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Short Communication

Impact of water saving techniques on leaf water potential of broccoli under various water stress conditions

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Water saving measures can reduce the evaporation loss and encourage transpiration and there by enhance the effective utilization of root zone water towards crop production. It happens by creating a barrier between the soil surface and atmosphere. Mulching minimizes evaporation loss and can influence root zone moisture distribution, which may enhance transpiration (Zribi *et al.,* 2015). With good management and adoption of appropriate practices, improved agricultural water conservation, and subsequent use of that water for more efficient crop production are possible under both dry and irrigated conditions (Kingra and Mahey, 2013). With application of 0.7 % and 5 % hydrogel in sandy soil increases 2.0 % and 9.48 % crop production over non-hydrogel application (Narjary, 2012). Weather elements as well as soil factors have significant influence on growth, berry development of grape, its quality and yield (Harwadikar *et al*., 2013). The soil-water extraction and utilization by plants are based on recognition that the field with all its components of soil, plant, and ambient atmosphere taken together-constitutes a physically integrated, dynamic system in which various flow processes occur interdependently like links in a chain. This unified system has been called the soil-plant-atmosphere continuum (SPAC). As we have come to understand, the various terms used to characterize the state of water in different parts of the soil-plant-atmosphere system are merely alternative expressions of the energy level, or potential of water. As an approximation, the flow rate through each segment of the system can be assumed to be proportional directly to the operating potential gradient, and inversely to the segment's resistance (Hillel, 1998).

To measure broccoli plant moisture stress (PMS) and to correlate for irrigation application to maximize the use efficiency of water resources a field experiment was planned to assess the effect of irrigation régimes and water saving techniques on leaf water potential of broccoli. A field experiment was carried out during the post rainy season of 2016-17 and 2017-18, in the "C" Block Research Farm of the BCKV, Mohanpur, (W.B.) at Kalyani (Latitude $22^0 58'$N, Longitude $88^0 31'$E and altitude 9.75 m above mean sea level) on a sandy loamy soil classified as *Aeric haplaquept*. The experiment was set up with a split-plot design. Treatments were distributed randomly and replicated thrice. Four irrigation regimes (IR) ($I_{1.0}$: IW/CAET = 1.0, $I_{0.75}$: IW/ CAET = 0.75, $I_{0.50}$: IW/ CAET = 0.50, $I_{0.25}$: IW/ CAET = 0.25) were placed in main plots, and five water saving techniques (WST) (M_C- controlled (No application), M_H- hydrogel @ 50 kg/ha, M_K- potassium nitrate (KNO_3) @1.5 % M_{BP}-black polyethylene mulch @ 30 µ thickness) and M_{PS} – paddy straw mulch @ 5 t/ha applied in sub-plots. Depth of irrigation in each occasion was kept 25 mm. After attainment of 25, 33.3, 50 and 100 mm cumulative actual evapotranspiration (CAET) value irrigations were applied to $I_{1.00}$, $I_{0.75}$, $I_{0.50}$ and $I_{0.25}$ treatment, respectively. Irrigation was applied initially to each plant by water can for plant establishment, which accounts in total 4.0 mm to each plot followed by direct irrigation to each plot through discharge pipe. For each plot an amount of 219.0 liter of water were applied during irrigation every time. The experimental plot was composed of raised bed (100 cm) and furrow (30 cm) system. In each ridge, two rows of broccoli crop were transplanted. In case of mulches a strip of 15 cm wide area at the middle part of the furrow remain uncovered for easy entry of rainfall and irrigation water respectively. Irrigation was applied in the furrows and water seeped into the root zone of the crop in raised bed. This is common irrigation practice followed by the farmers of the locality. Farmers even deeper the raised bed during irrigation, however, in this study depth of irrigation was fixed in such a manner that the furrows remain filled with water and no spilling of water into the raise bed. To schedule irrigation, daily ETc (AET) was calculated based on the product of daily ET_O times a crop coefficient. The FAO-56 Penman–Monteith (FAO-56 PM) equation was used (Allen *et al.,* 1998a) to calculate ET_O. Climatic data was obtained from the agrometeorological observatory, which was located less than 500 m away from the experimental broccoli field (AICRP on Agrometeorology, Kalyani, B.C.K.V., Mohanpur, Nadia). Crop coefficient (K_C) values used for calculation of AET were: 0.7 during the rosette development (RSD) period; 1.05 during heading (HD) and 0.95 during the harvesting (HT) growth stage (Allen *et al.,* 1998b; Lopez-Urrea *et al.,* 2009).

