

Effects of Water Stress on Plant Canopy, Yield Attributes and Yield of Potato

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ABSTRACT

Four potato clones of the International Potato Center with one check variety (Asterix) were planted in the third week of November 2010 at the Horticultural Research Farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University to observe the effect of water stress on plant canopy growth, development and yield of potato. Plant heights, the number of leaves and leaf area of all the clones were significantly affected by water stress. Tolerant clones produced greater tuber dry matter under stressed conditions. The largest reduction in yield (greater than 50%) was found in the susceptible clones; the tolerant clones showed comparatively less yield reduction (less than 50%). The yield reduction caused by water stress was attributed mainly to the reduction in number of tubers per plant with small-sized tuber production. In addition, the percentage difference in dry matter in the tubers of susceptible clones was greater than in the tolerant clones due to the utilization of water from the tubers in the water stress treatment.

Keywords: growth index, leaf number, leaf area, yield and harvest index

INTRODUCTION

Potatoes are grown all over the world, even in many arid regions and are characterized as water stress sensitive (Deblonde and Ladent, 2001; Onder *et al.*, 2005; Hassanpanah, 2009) which affects their growth and yield. Plant growth and development is affected by a water deficit and is dependent on the degree of the stress and the stage of growth at which the stress occurs (Boyer, 1983). Water deficit is a common stress for potato production, which leads to tuber quality and

yield reduction (Hassanpanh *et al.*, 2008); thus, arranging adequate water is very important for improving potato quality and increasing quantity. Many scientists have reported that water deficit in potato *in vitro* and *in vivo* decreased plant height (Donnelly *et al.*, 2003; Tourneux *et al.*, 2003) leaf number (French, 1997), tuber number per plant, average tuber size (Hassanpanah, 2010) and yield per plant which in the end, severely lowers the tuber yield per plant (Schittenhelm *et al.*, 2006; Hassanpanah, 2010). The plant height of potato is very sensitive to moderate water stress

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conditions (Deblonde and Ladent, 2001). Tuber yield is also influenced by the redistribution of stored assimilates into economically important organs (Nagaranjan and Bansal, 1991). Water deficits affect adversely tuber number, tuber size and quality (Levy, 1986). Under normal and water deficit conditions, differential effects have been observed among potato clones for dry matter distribution and its translocation to the yield components (Deblonde *et al.*, 1999; Deblonde and Ladent, 2001). Several studies have shown that water deficits imposed during the vegetative and tuberization stages of potato reduced the number of tubers per plant, yield per plant and average tuber size and weight (Yuldashev and Carli, 2010). In general, the tuber number per plant and tuber weight per plant appeared to be the yield components that are affected by water deficit during tuberization stage, and can decrease the tuber yield by up to 69% subject to the period and strength of the stress period (Schafleitner *et al.*, 2007). From these previous studies, it was clear that water deficit has a major role in decreasing potato productivity and variations in plant characters. Therefore, the present investigation was undertaken with the following objectives: 1) to assess the effect of water stress on the plant canopy growth and development and 2) to determine the yield reduction rate of potato under water stress conditions.

MATERIALS AND METHODS

In 2009–2010, 20 potato clones and varieties were assessed against water stress for developing water stress tolerant potato varieties in Bangladesh (Mahmud, 2012). On the basis of stress attributes (drought susceptibility index, drought tolerance index, relative performance and yield reduction), three were selected as relatively tolerant (CIP 393371.58, CIP 396031.119 and CIP 96244.12), one was highly susceptible (CIP 391004.18) and Asterix (high yielding in

