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VARIETAL CHANGES IN MORPHOLOGICAL TRAITS IN POTATO CULTIVARS SUBJECTED TO WATER STRESS

Subhash Kumar[1,4*], Pushpendra Kumar[2], Devendra Kumar[3] and Punjab Singh Malik[4*]

[1]Department of Botany, C.C.S. University, Meerut - 250 004 (U.P.), India.
[2]Department of Biotechnology, College of Agriculture, S.V.B.P.U.A.T., Meerut - 250 110 (U.P.), India.
[3]Central Potato Research Institute, Campus Modipuram, Meerut - 250 110 (U.P.), India.
[4]Department of Botany, Meerut College, Meerut - 250 001 (U.P.), India.

Abstract

Potato (*Solanum tuberosum* L.) with small fibrous root system is very sensitive to water stress. In present study, we analysed morphological traits (shoot height, root depth and leaf area) of four potato cultivars which were given water stress treatments at different growth stages. The shoot height was reduced significantly due to water stress and maximum reduction was found when stress given at tuber initiation stage. Among cultivars Kufri Pukhraj showed least reduction (about 30%) in shoot height whereas Kufri Lauvkar showed highest reduction (about 40%) in shoot height at tuber initiation stage. Root depth was reduced significantly by water stress treatments and highest impact was found due to water stress at tuber maturity stage. Leaf area was decreased due to adverse effect of water stress at all growth stages in all the cultivars. Reduction in leaf area was higher when plants were given stress at tuber initiation ($\mathbf{T_2}$). Among the studied cultivars, Kufri Pukhraj maintained highest leaf area at this stage.

Key words : Desiree, Kufri Chipsona-1, Kufri Pukhraj, Kufri Lauvkar, leaf area, potato, shoot height, water stress.

Introduction

Water deficit is the most limiting factor for crop production and is becoming increasingly severe problem in many regions of the world. Potato crop is very sensitive to water stress due to presence of shallow, small and fibrous root system. This shallow root system is wide ranging and upper soil layers have relatively higher root density (Brouwer *et al*., 1976; Bohnert *et al*., 1995). A large root system is thought to be one of the plants' drought adaptation mechanisms (Levitt, 1972). Another good indicator of drought adaptation is root to shoot ratio which was shown to increase in response to drought (Begg *et al*., 1976; Harris, 1978; Jefferies, 1992). The first process affected by water stress is elongation of stem, leaves and root (Hsiao, 1973).

Leaf expansion was closely related with soil moisture deficit. Bansal and Nagarajan (1987) showed a negative correlation between the reduction in stomatal conductance and reduction in leaf growth. It suggested that tolerance to drought may also be linked to stomatal control of leaf. Jefferies (1993) found that reduction in leaf size due to water stress lead to reduction in the amount of intercepted radiation and caused a decrease in tuber dry matter accumulation. Kumar and Minhas (1999) showed that leaf area declined more drastically at tuber initiation stage (35%) than of tuber development stage. In this study, we analysed effects of water stress on shoot heights, root depths and leaf area of four cultivars of potato.

Materials and Methods

The field experiments were conducted at Research Farm of CPRI Campus, Modipuram, Meerut (U.P.), India during *rabi* season of 2005-06 and 2006-07. The climate of this region is sub-tropical and semi arid with hot summers and cold winters. Forty eight plots were used in a split plot design for accommodating 4 treatments (as main plots) each having 4 varieties (as sub-plots) in 3 replications. A plot of 7.2 m^2 (3 × 2.4 m) size was used for each treatment in every replication during main crop in *rabi* season of the year 2005-06 and 2006-07. Field trials were conducted in split plots with three replicates

***Authors for correspondence** : E-mail : punjabmalik@gmail.com, subhashvikal2012@gmail.com

employing the 4 varieties (*i.e.* Kufri Chipsona-1, Kufri Pukhraj, Kufri Lauvkar and Desiree) having following treatments:

T_1 : Control (well watered plants)

T_2 : Water stress at- tuber initiation stage

T_3 : Water stress at -tuber enlargement stage

T_4 : Water stress at - tuber maturation stage

T_1 control (well watered) plots were irrigated at 6 DAP (days after planting), 27 DAP, 42 DAP, 63 DAP and 80 DAP during the year 2005-06 and at 8 DAP, 25 DAP, 44 DAP, 67 DAP and 83 DAP during the year 2006-07. The water stress was imposed by withholding water in **T_2**, **T_3** and **T_4** treatments at different growth stages according to table 1. The growth stage was identified and confirmed by uprooting the plants and by examining the stage of tuber development. Experimental plots were dehaulmed at 90 DAP and harvesting was done 10-15 days after of dehaulming so that tuber skin is matured.

