growth rate (AGR) of barley was recorded at 0–30, 30–60, 60–90, 90–120 DAS and 120 DAS to maturity are given in Table 2. Absolute growth rate was higher during 90–120 DAS than the previous (0–30, 30–60 and 60–90 DAS) and subsequent (120 DAS to maturity) stages of the crop under all the treatments. Cultivar 'DWRUB 52' revealed the highest values of AGR, followed by 'PL 807' and 'PL 426' up to 120 days of crop growth during both the years. Thereafter, 'PL 426' cultivar showed higher AGR than 'DWRUB 52' and 'PL 426'. The highest values of AGR during 30–60 DAS were

Table 2. Effect of clipping management on absolute growth rate of barley cultivars

Treatment	Absolute growth rate (g/m row length/day)									
	0–30 DAS		30–60 DAS		60–90 DAS		90–120 DAS		120–maturity	
	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17
Cultivars										
‘DWRUB 52’	0.96	1.19	1.76	1.78	1.61	1.52	3.86	3.99	0.53	0.83
‘PL 807’	0.83	1.14	1.72	1.60	1.48	1.48	3.66	3.76	0.74	0.88
‘PL 426’	0.79	1.00	1.58	1.60	1.37	1.45	3.18	3.25	1.33	0.95
Clipping management										
Control	0.88	1.13	1.78	1.70	1.46	1.46	3.45	3.37	0.69	0.89
Clipping at 50 DAS	0.85	1.10	1.56	1.58	1.72	1.73	3.45	3.48	0.75	0.88
Clipping at 60 DAS	0.83	1.10	1.82	1.76	1.23	1.22	3.29	3.42	0.62	0.86
Clipping at 50 DAS + Zn (f)	0.82	1.07	1.58	1.59	1.74	1.73	3.92	4.02	0.80	0.92
Clipping at 60 DAS + Zn (f)	0.92	1.16	1.70	1.67	1.27	1.25	3.88	4.02	0.79	0.90

DAS, Days after sowing; Zn (f), 0.5% $ZnSO_4$ foliar application at anthesis and early milk stage

recorded in clipping at 50 DAS and clipping at 50 DAS + Zn (f) treatments than the other clipping treatments which might be due to removing vegetation by clipping reduced the dry matter of crop under these treatments. Thereafter, during 60–90 DAS, clipping at 50 DAS and clipping at 50 DAS + Zn (f) treatment ensued higher values of AGR, whereas clipping at 60 DAS and clipping at 60 DAS + Zn (f) recorded lower AGR during 60–90 DAS during 1st and 2nd year, respectively, which might be due to clipping that was done at 60 DAS reduced the dry-matter of crop. Foliar application of Zn at anthesis and early milk stages increased the crop growth, leading higher AGR at 90–120 DAS and at 120 DAS to maturity.

Crop growth rate (g/m/day): Crop-growth rate (CGR), the gain in weight of a community of plants on a unit of land in a unit time. It is regarded as the most common representative of growth function because it represents the net results of photosynthesis, respiration and canopy area interaction. The data pertaining to CGR (g/m/day) recorded at 0–30, 30–60, 60–90, 90–120 DAS and 120 DAS to maturity are presented in Table 3. The CGR increased up to 120 DAS in cultivars and decreased thereafter. Data revealed that, ‘DWRUB 52’ recorded the higher CGR than the ‘PL 807’ and ‘PL 426’ up to 120 days of crop growth. Thereafter, the CGR of ‘PL 426’ surpassed the ‘DWRUB 52’ and ‘PL 807’ and maintained its superiority till maturity during both the years. Mal (2013) observed that, ‘DWRUB 52’ exhibited significantly higher value of CGR than ‘DWR 91’, ‘DWRUB 64’ and ‘DWR 73’. Clipping at 50 DAS (6.93 and 7.00 g/m^2/day) and clipping at 50 DAS + Zn (f) treatment (7.03 and 7.07 g/m/day) resulted in lower CGR during 30–60 DAS than the other clipping treatments during 1st and 2nd year, respectively, which might be due to removing vegetation by clipping reduced the dry-matter during both the years. Thereafter, clipping at 50 DAS and clipping at 50 DAS + Zn (f) resulted in the higher values of CGR during 60–90 DAS, whereas clipping at 60 DAS and clipping at 60 DAS + Zn (f) recorded lower values of CGR 60–90 DAS, which might be due the fact that clipping done at 60 DAS reduced the dry matter of crop under these

Table 3. Effect of clipping management on crop growth rate (CGR) of barley cultivars