Individual plot size was 2.5 m x 3.5 m (8.75 m_2), where, both row-to-row and plant-to-plant spacing's were maintained as 50 cm. Broccoli (Cv. Centauro) was taken as the test crop. Twenty-five days old seedlings were transplanted on 9th and 6th November respectively during 2016-17 and 2017-18 cropping season. Final harvesting in respective growing seasons was done on 19.01.17 and 23.01.18. Organic (FYM @ 15.0 t ha^{-1}) and chemical fertilizers (@ 180.0 kg N Urea), 80.0 kg P_2O_5 (SSP) and 80.0 kg K_2O (MOP) were applied according to Thapa and Rai (2012). Entire dose of phosphate and potassium were applied as basal; while, nitrogen was applied in three splits, 50 % as basal and 25 % at 30 DAT + 25 % at 50 DAT. Boron as a micronutrient @ 15.0 g/lit in the form of borax (20 %) was applied as a foliar spray on plant at 30 and 50 DAT.

Status of leaf water potential (Ψ_L) were taken before and after 2 days of each irrigation during noon time at 1130 to 1300 h by using Pressure Chamber instrument (Soil Moisture Equipment, Santa Barbara, CA). Unit of recorded Ψ was presented in bar. Two fully expanded leaves (North and South facing) from the middle portion of each plot were taken and immediately Ψ_L was measured in shed near by the experimental field. Ψ_L measurement directly determines the pressure given to ooze out the water adheres within the leaf. Thus, the pressure at which the water is withheld with the leaf is determined by Ψ_L measurement. The equilibrium pressure required bringing water to ooze out from mid-rib of leaves or the cut mid rib cross-section was recorded as the leaf water potential according to O'toole *et al.* (1980). According to (Dennis, 2014) the crop is in no stress, mild stress, moderate stress, high stress and very high stress condition when the Ψ_L value remain in the range -7 to -8 bar, -8 to -10 bar, -10 to -12 bar, -12 to -14 bar and -14 bar to -16 bar, respectively. During the experimentations, we have taken the Ψ_L observation before and after every irrigation at noon time. And descriptive statistical analysis was carried out using MS Excel (version 10.0) for presenting the data.

The data (Table 1) revealed that first year of the experimentation Ψ_L under $I_{1.0}$ showed that during first irrigation; there was no stress within the water saving techniques. The Ψ_L value ranged between -1.2 to -3.2 and -0.8 to -2.6 before and after irrigation, respectively. However, before second irrigation, the Ψ_L values were -11, -11 and -10 bar, respectively under M_C, M_K and M_H. Thus, the crop growth under no mulch condition showed mild water stress. On the other hand, Ψ_L under M_{PS} and M_{BP} was -9.7 bar and -7.3 bar, respectively. After irrigation, the Ψ_L value depicted that the crop under all WST released their stress. Similar observation was also made during 3rd and 4th irrigation. In general, the crop growth under M_C and M_K registered higher Ψ_L and M_{BP} registered the lowest one. Under controlled treatment, quick drying of soil water observed due to higher evaporation from open soil surface, resulted lower water availability for transpiration. Thus, the water held more tightly within the plant. Under M_K, as KNO_3 regulated the osmotic potential of guard cell, the water withheld with more pressure inside the plant cell.