nonstress conditions but susceptible to water stress conditions) was selected as the latest released high yielding variety of potato (BARI Potato-25) in Bangladesh. During 2010–2011, the experiment was conducted in a vinyl house at the Horticultural Research Farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh following a completely randomized design with four replications consisting of these four potato clones and one variety. Apparently disease-free, uniform-sized (28–40 mm) and well sprouted tubers were selected as planting material. The tubers were planted in plastic pots of 30 cm diameter and 24 cm height. The potting mixture was prepared with sandy loam soil and well-rotted dried cow dung (5:1 ratio) and held at about 30% moisture at field capacity. The pots were fertilized uniformly with 1.65, 1.10, 1.25, 0.60 and 0.60 g urea, triple superphosphate, muriate of potash, gypsum and magnesium sulfate corresponding to 325:220:250:120:120 kg.ha⁻¹, respectively. Half of the urea and the remaining fertilizers were applied as a basal dose. The rest of the urea was applied at 30 days after planting (DAP). Seed tubers of each genotype were treated with carbendazim (0.1%) to control *Rhizoctonia* infection. One tuber was planted in each plastic pot on 17 November 2011. Potato plants emerged within 12 d. The plants were watered regularly to maintain optimum soil moisture conditions until the water stress treatment was imposed. Plant protection measures were taken against diseases, insects and weeds throughout the growing season. Plants of all the clones were subjected to a water stress and nonstress environment. In the nonstress and water stress environments, soil moisture was maintained at 80% and 50% of field capacity (by weight), respectively, from 30 DAP until harvest. The pots were weighed at one-day intervals to determine the water loss by evapotranspiration. Finally, the crop was harvested on 5 February 2012. During the crop period, different climatic data were collected as shown in Table 1.

Table 1 Climatic data for 2010–2011 crop season at Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh.

Month	Air temperature (°C)			Relative humidity (%)	Rainfall (mm)	Evaporation (mm)
	Max	Min	Ave			
November	26.60	22.43	24.52	80.47	8.44	80.41
December	19.90	15.45	17.68	89.05	0.00	60.42
January	15.20	11.58	13.39	90.80	0.00	40.28
February	23.85	19.08	21.47	89.89	8.43	57.77
March	31.16	26.09	28.62	76.70	29.84	93.80

Data collection

Data were collected on plant canopy parameters and on the yield and yield attributes. Plant canopy parameter data were collected on: 1) plant height at 30, 40, 60 and 80 DAP; 2) number of leaves per plant at 40, 60 and 80 DAP; 3) leaf area at 40, 60 and 80 DAP; and 4) numbers of aboveground shoots per plant at 60 DAP. Yield and yield attribute data were collected on: 1) tuber number per plant; 2) average tuber size; 3) tuber fresh yield per plant; 4) harvest index; and 5) tuber dry matter. Plant height was measured from the soil surface to the top of the canopy at every stage. The growth index (GI) was determined at 40, 60 and 80 DAP using the following formula:

$$GI (\%) = \frac{(\text{Shoot height after stress} - \text{Height at the beginning of the stress treatment}) \times 100}{(\text{Shoot height after treatment period under control} - \text{Height at the beginning of the treatment period})}$$

A single plant was considered as one replication. Four plants were harvested from each treatment at every growth stage. At each stage, the plants from both the control and the water deficit treatment were segmented into components of stem, leaf, petiole, root and tubers. The segmented parts were then oven dried at 70 °C to a constant weight and the dry weights were recorded. The total dry matter (aboveground biomass) or shoot dry weight was calculated by summing the dry weights of the stem, petiole, and leaf of the plants. Roots were washed thoroughly in tap water and blotted dry before weighing. The leaf area per plant was measured with an automatic area meter (Model AAM-8; Hayashi Denko; Tokyo, Japan). The fresh

weight of tubers was measured immediately after harvest. For dry weight estimation, tubers were sliced and kept in an oven at 70 °C within 24 hr of harvest and allowed to dry until attaining a constant weight.

Data analysis

The recorded data were analyzed using the statistical package CROPSTAT (version 7.2; Developed by the Biometrical Division, International Rice Research Institute, Manila, the Philippines) and appropriate standard errors of the means were calculated and significance was tested at the 0.01 level of probability.

RESULTS AND DISCUSSION

Changes in plant growth in response to a water deficit environment in the present study were recorded up to maturity (80 DAP) for each genotype. Changes in plant canopy characteristics and yield attributes due to stress in the potato clones are described below.

Plant height

The plant height of plants from the five potato clones were recorded at 30 DAP (prior to treatment) and after treatment imposed at 40, 60 and 80 DAP (after imposing treatment) both under the control and water deficit treatments. Significant differences were observed between the treatments. Prior to treatment, plant height among the clones ranged from 20.90 to 28.30 cm.

