Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(3): 3381-3385
Received: 16-03-2019
Accepted: 18-04-2019

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Estimation of moisture depletion rate of barley in accordance with pan evaporation under diverse hydrothermal regimes

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Abstract
Two promising barley cultivars V_1 (DWRUB 52) & V_2 (PL 807) were sown in Ludhiana, Punjab during *rabi* season of 2016-17 under factorial split plot design including different sowing dates viz. D_1 (25th October), D_2 (10th November), D_3 (25th November) and three irrigation levels such as I_1 (Recommended), I_2 (Stress at Vegetative Stage) and I_3 (Stress at Anthesis Period) to estimate seasonal consumptive water use of crop vis-à-vis pan evaporation data during entire growing period. Significant differences in seasonal crop water use was observed and maximum water consumption took place under D_3 (381.72 mm) in association with I_1 (395.63 mm) for V_1 (375.07 mm). Water use efficiency with respect to straw and grain exhibited higher value in case of D_2 (25.64 & 12.83 kg/ha/mm respectively) and I_2 (24.88 & 12.25 kg/ha/mm respectively). The total pan evaporation for V_1 was greater for D_2 (446.5 mm) followed by D_3 (399.6 cm) and D_1 (348.5 mm). Linear regression equations explained 65.25, 71.92 and 69.04 per cent variability in leaf area index, dry matter, grain yield respectively with seasonal crop consumptive water use under modified environment.

Keywords: Barley, consumptive water use, pan evaporation, water use efficiency, leaf area index

Introduction

As an alternative to prime cereal crops, barley is now being extensively grown as summer crop in temperate regions and winter crop in tropics. In Punjab, barley covered 11 thousand hectares with a production of 39.40 thousand million tonnes and average yield of 35.82 q/ha during 2014-15 (Anonymous 2016) [1]. The crop needs adequate moisture to survive in semi-arid environment of Punjab. IPCC (2014) [7] reported globally averaged combined land and ocean surface warming of 0.85°C during the period from 1880 to 2012, thus the evaporative demand of the atmosphere gets increased due to enhancement of temperature. Hira (2009) [6] reported that the state of Punjab is facing water scarcity due to fast depleting ground water resources particularly in central Punjab. Therefore, it becomes very crucial to reduce crop evapotranspiration (ET) to save groundwater pumped for irrigation under irrigated farming.

In total, two-thirds of the precipitation over land is consumed in evapotranspiration in one year (Oki & Kanae, 2006) [9]. Changes in evaporation will affect agricultural irrigation, water resources utilization, as well as the ecological environment. When evaporation increases, the amount of water resources decreases, and global warming would therefore enforce the situation of water shortage (Cong, 2008) [36]. Thomas (2008) [12] stated that evapotranspiration and water use efficiency of crops will be altered by climate change in future. On the other hand, Peterson *et al*. (1995) [10] found that observed pan evaporation (Epan) continued to decrease in the last 50 years (1946–1995).

Different researchers recognized modification in sowing date, application of deficit irrigation and implementation of drought tolerating varieties in cropping practices could be of significant use in optimal utilization of natural water resources without hampering the crop yield. Sepaskhah and Akbari (2005) [11] reported that deficit irrigation strategy and rain fed cultivate are two of the management practices to cope with drought and shortage of water in arid and semi-arid region. Gregory (2004) [5] suggested the time of sowing and choice of the appropriate cultivars might be even more critical on soils that are prone to water logging.

Considering these facts, the present investigation was undertaken to evaluate the effects of different sowing dates, cultivars and irrigation levels on evaporation status and water use efficiency in barley crop field under semi-arid conditions of Punjab so that, a tentative guideline can be formulated for farmers based on obtained results for judicious and effective utilization of available water resources.

Materials and methods

Soil moisture depletion method

Following formula was used to calculate the per cent moisture on the basis of dry weight:

Soil water content (dry weight basis) = $\frac{W_1 - W_2}{W_2}$ (Gravimetric method)

Where, W_1 = Weight of fresh soil
W_2 = Weight of dry soil

The depth of water was obtained by:

$$P_V = \frac{P_w \times BD \times d}{100}$$

Where, P_V = Depth of water in cm
P_W = Per cent moisture on weight basis
BD = Bulk density
d = Depth of soil in cm

Total water use was obtained from summation of root zone soil water depletion at successive time intervals during growth season of crop. The retention at each soil moisture sampling was calculated by:

Root zone water retention = $\Sigma_{i=1}^{N} D_j$

Where, i = Soil depth interval e.g. 0-15 cm, 15-30 cm……90-120cm
Dj = Depth of water retained in the respective soil depth interval
N= Number of soil layers

To compute soil water depletion, between the two successive samplings the difference in water retention were estimated and the remainder amount was taken as soil water depletion by the crop. From the date of irrigation to the day of soil moisture sampling the daily evapotranspiration can be assumed to be 0.7 times the open pan evaporation. Pan evaporation can be used as indicator of ET for those days if canopy is fully developed. The water depletion by the crop computed with soil water depletion method is referred as water use by the crop.