Table 1 : Details of treatments in field experiments during year 2005-06 and 2006-07.

Treatment	Growth stage	Duration of water stress (days)	
		2005-06	**2006-07**
T_1	All growth stages	Nil	Nil
T_2	Tuber initiation	7(27 to 34 DAP*)	10(25 to 35 DAP)
T_3	Tuber enlargement	11(42 to 53 DAP)	13(44 to 57 DAP)
T_4	Tuber maturation	16(63 to 79 DAP)	15(67 to 82 DAP)

* DAP = Days after planting.

Following observations were recorded in well watered (control) and water stressed treatments on the peak stress day and crop was irrigated after completion of the observations.

Shoot height

Healthy and fully developed shoot was randomly chosen to measure the stem height per plant. Starting from lower most green part of the stem (near ground) to the youngest leaf was measured as stem height. Height was measured in centimeters by meter scale in the field itself.

Root depth

The root length was also measured in centimeters by meter scale. Root was considered to be started from where the plant was embedded in soil and tissues were white in colour. The root length was measured from white part to the last visible finest intact root end in the washed and cleaned sample.

Leaf area

Leaf area per plant was measured by portable leaf area meter Model LICOR LI-3000.

Data recorded during the course of study were subjected to statistical analysis by applying the technique of analysis of variance (ANOVA) prescribed for the split plot design (Gomez, 1984) to the significance of the overall difference among treatments by the "F' test. The critical difference at 5% level of probability was worked out to compare treatment means where "F" test was significant.

Results

Shoot height

Shoot height increased with the age of plants from tuber initiation stage to tuber maturation stage (table 2). Well watered control (**T_1**) plot maintained tallest plants at all growth stages in both the years. Water stress treatments **T_2** (water stress at tuber initiation stage), **T_3** (water stress at tuber enlargement stage) and **T_4** (water stress at tuber maturation stage) caused the significant reduction in shoot height in comparison to their respective control (**T_1**) in both the years. Under water stress conditions smallest plants were observed in **T_2** (22.7 and 23.6 cm during 2005-06 and 2006-07 respectively), whereas highest plants were observed in **T_4** (51.4 and 52.5 cm during 2005-06 and 2006-07 respectively). Maximum percent reduction in shoot height (35% and 33% in respective years) in comparison with respective well irrigated control was recorded when water stress was imposed at tuber initiation stage (**T_2**) whereas minimum percent reduction in shoot height (15% and 14% in respective years) in comparison with respective control was recorded when water stress was imposed at tuber maturation (**T_4**) stage.

In respect of different varieties (table 2) in **T_2** (water stress at tuber initiation stage), Kufri Chipsona-1 produced tallest plants (25.7 and 25.9 cm during 2005-06 and 2006-07, respectively), whereas cultivar Desiree produced smallest plants (20.3 and 21.5 cm during 2005-06 and 2006-07 respectively). As a result of water stress at this stage shoot height of cultivar Kufri Lauvkar was found most affected (37% and 38% reduction) while Kufri Pukhraj as least affected (31% and 27% reduction). In **T_3** (water stress at tuber enlargement stage) also Kufri Chipsona-1 recorded highest shoot height (59.3 and 60.1 cm during 2005-06 and 2006-07 respectively) whereas Desiree recorded lowest shoot height (42.1 and 42.2 cm during 2005-06 and 2006-07 respectively). Under water

Table 2 : Effect of water stress on shoot height (cm/plant) at various growth stages of potato cultivars.