Under $I_{0.75}$, almost similar trend was noted among the WST like $I_{1.0}$ and the average Ψ_L value was -0.23 to -0.71 bar higher than $I_{1.0}$. During second irrigation, the crop encountered higher stress grown under M_C (-13.1 bar) and M_K (-12.4 bar). Mild stress was observed under M_H (-11.2 bar) and M_{PS} (-11.0 bar). The crop grown under M_{BP} did not face any stress during that time. Crop grown under M_C (-10.3 bar) and M_K (-10.2 bar) faced mild stress before 3rd irrigation, which was closely followed by M_{PS} (-9.7 bar) and M_H (-9.4 bar). The lowest Ψ_L was again recorded under M_{BP}. Similar results were recorded by Francesco *et al.* (2015) that the lower Ψ_L (-8.7 bar) of the leaves of cucumber under application of hydrogel compare to no hydrogel (-10.3 bar) treatment. Under $I_{0.50}$ irrigation regime, the 1st irrigation was applied at 33 DAT. Thus, for a longer time the crop was thirsty. The Ψ_L value before irrigation under this irrigation regime was quite higher (-2.44 to -4.75 bar) compared to $I_{1.0}$ and $I_{0.75}$. Before 2nd irrigation, the crop showed mild stress under M_C (-11.7 bar), M_{PS} (-11.0 bar) and M_K (-10.8 bar). Like other treatment, the lowest Ψ_L value was again recorded under M_{BP} (-8.3 bar). Under $I_{0.25}$, irrigation was applied only one at 50 DAT. The crop grown under all the water saving measures showed mild water stress. In general, it was noted that the Ψ_L value decreases with increasing water application. Which is in agreement with reports for other broccoli cultivars (Saleh *et al.,* 2014) and similar effect observed by Isalam *et al.* (2011) for maize and O'toole *et al.* (1980) for rice. Amongst the WST, under same irrigation regime (IR) there was noted low variation and under $I_{1.00}$ and $I_{0.75}$ observed lower variation (1-4 %) compared to $I_{0.50}$ and $I_{0.25}$ treatment (Table 1).

Table 1: Temporal variation of leaf water potential (bar) under different irrigation regimes and water saving techniques before and after each irrigation during 2016-17

Treatment					Days after transplanting				
	19	21	31	33	39	41	51	53	
	BI*	AI*	BI	AI	BI	AI	BI	AI	
$I_{1.0}$	M_C	-1.2	-0.8	-11.0	-6.5	-11.7	-7.6	-10.3	-7.7
	M_H	-1.4	-0.8	-10.0	-4.7	-7.9	-5.5	-9.7	-9.7
	M_K	-3.2	-0.2	-11.0	-6.0	-10.6	-6.2	-9.8	-9.0
	M_{BP}	-2.4	-1.0	-7.3	-4.8	-8.3	-5.5	-7.7	-6.3
	M_{PS}	-2.0	-2.6	-9.7	-4.9	-7.2	-7.2	-9.7	-6.9
	Mean	-2.04	-1.08	-9.80	-5.38	-9.14	-6.40	-9.44	-7.92
	SD	0.80	0.90	1.51	0.82	1.92	0.97	1.00	1.42
	CV	-0.39	-0.83	-0.15	-0.15	-0.21	-0.15	-0.11	-0.18
				21	23	33	35	50	52
$I_{0.75}$	M_C			-2.4	-2.4	-13.1	-8.8	-7.7	-10.3
	M_H			-2.0	-2.4	-11.2	-7.6	-8.3	-9.4
	M_K			-3.2	-1.6	-12.4	-7.5	-7.5	-10.2
	M_{BP}			-2.4	-2.2	-9.4	-4.8	-6.5	-6.2
	M_{PS}			-2.0	-2.0	-11.0	-6.9	-6.2	-9.7
	Mean			-2.40	-2.12	-11.42	-7.12	-7.24	-9.16
	SD			0.49	0.33	1.42	1.47	0.87	1.69
	CV			-0.20	-0.16	-0.12	-0.21	-0.12	-0.19
						33	35	52	54
$I_{0.50}$	M_C					-9.3	-7.6	-11.7	-9.8
	M_H					-8.1	-6.6	-9.7	-8.8
	M_K					-7.3	-7.7	-10.8	-8.3
	M_{BP}					-9.0	-6.7	-8.3	-6.9
	M_{PS}					-9.7	-6.3	-11.0	-8.4
	Mean					-8.68	-6.98	-10.30	-8.44
	SD					0.97	0.63	1.33	1.05
	CV					-0.11	-0.09	-0.13	-0.12
								50	52
$I_{0.25}$	M_C							-11.0	-10.2
	M_H							-10.6	-10.5
	M_K							-10.6	-8.1
	M_{BP}							-9.7	-8.9
	M_{PS}							-11.0	-9.9
	Mean							-10.58	-9.52
	SD							0.53	1.00
	CV							-0.05	-0.10