Plant height at 40 DAP (10 days after

water stress was imposed) ranged from 29.25 to 41.75 cm under the control environment and from 24.25 to 39.00 cm under the water deficit environment (Table 2). Under the control environment, CIP 396244.12 produced the tallest plants (41.75 cm) and the CIP 391004.18 produced the shortest (29.25 cm). On the other hand, under the water deficit treatment, CIP 396244.12 produced the tallest mean plant height (39.00 cm) and CIP 391004.18 produced the shortest (24.25 cm). The greatest reduction (24.16%) in plant height was observed in Asterix and the lowest (6.58%) was in CIP 396244.12. Therefore, the highest growth index (80%) was found in CIP 396244.12 and the lowest was in Asterix (4.0%). Consequently, CIP 396244.12 may be selected as a water stress tolerant potato genotype because it showed the highest growth index at an early growth stage. This result supported the findings of Shateirian *et al.* (2008). Selection of clones with a high growth index at an early stage of growth during stress may be a useful tool for screening clones for yield potential under stress conditions.

Dissimilarities in plant height measured at 60 DAP (30 days after the onset of treatment) under both conditions varied significantly among clones and environmental settings. The genotype CIP 396244.12 attained the greatest height (62.25 cm) in the nonstress environment which was similar to CIP 396031.119 (60.25 cm) and these heights were 46.70 and 72.14% higher than for the 40 DAP environment (Table 2). CIP 391004.18 produced the shortest plants at 60 DAP (41.25 cm) which was 41.02 % higher than that at 40 DAP. Significant variation was also found among the clones under water stress conditions. The tolerant genotype CIP 396244.12 produced taller plants under water stress condition (47.75 cm) which was 14.74 % higher than that at 40 DAP. The genotype CIP 391004.18 produced the shortest plant (29.50 cm) which was similar to that of CIP 393371.58 and these heights were 21.64 and 14.91% taller than under the water stress conditions,

respectively. Genotype CIP 396244.12 produced the highest growth index (49%) which indicated its supremacy under water stress conditions.

A substantial variation in plant height among the clones was also measured at harvest age (80 DAP) in both environments (Table 2). CIP 396244.12 reached the greatest height (66.30 cm) under the control conditions which was similar to CIP 396031.119. There was no statistical difference between genotype CIP 393371.58 and Asterix. Genotype CIP 391004.18 produced the shortest plants (44.00 cm). The plant height of all the clones differed significantly under the water deficit environment where CIP 396244.12 was the tallest (48.70 cm) and CIP 391004.18 was the shortest (31.10 cm).

Irrespective of genotype, the plant height changed with the progression of the growth stages in both environments. The plant height increased sharply from 40 to 60 DAP and afterward increased more gently up to 80 DAP under the control conditions. However, under the water stress conditions, it seemed that the reduction was least (13.44%) at 40 DAP, highest at 60 DAP (32.56%) and afterward it remained almost the same because the potato plants had attained their greatest height at 60 DAP and the crop growth rate was also high during that stage. At maturity, the potato plants translocated photosynthates to the tubers and utilized their maximum energy for tuber bulking which resulted in minimal growth of the plant. However, under the water deficit conditions, the plants suffered from water scarcity which hindered physiological processes like cell expansion, wall synthesis, protein synthesis, transpiration, photosynthesis, and other activities (Taiz and Zeiger, 2006); depression in photosynthesis causes a lower production of carbohydrates and so growth was arrested. Thus, under water stress conditions, smaller plants are produced than under normal conditions. Plant height in potato is very sensitive to moderate water stress conditions (Deblonde and Ladent, 2001). Similar findings in potato were also reported by Shaterian *et al.* (2008), Nagarajan and

Table 2 Plant height (cm) by potato genotype under nonstress and water stress conditions.