Treatment*	2005-06			2006-07		
	Growth stage**			Growth stage		
	TI	TE	TM	TI	TE	TM
Kufri Chipsona-1						
T_1	38.8	62.4	64.1	37.5	63.1	65.1
T_2	25.7 (-34%)***	53.5	53.9	25.9 (-31%)	54.0	54.1
T_3	36.0	59.3 (-5%)	52.2	37.1	60.1 (-5%)	52.2
T_4	36.0	61.5	57.1 (-11%)	36.9	62.0	58.1 (-11%)
Mean	**33.4**	**59.2**	**56.8**	**34.4**	**59.8**	**57.4**
Kufri Pu--khraj						
T_1	32.9	60.3	61.4	34.1	61.4	62.5
T_2	22.8 (-31%)	45.0	52.3	24.8 (-27%)	44.8	53.3
T_3	33.0	42.0 (-30%)	45.2	33.9	42.4 (-31%)	45.7
T_4	32.9	61.0	52.9 (-14%)	34.0	62.0	53.8 (-14%)
Mean	**30.4**	**52.1**	**52.9**	**31.7**	**52.6**	**53.9**
Kufri Lauvkar						
T_1	34.8	58.2	59.6	36.1	58.6	60.1
T_2	22.0 (-37%)	41.6	45.5	22.4 (-38%)	42.1	46.2
T_3	34.8	49.5 (-15%)	50.0	36.0	50.5 (-14%)	51.2
T_4	34.8	58.4	50.3 (-16%)	35.8	59.4	52.0 (-14%)
Mean	**31.6**	**51.9**	**51.3**	**32.6**	**52.7**	**52.4**
Desiree						
T_1	32.4	46.6	56.5	33.0	47.6	57.3
T_2	20.3 (-37%)	34.1	37.0	21.5 (-35%)	34.1	37.1
T_3	33.0	42.1 (-10%)	47.1	32.9	42.2 (-11%)	47.3
T_4	32.8	47.0	45.1 (-20%)	33.0	48.3	46.2 (-19%)
Mean	**29.7**	**42.4**	**46.4**	**30.1**	**43.0**	**47.0**
Mean values of treatments						
T_1	34.8	56.9	60.4	35.2	57.7	61.3
T_2	22.7 (-35%)	43.6	47.2	23.6 (-33%)	43.8	47.7
T_3	34.2	48.3 (-15%)	50.9	35.0	48.8 (-15%)	49.1
T_4	34.4	57.0	51.4 (-15%)	34.9	57.9	52.5 (-14%)
CD at 5%						
Cultivar (C)	1.3	2.1	2.1	1.3	1.2	2.2
Treatment (T)	1.0	1.6	1.6	1.0	1.1	1.8
C × T	NS	3.3	3.2	NS	2.2	3.5

***Treatments:** $\mathbf{T_1}$ = -Control (well watered), $\mathbf{T_2}$ = water stress at tuber initiation, $\mathbf{T_3}$ = water stress at tuber enlargement and $\mathbf{T_4}$ = water stress at tuber maturation stage

****Growth stages:** TI = Tuber initiation, TE =Tuber enlargement and TM = Tuber maturation.

***** Figures in parenthesis are percent (%)** change in shoot height due to water stress treatment $\mathbf{T_2}$, $\mathbf{T_3}$ and $\mathbf{T_4}$ as compared with respective control.

stress conditions at tuber enlargement stage ($\mathbf{T_3}$) the shoot height of cultivar Kufri Pukhraj was found most affected by water stress (30% and 31% reduction) in comparison with respective control. Similarly in $\mathbf{T_4}$ (water stress at tuber maturation stage) also Kufri Chipsona-1 recorded tallest plants (57.1 and 58.1 cm during 2005-06 and 2006-07 respectively) and Desiree recorded shortest plants (45.1 and 46.2 cm during 2005-06 and 2006-07 respectively) under water stress. In $\mathbf{T_4}$ the cultivar Desiree was found most affected cultivar (20% and 19% reduction) whereas Kufri Chipsona-1 was found least affected cultivar (11% reduction in both the years) in comparison with respective well irrigated control. The interaction between cultivar and treatments was found significant except when water stress was imposed at tuber initiation stage.

Root depth

In general with the age of crop, root depth increased gradually from tuber initiation stage to tuber enlargement stage and then declined. Water stress treatments $\mathbf{T_2}$, $\mathbf{T_3}$ and $\mathbf{T_4}$ caused the significant reduction in root length in comparison with well watered control ($\mathbf{T_1}$) in both the years. Mean values of treatments showed that well watered control plants have highest root depth at all growth stages in both the years. Under water stress conditions maximum root depth (17.2 and 17.3 cm during 2005-06 and 2006-07 respectively) was recorded in T_3 while minimum root depth (9.9 and 10.1 cm during 2005-06 and 2006-07, respectively) was recorded in $\mathbf{T_4}$. The trend in reduction in root depth showed that water stress during tuber maturity ($\mathbf{T_4}$) caused maximum percent reduction (38% and 37% in respective years) in root depth whereas water stress at tuber initiation stage ($\mathbf{T_2}$) caused minimum percent reduction (13% and 14% in respective years) in comparison with respective control.