USDA open pan evaporimeter

With the help of fixed point gauge, the observation was taken daily at 8:30 a.m from the open pan evaporimeter installed in the observatory. Water was added to the pan such that top of fixed point gauge just touched the water level. Graduated cylinder was used to put the water in the pan and the amount of water given by the cylinder was recorded as it provide the estimate of the water evaporated. Pan water level rises on a rainy day. Therefore, during measurement of evaporation, rainfall should be added to get the accurate amount of evaporation. On the cylinder, twenty rings were marked and each ring denotes 0.1 mm of evaporation.

Water use efficiency

The water use efficiency is defined as the marketable crop produced per unit of water used in evapotranspiration. It was calculated by using the following formula:

WUE = Y/ET

Where,
WUE = Water use efficiency (kg/ha mm of water)
Y = The marketable yield (kg/ha)
ET = Evapotranspiration (mm)

Results and discussions

Consumptive Water Use

It is the amount of water required by a crop for its vegetated growth to evapotranspiration and building of plant tissues plus evaporation from soils and intercepted precipitation. It is expressed in terms of depth of water. Consumptive use varies with temperature, humidity, wind speed, topography, sunlight hours, method of irrigation, moisture availability. In the present study, it was observed that different dates of sowing, various moisture regimes and variation in cultivars significantly affected the seasonal water use or consumptive use of water during the entire crop growth period (Table 1). The maximum water use (381.72 mm) was obtained in case of D_3 at crop harvesting followed by D_1 (371.41 mm) and D_2 (359.19 mm). Although the recorded value was much closer between D_3 and D_1 but significantly higher as compared to D_2. Due to delayed planting, the peak water need stages of the crop coincided with higher temperature period resulted maximum water utilization. Among the three moisture regimes, I_1 recorded significantly higher water use of 395.63 mm as against of I_2 (336.62 mm) and I_3 (380.06 mm). I_2 consumed much less water while the value remained relatively statistically at par between I_1 and I_3. This could be due to uniform distribution of soil moisture throughout the experimental period under recommended irrigation management. Of the two varieties taken in experiment, V_1 consumed maximum water (375.07 mm) than V_2 (366.47 mm). It was also observed that V_1 was significantly better than V_2 in terms of consumptive water use.

Straw Water use efficiency

Water use efficiency with respect to final straw yield of barley were estimated at crop harvesting period (Table 1). Results revealed that D_2 recorded maximum straw water use efficiency (WUEs) of 25.64 kg/ha/mm followed by D_1 (24.80 kg/ha/mm) and D_3 (19.57 kg/ha/mm). Significant differences were observed in WUEs in terms of different sowing environment and D_1 & D_2 remained quite statistically at par but much higher than D_3. Among different moisture levels, I_2 remained superior with WUEs of 24.88 kg/ha/mm as compared to I_1 (22.87 kg/ha/mm) and I_3 (22.86 kg/ha/mm). Several moisture regimes seemed to put significant effect on WUEs of barley however, I_1 and I_3 remained statistically at par but much less than I_2 in terms of WUEs. Among irrigation levels, water use efficiency and NAR was highest when only two irrigations at tillering and grain development were applied (Asad *et al*. 2014) [2]. Different cultivars showed significant variation in WUEs at crop harvesting. V_2 recorded maximum WUEs of 23.53 kg/ha/mm than V_1 (23.15 kg/ha/mm).

Grain water use efficiency

Significant effect of different sowing dates were observed in case of grain water use efficiency (WUEg) of barley in the experiment (Table 1). Among different sowing windows, D_2 recorded maximum WUEg of 12.83 kg/ha/mm followed by D_1 (11.83 kg/ha/mm) and D_3 (10.04 kg/ha/mm), although the value remained much closer between D_2 & D_1 but significantly higher than D_3. Different irrigation levels showed significant variation in WUEg of barley. Among various moisture levels, I_2 recorded higher WUEg (12.25 kg/ha/ mm) than that of I_1 (11.27 kg/ha/mm) and I_3 (11.12 kg/ha/mm), however, the value stayed much nearer between I_1 and I_3 but quite lesser than I_2. Of the two varieties, V_1 possessed higher WUEg of 11.70 kg/ha/mm than that of V_2 (11.43 kg/ha/mm) and the variation in WUEg due to cultivars were found statistically significant in the experiment. Water deficit reduced water use however, high temperature had no effect on water use, but decreased WUE (Crauford *et al* 1999) [4].