Genotype	Plant height. (cm) at 30 DAP (At beginning of stress)	Plant height at 40 DAP			Plant height at 60 DAP			Plant height at 80 DAP		
		Non stress	Water stress	GI (%)	Non stress	Water stress	GI (%)	Non stress	Water stress	GI (%)
CIP 391004.18	20.90 ± 0.49	29.25 ± 0.79	24.25 ± 0.49 (17.09%)	40	41.25 ± 0.79	29.50 ± 0.88 (28.48%)	42	44.00 ± 0.86	31.10 ± 0.60 (29.31%)	44
CIP 393371.58	22.30 ± 0.73	30.50 ± 0.89	28.50 ± 0.77 (6.55%)	76	53.50 ± 0.96	32.75 ± 0.65 (38.78%)	34	55.50 ± 0.91	34.70 ± 0.65 (37.47%)	37
CIP 396031.119	24.90 ± 0.74	35.00 ± 0.80	30.50 ± 0.57 (12.85%)	56	60.25 ± 0.65	38.00 ± 0.94 (36.92%)	37	64.00 ± 0.89	39.80 ± 0.86 (37.81%)	38
CIP 396244.12	28.30 ± 0.80	41.75 ± 0.71	39.00 ± 0.94 (6.58%)	80	62.25 ± 0.65	44.75 ± 0.56 (28.11%)	49	66.30 ± 0.55	48.70 ± 0.53 (26.54%)	54
Asterix	28.30 ± 0.56	37.25 ± 0.69	28.25 ± 0.77 (24.16%)	4	54.00 ± 0.68	37.50 ± 0.85 (30.55%)	36	56.80 ± 0.56	39.10 ± 0.91 (31.16%)	38
Least significant difference _{0.05}	-	3.54	-	-	3.66	-	-	4.10	-	-
Significance of <i>F</i> -test										
Genotype (G)	**	**	**	**	**	**	**	**	**	**
Environment(E)	NS	**	**	**	**	**	**	**	**	**
G × E	NS	**	**	**	**	**	**	**	**	**

DAP = Days after planting.

Each value represents mean ± SE (n = 4).

Values in parentheses represents the percentage reduction in plant height of water stress over non stress.

NS = Not significant.

** = Significant at 0.01 level of probability.

Bansal (1991) and Schittenhelm *et al.*, (2006). The present study agreed with these previous studies which indicated the adverse effects of water stress on plant height. Mean genotypic differences were also measured which ranged from 37.55 to 57.50 cm. The mean plant heights among the clones varied significantly. The genotype CIP 396244.12 produced the tallest plants (57.50 cm) followed by CIP 396031.119 (51.90 cm), Asterix (47.95 cm) and CIP 393371.58 (45.10 cm). Genotype CIP 391004.18 produced the shortest plants (37.55 cm).

Number of leaves per plant

A decrease in the viable leaf number and an increase in leaf fall were observed at three stages—40, 60 and 80 DAP—under the control and water deficit environments (Tables 3, 4 and 5). Initially (40 DAP) there were no variations in viable leaves, fallen leaves and total leaves per plant but at the later stages of plant growth (60 and 80 DAP) genotypic variations were found in the number of viable leaves, fallen leaves and in the total leaves per plant in both environments. These results agreed with the findings of Choudhury (2009) in French bean.

At the 40 DAP stage (Table 3), the mean total number of viable leaves varied from 40.00 to 54.50 under the control conditions and from 39.00 to 55.70 under the water stress conditions. The mean number of fallen leaves varied from 1.00 to 1.50 under the control conditions and from 1.30 to 1.50 under the water stress conditions. Genotype CIP 396031.119 produced the maximum number of total leaves per plant under both sets of conditions and the lowest number was found in CIP 396244.12 under both sets of conditions.

At 60 DAP (Table 4), the total number of viable leaves decreased under the water stress conditions compared to the control. However, there was an accelerated rate in the number of fallen leaves under the water stress conditions compared with the control environment. The mean number of viable leaves varied significantly among the clones under both sets of conditions (from 50.00 to 73.00 in the control environment and from 32.30 to 48.00 under the water deficit conditions). Genotype CIP 396031.119 produced the highest mean number of viable leaves per plant in both environments (73.00 in the control and 48.00 under the water deficit conditions), while the lowest number was reported for CIP 396244.12

Table 3 Leaf numbers (viable and fallen) at 40 days after planting for potato genotypes under nonstress and water stress conditions.

Genotype	Viable leaf		Fallen leaf		Total leaf	
	Non stress	Water stress	Non stress	Water stress	Non stress	Water stress
CIP 391004.18	46.30 ± 0.56	45.50 ± 0.85	1.00 ± 0.25	1.30 ± 0.35	47.30 ± 0.58	46.80 ± 0.91
CIP 393371.58	48.30 ± 0.35	48.50 ± 0.57	1.30 ± 0.35	1.30 ± 0.25	49.50 ± 0.38	49.80 ± 0.49
CIP 396031.119	54.50 ± 0.38	55.70 ± 0.81	1.50 ± 0.38	1.30 ± 0.35	56.00 ± 0.54	57.00± 0.73
CIP 396244.12	40.00 ± 0.59	39.30 ± 0.56	1.30 ± 0.35	1.30 ± 0.35	41.30 ± 0.65	40.50± 0.50
Asterix	42.30 ± 0.56	39.00 ± 0.54	1.50 ± 0.38	1.50 ± 0.32	43.80± 0.49	40.50± 0.57
Least significant difference _{0.05}	2.31		-		2.34	
Significance of <i>F</i> -test						
Genotype (G)	**		ns		**	
Environ. (E)	**		**		ns	
G × E	**		ns		ns	

Each value represents mean ± SE (n = 4).