Varietal behavior showed that in $\mathbf{T_2}$, maximum root length (16.3 and 16.2 cm during 2005-06 and 2006-07 respectively) was observed in cultivar Kufri Chipsona-1 and minimum by Kufri Pukhraj (15.2 and 15.4 cm during 2005-06 and 2006-07, respectively). Water stress treatment T_2 caused maximum percent reduction (22% and 24% in respective years) in cultivar Kufri Chipsona-1 whereas minimum percent reduction (5% and 9% in respective years) in cultivar Kufri Lauvkar. In $\mathbf{T_3}$ maximum root length was recorded by cultivar Kufri Pukhraj (19.1 and 19.2 cm during 2005-06 and 2006-07 respectively) and minimum by Kufri Chipsona-1 (14.7 and 14.8 cm during 2005-06 and 2006-07, respectively) under water stress conditions. Water stress at this stage caused maximum percent reduction (30% and 31% in respective years) in root depth of cultivar Kufri Chipsona-1 and minimum percent reduction (7% in both the years) in root depth of cultivar Desiree. The cultivar Kufri Pukhraj showed considerable recovery in root depth at this stage. In $\mathbf{T_4}$ maximum root length was recorded by cultivar Kufri Lauvkar (11.3 cm and 11.3 cm during both the years) and minimum by Desiree (6.7 and 7.3 cm during 2005-06 and 2006-07, respectively). Water stress at tuber maturation stage ($\mathbf{T_4}$) caused maximum percent reduction (53% and 48% in respective years) in root depth of cultivar Desiree and minimum percent reduction (32% in both the years) in root depth of cultivar Kufri Pukhraj. Significant variation was also observed between cultivar and treatments during both the years.

Leaf area

Mean values of treatments shown in table 4, indicated that leaf area increased with advancement of age of crop plant in both the years. Water stress treatment at various growth stages brought about significant reduction in leaf area in comparison with well watered control ($\mathbf{T_1}$) in both the years. Under water stress conditions minimum leaf area per plant (237 and 241 cm^2 during 2005-06 and 2006-07, respectively) was recorded when water stress was imposed at tuber initiation stage ($\mathbf{T_2}$) whereas maximum leaf area per plant (2603 and 2610 cm^2 during 2005-06 and 2006-07 respectively) was recorded when water stress was imposed at tuber maturation stage ($\mathbf{T_4}$).

As a result of water stress, maximum percent reduction in leaf area (75% in both the years) in comparison with respective control was recorded when water stress was imposed at tuber initiation stage ($\mathbf{T_2}$) whereas minimum percent reduction (13% in both the years) in leaf area was recorded when water stress was imposed at tuber maturation stage ($\mathbf{T_4}$).

Table 4 showed that under water stress conditions at tuber initiation stage ($\mathbf{T_2}$), maximum leaf area per plant was recorded by cultivar Kufri Pukhraj (255 and 260 cm^2 during 2005-06 and 2006-07 respectively) whereas minimum by Kufri Chipsona-1 (197 and 200 cm^2 during 2005-06 and 2006-07, respectively). Maximum percent reduction in leaf area per plant due to water stress at tuber initiation stage ($\mathbf{T_2}$) was found in cultivar Kufri Pukhraj (81% in both the years) while minimum in cultivar Kufri Chipsona-1 (68% and 67% in respective years) in comparison with respective well irrigated control.

Under water stress conditions at tuber enlargement stage ($\mathbf{T_3}$), maximum leaf area was observed in cultivar Kufri Chipsona-1 (1982 and 1980 cm^2 during 2005-06 and 2006-07, respectively) and minimum in Desiree (1527 and 1528 cm^2 in 2005-06 and 2006-07, respectively). At this stage also leaf area of cultivar Kufri Pukhraj affected more (50% reduction in both the years) than other cultivars.

Under water stress conditions at tuber maturation stage ($\mathbf{T_4}$) maximum leaf area was recorded by cultivar Kufri Pukhraj (3024 and 3035 cm^2 during 2005-06 and 2006-07, respectively) and minimum by Kufri Lauvkar (1927 and 1930 cm^2 during 2005-06 and 2006-07 respectively). Maximum percent reduction in leaf area per plant due to water stress at tuber maturation stage ($\mathbf{T_4}$) was found in cultivar Kufri Chipsona-1 (22% in both the years) while minimum in cultivar Kufri Lauvkar (4% in both the years) in comparison with respective well irrigated control.