*BI= Before irrigation, *AI = after irrigation

Table 2: Temporal variation of leaf water potential (bar) under different irrigation regimes and water saving techniques before and after each irrigation during 2017-18

Treatment		Days after transplanting					
		26	28	41	43	57	59
		BI*	AI*	BI	AI	BI	AI
$I_{1.00}$	M_C	-10.3	-7.2	-4.1	-8.4	-10.4	-9.0
	M_H	-9.7	-6.3	-4.8	-8.2	-8.0	-7.8
	M_K	-8.3	-7.2	-5.2	-8.2	-11.2	-9.8
	M_{BP}	-8.6	-8.4	-5.2	-7.6	-11.0	-7.8
	M_{PS}	-8.7	-8.7	-4.3	-8.4	-9.0	-8.2
	Mean	-9.12	-7.57	-4.72	-8.16	-9.92	-8.52
	SD	0.85	0.97	0.49	0.33	1.38	0.87
	CV	-0.09	-0.13	-0.10	-0.04	-0.14	-0.10
		26	28	52	54		
$I_{0.75}$	M_C	-10.7	-7.6	-9.8	-9.4		
	M_H	-9.4	-9.0	-10.2	-8.4		
	M_K	-9.0	-4.3	-10.2	-9.0		
	M_{BP}	-8.4	-6.2	-10.0	-8.8		
	M_{PS}	-8.7	-8.7	-10.4	-9.8		
	Mean	-9.24	-7.15	-10.12	-9.08		
	SD	0.90	1.94	0.23	0.54		
	CV	-0.10	-0.27	-0.02	-0.06		
				41	43		
$I_{0.50}$	M_C			-4.55	-8.80		
	M_H			-4.83	-8.80		
	M_K			-4.55	-9.80		
	M_{BP}			-4.14	-8.00		
	M_{PS}			-4.83	-8.00		
	Mean			-4.58	-8.68		
	SD			0.28	0.74		
	CV			-0.06	-0.09		
				43	45		
$I_{0.25}$	M_C			-11.6	-9.0		
	M_H			-11.8	-7.9		
	M_K			-11.6	-8.2		
	M_{BP}			-11.4	-8.0		
	M_{PS}			-11.8	-8.2		
	Mean			-11.64	-8.24		
	SD			0.17	0.41		
	CV			-0.01	-0.05		

*BI= Before irrigation, *AI = after irrigation

Table 3: Leaf water potential (bar) under different irrigation regimes and water saving techniques at 41 DAT during 2017-18

Treatment	M_C	M_H	M_K	M_{BP}	M_{PS}	Mean	SD	CV
$I_{1.00}$	-4.14	-4.83	-5.17	-5.17	-4.28	-4.72	0.25	-0.05
$I_{0.75}$	-4.50	-5.20	-4.81	-4.80	-4.80	-4.82	0.32	-0.07
$I_{0.50}$	-4.40	-5.00	-4.51	-4.20	-4.82	-4.59	0.27	-0.06
$I_{0.25}$	-4.51	-5.10	-4.60	-4.40	-4.60	-4.64	0.24	-0.05
Mean	-4.39	-5.03	-4.77	-4.64	-4.63			
SD	0.17	0.16	0.29	0.43	0.25			
CV	-0.04	-0.03	-0.06	-0.09	-0.05			