Values in parentheses represent the percentage reduction in leaf number for water stress over control.

(50.00) in the control and for CIP 391004.18 (32.30) and Asterix (32.30) in the water deficit environment. However, a greater reduction in the percentage of viable leaves per plant was found in CIP 391004.18 (49.92%), followed by Asterix (45.98%). Genotype CIP 396244.12 showed the lowest reduction (27.40%) in viable leaves per plant.

In comparison with the control, genotype CIP 391004.18 under water stress conditions showed the highest acceleration (-50.90%) of shedding of leaves per plant and the next highest was in CIP 393371.58 (-50.00%) and Asterix (-45.45%), while the lowest was recorded in CIP 396244.12 (-22.2%) and the second lowest was in CIP 396031.119 (-19.04%). Consequently, water stress affected the total number of leaves per plant. The highest reduction in the total number of leaves was reported in CIP 391004.18 (42.14%) followed by Asterix (41.04%), and the lowest reduction was in CIP 396244.12 (17.19%).

At 80 DAP (Table 5), the total number of viable leaves decreased more under the water stress conditions compared with the control and the previous stages. The number of viable leaves at this stage varied significantly among the clones in both environments and ranged from 26.50 to 60.80 in the control and from 12.50 to 27.80 in the water deficit environment. Genotype CIP 396244.12 produced the highest number of viable leaves per plant in both environments with the minimum reduction (33.94%), while the maximum reduction (72.64%) was in CIP 391004.18. The trend of acceleration in this stage was quite different from the previous stage. Genotype CIP 396244.12 showed minimum acceleration (27.90 %) followed by CIP 393371.58 (-28.8%) and the maximum was in CIP 391004.18 (-130.76%). At maturity, water stress also affected the total number of leaves per plant. The highest reduction was in CIP 391004.18 (45.87%) and the lowest was recorded in CIP 396244.12 (27.52%). Leaf number and

Table 4 Leaf number (viable and fallen) at 60 days after planting in potato genotypes under nonstress and water stress conditions.

Genotype	Viable leaf		Fallen leaf		Total leaf	
	Non stress	Water stress	Non stress	Water stress	Non stress	Water stress
CIP 391004.18	64.50 ± 0.96	32.30 ± 0.35 (49.92)	5.50 ± 0.38	8.30 ± 0.35 (-50.90)	70.00 ± 0.97	40.50 ± 0.38 (42.14)
CIP 393371.58	62.80 ± 0.65	40.80 ± 0.61 (35.03)	4.00 ± 0.45	6.00 ± 0.45 (-50.00)	66.80 ± 0.72	48.80 ± 0.74 (26.94)
CIP 396031.119	73.00 ± 0.59	48.00 ± 0.64 (34.24)	6.30 ± 0.49	7.50 ± 0.38 (-19.04)	79.30 ± 0.49	56.50 ± 0.57 (28.75)
CIP 396244.12	50.00 ± 0.45	36.30 ± 0.72 (27.40)	4.50 ± 0.38	5.50 ± 0.45 (-22.2)	53.50 ± 0.38	44.30 ± 0.74 (17.19)
Asterix	59.80 ± 0.56	32.30 ± 0.69 (45.98)	5.50 ± 0.38	8.00 ± 0.49 (-45.45)	65.30 ± 0.56	38.50 ± 0.57 (41.04)
Least significant difference _{0.05}		2.65		1.06		2.68
Significance of <i>F</i> -test						
Genotype (G)		**		**		**
Environ. (E)		**		**		**
G × E		**		**		**

Each value represents mean ± SE (n = 4).