Treatment	Crop-growth rate (g/m^2/day)									
	0–30 DAS		30–60 DAS		60–90 DAS		90–120 DAS		120–maturity	
	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17
Cultivars										
‘DWRUB 52’	4.27	5.27	7.83	7.90	7.13	6.73	17.1	17.7	2.35	3.67
‘PL 807’	3.67	5.07	7.63	7.10	6.57	6.57	16.3	16.7	3.30	3.92
‘PL 426’	3.50	4.43	7.03	7.10	6.07	6.43	14.1	14.4	5.89	4.21
Clipping management										
Control	3.90	5.00	7.90	7.53	6.50	6.50	15.3	15.0	3.08	3.94
Clipping at 50 DAS	3.77	4.87	6.93	7.00	7.63	7.70	15.3	15.5	3.35	3.92
Clipping at 60 DAS	3.70	4.90	8.07	7.80	5.47	5.43	14.6	15.2	2.77	3.81
Clipping at 50 DAS + Zn (f)	3.63	4.73	7.03	7.07	7.73	7.70	17.4	17.8	3.55	4.07
Clipping at 60 DAS + Zn (f)	4.07	5.13	7.57	7.43	5.63	5.53	17.2	17.9	3.52	3.98

DAS, Days after sowing; Zn (f), 0.5% $ZnSO_4$ foliar application at anthesis and early milk stage treatments. The Zn spray at anthesis and early milk stages increased the crop growth, resulting higher CGR between 90 and 120 DAS and 120 DAS and maturity.

Relative growth rate: The data on relative growth rate (RGR) (Table 4) showed that, RGR (g/g/day) followed the decreasing trend with the advancement of age under all the treatments. The RGR did not follow any consistent pattern during the entire crop season under the influence of sowing dates. However, cultivar 'DWRUB 52' showed in the highest RGR during 0–30 DAS in the 1st and 2nd year and during 60–90 DAS in the 1st year. Cultivars, 'PL 807' and 'DWRUB 52' revealed higher RGR during 30–60 and 60–90 DAS, respectively, in the 1st year. Barley cultivar 'PL 426' recorded higher RGR during 30–60 and 60–90 DAS in 2nd year and during 120 DAS – maturity, while during 90–120 DAS, this cultivar recorded lower RGR during both the years. This parameter also did not follow any consistent pattern during the entire crop season under the influence of clipping management. However, between 60 and 90 DAS, clipping at 50 DAS and clipping at 50 DAS + Zn (f) treatment exhibited the higher values of RGR between 60 and 90 DAS. The clipping at 60 DAS and clipping at 60 DAS + Zn (f) treatment resulted in the lower values of RGR during 60–90 DAS in the 1st and 2nd year, respectively, which might be due to clipping that was done at 60 DAS reduced the dry-matter of crop under these treatments. The Zn foliar application at anthesis and early milk stages increased the crop growth, led to higher RGR during 90–120 DAS.

Photosynthetic parameters

Barley cultivars and clipping management significantly influenced the transpiration rate (Table 5). Cultivar 'PL 426' showed the highest transpiration rate, being statistically similar with to 'PL 807' and significantly higher than 'DWRUB 52'. Among the clipping management, foliar application of Zn at anthesis and early milk stages with both clippings 50 and 60 days resulted in the statistically

Table 4. Effect of clipping management on relative growth rate of barley cultivars

Treatment	Relative-growth rate (g/g/day)									
	0–30 DAS		30–60 DAS		60–90 DAS		90–120 DAS		120–maturity	
	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17
Cultivars										
'DWRUB 52'	0.0702	0.0733	0.0151	0.0133	0.0067	0.0060	0.0092	0.0092	0.0009	0.0013
'PL 807'	0.0680	0.0727	0.0163	0.0127	0.0066	0.0062	0.0094	0.0092	0.0013	0.0015
'PL 426'	0.0674	0.0708	0.0159	0.0138	0.0066	0.0064	0.0089	0.0085	0.0026	0.0018
Clipping management										
Control	0.0689	0.0725	0.0160	0.0133	0.0064	0.0060	0.0088	0.0084	0.0013	0.0016
Clipping at 50 DAS	0.0684	0.0721	0.0151	0.0129	0.0078	0.0072	0.0088	0.0084	0.0014	0.0015
Clipping at 60 DAS	0.0682	0.0722	0.0167	0.0138	0.0055	0.0052	0.0089	0.0088	0.0012	0.0016
Clipping at 50 DAS + Zn (f)	0.0679	0.0717	0.0156	0.0132	0.0079	0.0073	0.0096	0.0094	0.0014	0.0015
Clipping at 60 DAS + Zn (f)	0.0695	0.0729	0.0152	0.0130	0.0057	0.0053	0.0100	0.0099	0.0014	0.0015

DAS, Days after sowing; Zn (f), 0.5% $ZnSO_4$ foliar application at anthesis and early milk stage

Table 5. Transpiration rate, stomatal conductance and grain yield of barley as influenced by cultivars and clipping management (mean of 2 years ± S.D.)