Significant variation was also observed between cultivar and treatments during both the years.

Discussion

It has long been recognized that morphological parameters indicate the influence of water stress on

Table 3 : Effect of water stress on root depth (cm/plant) at various growth stages of potato cultivars.

Treatment*	2005-06			2006-07		
	Growth stage**			Growth stage		
	TI	TE	TM	TI	TE	TM
Kufri Chipsona -1						
T_1	21.0	21.1	16.1	21.2	21.5	16.1
T_2	16.3 (-22%)***	16.6	15.3	16.2 (-24%)	16.7	15.4
T_3	21.7	14.7 (-30%)	14.5	21.8	14.8 (-31%)	14.5
T_4	21.5	20.9	10.5 (-35%)	21.2	21.0	10.6 (-34%)
Mean	**20.1**	**18.3**	**14.1**	**20.1**	**18.5**	**14.1**
Kufri Pu--khraj						
T_1	17.7	21.8	16.4	17.8	22.0	16.4
T_2	15.2 (-14%)	17.5	13.6	15.4 (-14%)	17.6	13.7
T_3	17.9	19.1 (-12%)	14.1	17.9	19.2 (-13%)	14.2
T_4	17.6	21.7	11.1 (-32%)	18.0	21.8	11.1 (-32%)
Mean	**17.1**	**20.1**	**13.8**	**17.3**	**20.2**	**13.8**
Kufri Lauvkar						
T_1	16.8	20.3	17.0	17.0	20.3	17.3
T_2	15.9 (-5%)	18.0	15.1	15.5 (-9%)	18.0	15.2
T_3	16.7	18.5 (-9%)	16.2	16.7	18.5 (-9%)	16.2
T_4	17.0	20.7	11.3 (-34%)	17.1	20.7	11.3 (-35%)
Mean	**16.6**	**19.3**	**14.9**	**16.9**	**19.4**	**15.0**
Desiree						
T_1	17.6	17.7	14.1	17.6	17.8	14.1
T_2	15.6 (-11%)	16.1	7.5	15.5 (-12%)	16.1	8.5
T_3	17.6	16.5 (-7%)	12.2	17.7	16.5 (-7%)	11.5
T_4	17.9	17.7	6.7 (-53%)	17.9	17.7	7.3 (-48%)
Mean	**17.2**	**17.0**	**10.1**	**17.4**	**17.0**	**10.3**
Mean values of treatments						
T_1	18.3	20.2	15.9	18.4	20.4	16.0
T_2	15.7 (-13%)	17.0	12.9	15.7 (-14%)	17.1	13.2
T_3	18.5	17.2 (-15%)	14.3	18.5	17.3 (-15%)	14.1
T_4	18.5	20.2	9.9 (-38%)	18.6	20.3	10.1 (-37%)
CD at 5%						
Cultivar(C)	0.8	0.9	0.5	0.6	0.9	0.5
Treatment (T)	0.6	0.7	0.5	0.4	0.7	0.5
C × T	1.3	1.4	0.9	0.9	1.4	1.0

***Treatments:** $\mathbf{T_1}$ = -Control (well watered), $\mathbf{T_2}$ = water stress at tuber initiation, $\mathbf{T_3}$ = water stress at tuber enlargement and $\mathbf{T_4}$ = water stress at tuber maturation stage.

****Growth stages:** TI = Tuber initiation, TE =Tuber enlargement and TM = Tuber maturation.

***** Figures in parenthesis are percent (%)** change in root depth due to water stress treatment $\mathbf{T_2}$, $\mathbf{T_3}$ and $\mathbf{T_4}$ as compared with respective control.

growth and development of potato crop (Kumar *et al.*, 2005).

The shoot height increased with the increase in age of crop (table 2). In some observations it was found to be reduced at maturity, it is due to herbaceous nature of potato shoot, as aerial shoot of potato is initially erect but later becomes partially procumbent (Artschwager,1918). Shoot growth is one of the best indices for evaluation of plant responses to environmental or abiotic stress (Nilsen and Orcutt, 1996). Water stress caused significant reduction in shoot height at all growth stages but it was found much prominent at tuber initiation stage ($\mathbf{T_2}$). At this stage shoot height was reduced up to 35% as a result of water stress (table 2) whereas about 15% reduction was observed when water stress was imposed at tuber enlargement stage ($\mathbf{T_3}$) and tuber maturation stage ($\mathbf{T_4}$).