During the 2[nd] year of experimentation, Ψ_L was higher after irrigation compared to that of before irrigation for treatments $I_{1.0}$ and $I_{0.50}$ during 41-43 DAT, 52-54 DAT, respectively, which was in stark contrast to that of first year. The average Ψ_L before irrigation under $I_{1.0}$ (41 DAT) was -4.72 bar, while that of after irrigation (43 DAT) was -8.16 bar. The average Ψ_L before irrigation under $I_{0.50}$ (52 DAT) was -4.58 bar, while that of after irrigation (54 DAT) was -8.68 bar (Table 2). It might be due the water vapour concentration in the internal (sub-stomatal/intercellular) cavity is lower than that corresponding to the relative humidity (RH) of 100% of the ambient air. This condition might have caused the direct stomatal water vapour intake, which is also known as 'reverse transpiration' as described by Vesala *et al.* (2017). The climatic condition during that stage was strongly supported to the above stated reason and at 41 DAT the atmosphere was completely cloudy (8 okta) and foggy (mild fog); the day temperature suddenly decreased by 5.0 to 6.0 °C and diurnal temperature range was recorded very low (T_{max} - 19. 0 °C and T_{min}. - 15.0 °C), relative humidity was very high (RH-I-91 % & RH-II- 84%) and higher amount of dew fall was observed (dew record is not available but it was observed on leaves of broccoli crop up to 1130 to 1200 h). In general, more or less similar weather condition was observed during 52 DAT. Because of these reasoning, the Ψ_L under such weather situation was showed non-stress condition in all the irrigation regimes and in all the WST (Table 3), whereas it showed low variation amongst WST under all the irrigation regimes.

The highest average Ψ_L under treatment $I_{1.0}$ was recorded under M_C and M_K (-8.3 bar) and the least was recorded under M_H (7.5). Similar effect observed by (Francesco *et al.,* 2015) for cucumber. Under $I_{0.75}$ treatment, M_C and M_{PS} recorded the highest Ψ_L of 9.4 bar, while M_{BP} recorded the lowest (-7.9 bar). M_K recorded the highest Ψ_L of -7.2 bar and M_{BP} recorded the lowest (-6.1 bar) under the treatment $I_{0.5}$. Under the treatment $I_{0.25}$, M_C recorded the highest Ψ_L (-10.3 bar) and M_{BP} recorded the lowest (-9.7 bar). In general effect of irrigation regimes on Ψ_L of broccoli was observed in agreement with reports for other broccoli cultivars (Saleh *et al.,* 2014; Isalam *et al.* 2011; O'toole *et al.,* 1980). Amongst the WST, under same irrigation regime (IR) there was not observed any pattern in variation percentage in all the irrigation regimes (Table 2). It may cause due the weather variability availed during the second year as above stated. It means that the Ψ_L is not depends only soil moisture condition, but also (more) dependent on the weather condition prevailed (i.e. microclimatic condition of the field) at the time of observation.

CONCLUSION

Leaf water potential (Ψ_L) value decreased with increase in root zone soil moisture status. Under the different irrigation regimes and water saving treatment combinations, at noon time, more $Ø_L$ value (26-40 %) was recorded before irrigation than two days after irrigation. In general, Ψ_L value increased with increasing water stress (at normal climatic condition) by 3 % ($I_{0.75}$), 34 % ($I_{0.50}$) and 51 % ($I_{0.25}$) compared to $I_{1.00}$. Negligible difference in Ψ_L was recorded (3 %) in between $I_{1.0}$ and $1_{0.75}$ irrigation regimes. Out of different criteria considered for fixing the irrigation schedule, Ψ_L observation is one of the microclimatic criteria but during the very high atmospheric moisture condition/microclimatic condition (relative humidity near to 100 %), crop may sustain soil moisture stress and not shows higher Ψ_L due to 'reverse transpiration' phenomenon. Based on this fundamental principal, spraying or sprinkling of water to crop canopy, it may be possible to mitigate the soil moisture stress of crop under drought situation in rainfed or dry land farming.

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