Values in parentheses represent the percentage reduction in leaf number For water stress over control.

leaf length are very sensitive to moderate water stress conditions (Deblonde and Ladent, 2001). Schittenhelm *et al.* (2006) reported that the stem type of potato plant exhibits less self-shading of leaves than the leaf types, and thus might be able to better use their aerial environment. Water stress causes premature leaf shedding. Older leaves and fallen leaves became affected first. Leaf shedding is detrimental to plant growth as it reduces the plant assimilation area. Such an abscission of leaves under stress appears to be due to the rearrangement of the hormonal metabolism (Krishnamoorthy, 1993).

Leaf area

The leaf area of the five potato clones was measured three times under nonstress (control) and water stress conditions at 20 d intervals after the onset of the water stress treatment and there was a significant difference among the treatments. After 10 d of water stress (at 40 DAP), the tolerant clones

exhibited the minimum (5.22%) reduction over the control environment, whereas the susceptible clones (CIP 391004.18 and Asterix) were reduced by 22.05 and 23.81%, respectively (Table 6). At this stage, the susceptible clones had a minimum leaf area under both environments but this changed in later stages. After 30 d of water stress (60 DAP stage) a higher leaf area reduction (66.62%) was observed in the susceptible genotype (Asterix) followed by CIP 391004.18 (58.93%), and CIP 393371.58 (57.12%). The tolerant genotype CIP 396244.12 (45.97%) showed the lowest reduction and CIP 393371.58 was the second lowest (47.12%) (Table 6). This genotype displayed the greatest leaf area under both environments. A high leaf area was observed at this stage in three clones (CIP 391004.18, CIP 396031.119, and Asterix) due to the greater leaf number per plant (Tables 3, 4 and 5). After 50 d of water stress (80 DAP stage) the highest leaf area reduction (63.71%) was observed in the susceptible genotype (Asterix)

Table 5 Leaf number (viable and fallen) at 80 days after planting in potato genotypes under nonstress and water stress conditions.

Genotype	Viable leaf		Fallen leaf		Total leaf	
	Non stress	Water stress	Non stress	Water stress	Non stress	Water stress
CIP 391004.18	46.80 ± 0.79	12.50 ± 0.50 (72.64)	7.80 ± 0.35	18.00 ± 0.45 (-130.76)	54.50 ± 0.77	29.50 ± 0.57 (45.87)
CIP 393371.58	50.50 ± 0.38	26.50 ± 0.57 (47.52)	8.00 ± 0.49	10.30 ± 0.49 (-28.75)	57.30 ± 0.49	37.80 ± 0.72 (34.03)
CIP 396031.119	60.80 ± 0.49	27.80 ± 0.49 (54.27)	10.00 ± 0.45	13.00 ± 0.45 (-30.00)	70.80 ± 0.35	40.80 ± 0.61 (42.37)
CIP 396244.12	38.30 ± 0.56	25.30 ± 0.35 (33.94)	4.30 ± 0.49	5.50 ± 0.38 (-27.90)	42.50 ± 0.66	30.80 ± 0.49 (27.52)
Asterix	26.50 ± 0.57	14.50 ± 0.50 (45.28)	8.50 ± 1.13	13.50 ± 0.38 (-58.82)	35.00 ± 1.44	23.00 ± 0.45 (34.28)
Least significant difference _{0.05}		1.80		2.55		2.82
Significance of <i>F</i> -test						
Genotype (G)		**		**		**
Environ. (E)		**		ns		**
G × E		**		**		**

Each value represents mean ± SE (n = 4).

Values in parentheses represent the percentage reduction in leaf number For water stress over control.

followed by CIP 391004.18 (62.91%). A lower reduction was observed in the genotype CIP 396244.12 (49.78%). At this stage, the genotype CIP 396031.119 displayed the greatest leaf area (3,022 cm²) under the control conditions, while the genotype CIP 396244.12 had the greatest leaf area in the water deficit environment. It was clear that water stress caused a reduction in the leaf area and that this varied with the duration of the water stress. Leaf fall under water stress conditions resulted in minimal growth due mainly to the leaf area reduction.

The results agreed with the findings of Nagarajan and Bansal (1991). Jefferies (1993) reported that a decrease in soil moisture resulted in a decrease in the relative leaf growth rate and

consequently in decreased leaf area. Ludlow and Muchow (1990) reported that reduced leaf growth and accelerated leaf senescence are common responses to water stress. This reduction in leaf area ultimately hampers photosynthesis and other physiological activities which reduce the ultimate plant productivity.