Treatment	Transpiration rate (m mol/m/sec)	Stomatal conductance (mol/m²/sec)	Grain yield (kg/ha)
Cultivars			
'DWRUB 52'	0.48±0.03	0.13±0.02	4020±471
'PL 807'	0.53±0.04	0.13±0.00	3775±431
'PL 426'	0.55±0.05	0.14±0.01	3265±447
CD (P=0.05)	0.03	NS	190
Clipping management			
Control	0.52±0.00	0.12±0.01	3540±491
Clipping at 50 DAS	0.50±0.02	0.13±0.00	3700±753
Clipping at 60 DAS	0.49±0.01	0.13±0.02	3365±525
Clipping at 50 DAS + Zn (f)	0.55±0.03	0.14±0.01	3985±740
Clipping at 60 DAS + Zn (f)	0.54±0.01	0.13±0.01	3855±629
CD (P=0.05)	0.01	NS	265

DAS, Days after sowing; Zn (f), 0.5% $ZnSO_4$ foliar application at anthesis and early milk stage similar transpiration rates, which were significantly higher than the other treatments. Fu *et al*., (2014) observed that, Zn deficiency lowers the photosynthetic activity of plants.

Productivity

Cultivars differed significantly with relation to grain yield of barley (Table 5). Cultivar 'DWRUB 52' gave significantly higher grain yield than cultivars 'PL 807' and 'PL 426'. Cultivar 'PL 426' gave significantly lower grain yield than both the cultivars. Barley cultivar 'DWRUB 52' exhibited in 6.0% higher grain yield than 'PL 807' whereas, 18.7% higher than 'PL 426'. Increased grain yield of 'DWRUB 52' cultivar might be owing to higher number of effective tillers/m^2, more 1,000-grain weight and higher number of grains/spike. Reduction in the grain yield of 'PL 426' was attributed to more lodging under this cultivar. Lodging of 'PL 426' resulted in lower number of grains/ spike and 1,000-grain weight ensuing in lower yield. Yeo and Flower (1984), Jat and Singh, (2003), Kaur and Singh (2012) also reported varietal differences for grain yield.

Clipping management influenced the grain yield of barley. Clipping at 50 DAS + Zn (f) treatment resulted in the highest grain yield, being statistically at par with clipping at 60 DAS + Zn foliar application but significantly higher than clipping at 50 DAS, clipping at 60 DAS and the control crop. There was an increase of 12.6% in grain yield when clipping was done at 50 DAS with foliar application of Zn and an increase of 8.9% in grain yield when clipping was done at 60 DAS with foliar application of Zn than the control. The grain yield of the control crop was statistically at par with both clipping stages, i.e. at 50 and 60 DAS. So, there was non-significant effect of both clipping times done at 50 and 60 DAS on the grain yield of crop. El-Shatnawi and Haddad (2004) reported that, yield components reduced by clipping, were the most important contributors to loss of grain yield. However, there was a significant effect of foliar application of Zn with both clipping stages, i.e. at 50 and 60 DAS, on the grain yield of crop during both the years. Zinc increased membrane-integrity, heat-tolerance, synthesis of carbohydrates, cytochrome and nucleotide synthesis, auxin-synthesis, chlorophyll synthesis, and metabolism of nitrogen (Marschner *et al.,* 1996), thereby enhancing photosynthesis, photosynthates, their translocation to grain and finally crop yield in the treatments such as clipping at 50 DAS+ Zn (f) and clipping at 50 DAS+ Zn (f). Jan *et al.,* (2013) reported similar results related to increase in the grain yield owing to foliar application of Zn.

Thus, barley cultivar 'DWRUB 52' registered higher photosynthetically active radiation (PAR) interception, normalized difference vegetative index (NDVI), absolute growth rate (AGR) and crop-growth rate (CGR) followed by 'PL 807' and 'PL 426'. The Zn foliar spray at anthesis and early milk stages significantly enhanced the intercepted PAR and NDVI in barley crop. Spray of Zn also improved the AGR, CGR and PGR at 90–120 DAS and at 120 DAS to maturity. Cultivar 'DWRUB 52' gave 6.0 and 18.7% higher grain yield than 'PL 807' and 'PL 426' respectively. Foliar application of Zn significantly increased 12.6 and 8.9% grain yield with clipping at 50 and 60 DAS, respectively, than the control crop.

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