Table 4 : Effect of water stress on leaf area (cm^2/plant) at various growth stages of potato cultivars.

Treatment*	2005-06			2006-07		
	Growth stage**			Growth stage		
	TI	TE	TM	TI	TE	TM
Kufri Chipsona -1						
T_1	608	3521	3614	612	3530	3624
T_2	197 (-68%)***	1973	2215	200 (-67%)	1975	2217
T_3	597	1982 (-44%)	2310	615	1980 (-44%)	2314
T_4	610	3530	2809 (-22%)	613	3529	2815 (-22%)
Mean	**503**	**2752**	**2737**	**510**	**2754**	**2743**
Kufri Pukhraj						
T_1	1372	3188	3315	1381	3200	3320
T_2	255 (-81%)	1572	1618	260 (-81%)	1574	1621
T_3	1361	1591 (-50%)	1723	1375	1600 (-50%)	1726
T_4	1382	3200	3024 (-9%)	1386	3210	3035 (-9%)
Mean	**1093**	**2388**	**2420**	**1101**	**2396**	**2426**
Kufri Lauvkar						
T_1	927	1826	2014	931	1872	2014
T_2	244 (-74%)	1469	1515	251 (-73%)	1472	1520
T_3	930	1550 (-15%)	1604	929	1553 (-17%)	1608
T_4	929	1830	1927 (-4%)	931	1831	1930 (-4%)
Mean	**757**	**1669**	**1765**	**760**	**1682**	**1768**
Desiree						
T_1	1176	2991	3148	1179	3000	3152
T_2	252 (-79%)	1477	1602	254 (-79%)	1478	1612
T_3	1170	1527 (-49%)	1715	1176	1528 (-49%)	1722
T_4	1178	2991	2652 (-16%)	1179	2997	2660 (-16%)
Mean	**944**	**2246**	**2279**	**947**	**2251**	**2287**
Mean values of treatments						
T_1	1021	2882	3023	1026	2900	3028
T_2	237 (-75%)	1623	1737	241 (-75%)	1625	1743
T_3	1015	1663 (-40%)	1838	1024	1665 (-40%)	1843
T_4	1025	2888	2603 (-13%)	1027	2982	2610 (-13%)
CD at 5%						
Cultivar(C)	42	81	67	37	113	109
Treatment (T)	31	64	56	29	89	89
C × T	63	128	113	58	178	177

***Treatments:** T_1 = -Control (well watered), T_2 =water stress at tuber initiation, T_3 = water stress at tuber enlargement and T_4 = water stress at tuber maturation stage

****Growth stages:** TI = Tuber initiation, TE =Tuber enlargement and TM = Tuber maturation

*** **Figures in parenthesis are percent (%)** change in leaf area per plant due to water stress treatment T_2, T_3 and T_4 as compared with respective control.

Hsiao (1973) also reported reduction in elongation of shoot as a result of water stress. Shoot growth and physiology of plants as a consequence of water stress is modified as a function of soil drying (Janardan and Bhojaraja, 1999). Shoot physiology can often be linked more closely to the changes in soil water status than of leaf water status (Turner, 1982). Plants sense stress of water in soil around the root and communicate this information to the shoot (Bates and Hall, 1981).The cell expansion is correlated with availability of water. Water stress can cause a decrease in cell expansion and cell division (Hsiao, 1973). For cells and tissues to grow, turgor pressure is required to stretch the cell walls at a rate determined by their cell extension properties (Janardan and Bhojaraja, 1999). Decrease in the cell enlargement rate results in reduced cell size in shoots. The consequence of reduced cell size to growth pattern of the whole plant is also dependent on timing of water limitation (Nilsen and Muller, 1981b).

All cultivars showed almost similar trend in shoot height under water stress conditions except Kufri Pukhraj which showed appreciable recovery in shoot height in $\mathbf{T_2}$ having water stress at tuber initiation stage. Shoot height of cultivar Kufri Pukhraj and Kufri Chipsona-1 was found least affected by water stress in comparison with other cultivars, indicating a better resilience to water stress.