Estimation of rate of Evapotranspiration –USDA Open Pan Evaporimeter

Evaporation from natural surfaces such as open water, bare soil or vegetation is diffusive process, by which water in the form of vapour is transfer from underline surface to the atmosphere. The rate of evaporation was measured using USDA open pan evaporimeter installed in Agrometeorogical observatory, PAU, Ludhiana and presented in Table 2 to 4. The total evaporation for V_1 was highest for D_2 (446.5 mm) followed by D_3 (399.6 cm) and D_1 (348.5 mm). Likewise, for V_2, the potential evaporation was highest for D_2 (430.5 mm) as against of D_3 (374.4 mm) and D_1 (323.7 mm). This may be due to the increase in temperature during the later dates of sowing. Among all three dates of sowing, significant increase in the potential evaporation rate was observed during milking to physiological maturity stage for both the crop varieties as these stages encountered significant higher temperature from mid-March to April period.

Table 1: Influence of different sowing dates, moisture levels and varieties on seasonal water use and its utilization efficiency on barley

Treatments		Consumptive Water use (mm)	Straw Water Use Efficiency (Kg/ha/mm)	Grain Water Use Efficiency (kg/ha/mm)
D1 (25th October)		371.41	24.80	11.83
D2 (10th November)		359.19	25.64	12.83
D3 (25th November)		381.72	19.57	10.04
Sem(±)		0.13	0.16	0.09
CD (p=0.05)		0.38	0.47	0.27
I1 (Recommended Irrigation)		395.63	22.27	11.27
I2 (Stress at Vegetative Stage)		336.62	24.88	12.25
I3 (Stress at Anthesis Stage)		380.06	22.86	11.18
Sem(±)		0.13	0.16	0.09
CD (p=0.05)		0.38	0.47	0.27
V1 (DWRUB 52)		375.07	23.15	11.70
V2 (PL 807)		366.47	23.53	11.43
Sem(±)		0.10	0.13	0.07
CD (p=0.05)		0.31	0.39	0.22
D*I	Sem(±)	0.22	0.27	0.16
	CD (p=0.05)	0.65	0.82	NS
D*V	Sem(±)	0.22	0.27	0.16
	CD (p=0.05)	0.65	0.82	0.47
V*I	Sem(±)	0.22	0.27	0.16
	CD (p=0.05)	0.65	NS	NS
D*I*V	Sem(±)	0.31	0.39	0.22
	CD (p=0.05)	0.92	1.16	0.67

Table 2: Open pan evaporation computed Potential evaporation at different growth stages of barley sown on 25th October during *rabi* 2016-17

Varieties	V_1 (DWRUB 52)		V_2 (PL 807)	
Crop growth stages	Cumulative PE (mm)	Daily PE rate (mm day^{-1})	Cumulative PE (mm)	Daily PE rate (mm day^{-1})
Sowing-CRI	57.2	2.5	54.2	2.46
CRI-Tillering	42.6	1.93	44.9	2.04
Tillering-Jointing	29.5	1.34	30.2	1.31
Jointing-Flag leaf	32.4	1.35	29.2	1.32
Flag leaf-Boot	10.1	1.26	12	1.33
Booting-Heading	12.0	2	9	1.5
Heading-Anthesis	40.4	2.5	35.4	2.36
Anthesis-Milking	41.2	3.4	34	3.09
Milking-Physiological Maturity	83.1	3.92	74.8	3.56
Sowing- Maturity	348.5	2.24	323.7	2.10

Table 3: Open pan evaporation computed Potential evaporation at different growth stages of barley sown on 10th November during *rabi* 2016-17

Varieties	V_1 (DWRUB 52)		V_2 (PL 807)	
Crop grpwth stages	Cumulative PE (mm)	Daily PE rate (mm day^{-1})	Cumulative PE (mm)	Daily PE rate (mm day^{-1})
Sowing-CRI	57.3	2.38	55.8	2.42
CRI-Tillering	25.3	1.20	26.8	1.21
Tillering-Jointing	29.5	1.40	30.7	1.46
Jointing-Flag leaf	34.2	1.36	32.0	1.39
Flag leaf-Booting	28.2	2.56	27.2	2.47
Booting-Heading	20.7	2.95	19.0	2.71
Heading-Anthesis	42.3	3.25	46.0	3.28