The most frequently reported reason for higher sensitivity of potato to water stress is its shallower root system (Harris, 1978; Van Loon, 1981). Root traits are considered to be the most important for regulating water stress in potato (Harris, 1978; Gregory and Simmonds, 1992). The root system developed rapidly during early growth and achieved maximum development at tuber enlargement stage (table 3). Root depth was found relatively lesser as plants approached towards maturity. These findings are similar to with that of Pereira and Shock (2006) and Lesczynski and Tanner (1976), who also found decrease in root system at maturity. Water deficits can cause reduction in yielding properties (extensibility) of the root cell wall (Nenami and Boyer, 1990). In present study also water stress caused reduction in root depth at different growth stages (table 3). Tuber maturation stage of potato was found to be most affected stage to water stress in respect of root length whereas tuber initiation stage as least affected.

Kufri Chipsona-1, a moderate maturing cultivar was found with largest root system among all cultivars studied in control as well as under water stress conditions at tuber initiation (table 3). Root growth in potato is generally dependent on the maturity time period of cultivars. In early maturing cultivars, root growth stops earlier while it continues to grow longer and become greater in late maturing cultivars (Iwama *et al.,* 1981). Hence, the root depth is shallower in early cultivars than in late cultivars (Iwama, 1998). A large root system is also thought to be one of the drought adaptation mechanism of plants (Iwama *et al.*, 1999). Greater root production in cultivar Kufri Chipsona-1 enabled plants to extract more water from the soil profile, therefore avoiding water stress and maintaining water supply to the shoots. Weisz *et al.* (1994) also reported that drought sensitivity of potato in terms of transpiration appear to be due to an inability to extract as much total transpirable soil water as extracted by other crops due to potato's shallow rooting system.

Water deficits influence strongly the production of leaf by affecting the numbers, size and duration of leaves (Jefferies, 1989). In potatoes, as in many other crops (Boyer, 1970), the processes of leaf extension are highly sensitive to tissue water status (Gander and Tanner, 1976). Restriction of leaf growth as a result of decrease in cell expansion and cell division is a crucial trait for evaluation under water stress (Hsiao, 1973). Leaf area decreased in response to water stress at all three growth stages of potato plant (table 4). Drastic effect of water stress on leaf area was observed when water stress was imposed at tuber initiation stage ($\mathbf{T_2}$) because this stage showed 75% reduction in leaf area in comparison with well irrigated control. Moderate effect in reduction of leaf area (40%) was observed when water stress was imposed at tuber enlargement stage ($\mathbf{T_3}$) and slight effect (13%) when water stress was imposed at tuber maturation stage (table 4). The results of Kumar and Minhas (1999) supported our findings who showed that leaf area declined more drastically at tuber initiation stage than tuber development stage due to water stress. Rooting depth and rooting intensity determine the depth and extent to which the potato crop can extract water from soil (Van Loon, 1981). Comparatively lower root depth (15.7 cm) at tuber initiation stage (table 3) may be attributed to higher reduction in leaf area. Reduced leaf growth due to water stress adversely affects the amount of solar radiation captured by the plant canopy, resulting in reduced plant dry matter production and tuber yield (Wolfe *et al.*, 1983; Jefferies, 1989).

Among four cultivars studied, Kufri Chipsona-1 was found to be less affected by water stress in respect of leaf area reduction (68% and 67%) at tuber initiation stage (table 4), which is considered as the most critical stage for water stress in potato. Highest canopy of cultivar Kufri Chipsona-1 may be attributed by highest root depth (table 3) at tuber initiation stage. The cultivar Kufri Pukhraj showed highest reduction (81%)in leaf area under water stress at tuber initiation stage (table 4). Decreased leaf area is an early adaptive response to water deficit (Matthews *et al*., 1984). As leaf expansion mostly depends on cell expansion (Hsiao, 1973) and inhibition of cell expansion results in a slowing of leaf expansion during water stress. The smaller leaf area transpires less water; effectively conserving a limited water supply in the soil over a longer period (Burssens *et al*., 2000). Thus, reduction in leaf area can be considered a first line of defense against water stress.

Water stress caused reduction in shoot height, root depth and leaf area. Shoot height of cultivar Kufri Pukhraj and Kufri Chipsona-1 was found least affected by water stress indicating a better resilience to water stress. Greater root production in cultivar Kufri Chipsona-1 enabled plants to extract more water from the soil profile, therefore avoiding water stress and maintaining water supply to the shoots whereas, decreased leaf area is an early adaptive response to water deficit.

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