Anthesis-Milking	60.0	4.00	60.0	4.00
Milking-Physiological Maturity	149.0	7.09	133.0	7.00
Sowing-Maturity	446.5	2.91	430.5	2.88

Table 4: Open pan evaporation computed Potential evaporation at different growth stages of barley sown on 25th November during *rabi* 2016-17

Varieties	**V_1 (DWRUB 52)**		**V_2 (PL 807)**	
Crop grpwth stages	**Cumulative PE (mm)**	**Daily PE rate (mm day^{-1})**	**Cumulative PE (mm)**	**Daily PE rate (mm day^{-1})**
Sowing-CRI	36.1	1.44	34.1	1.42
CRI-Tillering	31.3	1.42	32.3	1.46
Tillering-Jointing	24.7	1.3	25.7	1.3
Jointing-Flag leaf	48.7	2.11	41.5	2.07
Flag leaf-Booting	27.4	3.04	28.1	1.40
Booting-Heading	15.6	3.9	18.1	3.62
Heading-Anthesis	25.8	2.86	27.8	3.08
Anthesis-Milking	55.5	4.62	51.0	4.25
Milking-Physiological Maturity	134.5	7.07	115.8	6.81
Sowing-Maturity	399.6	3.08	374.4	2.82

Crop water production functions
To enhance crop water productivity, reduction in evapotranspiration through deficit irrigation and selection of most crucial water need stages i.e. growth stages most vulnerable to water stress conditions has already been reported by Jalota *et al.* (2006) [8]. Grain yield hampered severely under water stress conditions. Therefore, it is important to know different associations between water use and crop growth and yield parameters.

Water use vs maximum leaf area index, dry matter production & grain yield
Regression analysis was done by fitting linear response function between seasonal water use and different growth attributes such as maximum leaf area index, dry matter accumulation and finally grain yield of barley (Fig. 1). The linear regression equation explained 65.25 per cent variability in leaf area index with water use under various treatments. Strong linear and positive relationship were obtained between consumptive water use and growth parameters of the crop. The linear regression equation explained 65.25 per cent variability in leaf area index with water use under various treatments. Similarly, from dry matter production and final grain yield point of view, the regression equation showed 71.92 percent and 69.04 variation with water consumption rate of the crop respectively under different sowing time, cultivars and moisture levels. The R^2 value remained on the higher side mainly due to less amount of rainfall during crop growing season and thus the applied treatments performed well under field conditions.

Acknowledgements
The authors are highly grateful to Indian Council of Agricultural Research, New Delhi, Govt. of India, for providing grant in the form of Junior Research Fellowship to conduct this study at the research farm of Department of Climate Change and Agriculture Meteorology, PAU, Ludhiana.

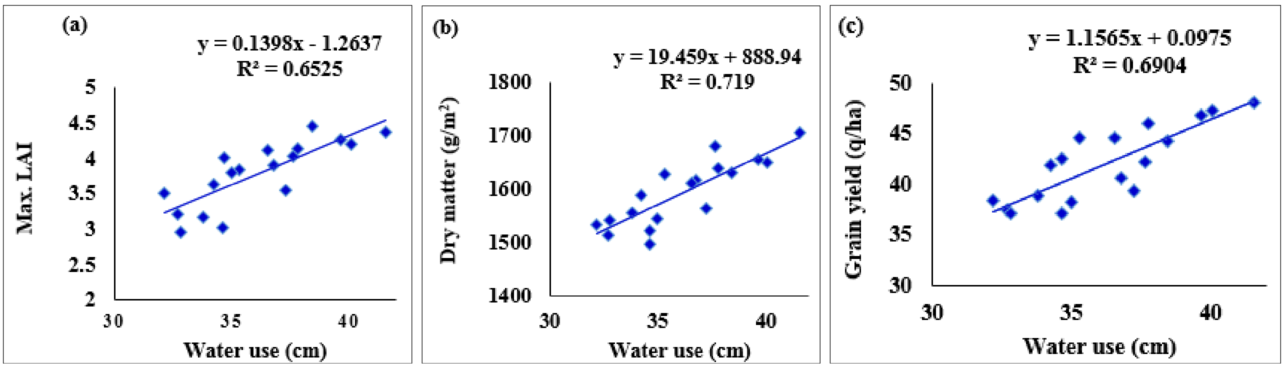

Fig 1: Relationship between water use and maximum leaf area index (a), dry matter accumulation (b), Grain yield (c) respectively under different sowing dates, varieties and various moisture regimes during *rabi* 2016-17

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