Number of aboveground shoots per plant

There was no significant difference between the environments among the number of aboveground shoots of the five potato clones at 60 DAP but there was variation from genotype to genotype (Table 7). The maximum mean shoot number was produced by CIP 391004.18 (6.65) which was similar to Asterix (6.35), CIP

Table 6 Leaf area (cm²) at different growth stages in potato genotypes under nonstress and water stress conditions.

Genotype	40 DAP		60 DAP		80 DAP	
	Non stress	Water stress	Non stress	Water stress	Non stress	Water stress
CIP 391004.18	1073.85 ± 13.01	837.01 ± 14.02 (22.05)	1692.48 ± 12.82	695.02 ± 16.52 (58.93)	1428.00 ± 18.81	529.51 ± 12.89 (62.91)
CIP 393371.58	1799.00 ± 13.82	1597.03 ± 13.61 (11.22)	3101.86 ± 15.23	1640.05 ± 10.71 (47.12)	2826.01 ± 18.21	1410.01 ± 15.20 (50.10)
CIP 396031.119	2035.02 ± 13.51	1575.02 ± 13.22 (22.60)	3245.54 ± 16.81	1712.00 ± 12.62 (47.25)	3022.02 ± 16.6	1445.00 ± 12.81 (52.18)
CIP 396244.12	2260.04 ± 14.14	2142.02 ± 15.86 (5.22)	3655.56 ± 14.41	1975.01 ± 11.69 (45.97)	2964.04 ± 18.21	1488.44 ± 16.82 (49.78)
Asterix	1731.23 ± 12.9	1318.87 ± 14.49 (23.81)	3001.80 ± 15.53	1002.00 ± 15.61 (66.62)	2202.01 ± 16.51	799.04 ± 13.00 (63.71)
Least significant difference _{0.05}	133.2		169.6		731.2	
Significance of <i>F</i> -test						
Genotype (G)	**		**		**	
Environ. (E)	**		**		**	
G × E	**		**		**	

DAP = Days after planting.

Each value represents mean ± SE (n = 4).

Values in parentheses represent the percentage reduction in leaf area for water stress over control.

396031.119 (6.40) and CIP 393371.58 (5.30). The minimum was found in CIP 396244.12 (4.30). The number of shoots per plant was determined by the size of the tuber (Wurr, 1974; Wurr *et al.*, 1997), soil conditions and soil moisture at planting (Amanullah *et al.*, 2010), although pathogens (black scurf; Horton *et al.*, 2007) and pests may have an effect. It may also be influenced by the length and conditions of the pre sprouting period (Allen, 1978). Haverkort *et al.* (1990) reported that the later dry period does not affect the number of stolons and tubers.

Tuber number per plant

A reduction in the tuber number per plant was observed under the water stress conditions compared with the control. For both the normal and water deficit environments irrespective of clone, the number of tubers varied significantly (Table 8). In the control environment, the highest mean number of tubers was recorded in genotype CIP 396031.119 (14.37), which was similar to CIP 396244.12 (13.87) and CIP 393371.58 (12.87). The lowest was in Asterix (11.25) and in CIP 391004.18 (11.25). In the water stress situation, the tuber number per plant also varied significantly. Genotype CIP 396031.119 exhibited the maximum mean number of tubers per plant

(13.25) with the minimum reduction (7.79 %). There was no significant difference among clones CIP 393371.58 (10.87), CIP 396244.12 (10.37) and Asterix (9.63) in the mean number of tubers per plant with a reduction of 15.54, 25.23 and 14.4%, respectively, compared with the control. Genotype CIP 391004.18 exhibited the lowest mean tuber number (8.50) with the highest reduction (24.44%) compared with the control. Similar results were reported by Deblonde and Ladent (2001) and Schafleitner *et al.* (2007). Potato plants are especially sensitive to water stress during the stolonization and tuberization stages (Steckel and Gray, 1979). The main cause of tuber reduction under water stress conditions was the reduction in the number of stolons per plant, and not through a reduction of the number of tubers per stolon (Haverkort *et al.*, 1990). Once stolons were initiated, they yielded tubers regardless of a subsequent water stress period.

Average tuber size

The average tuber size varied significantly among the clones and environments and decreased when potatoes were grown under the water stress conditions (Table 8). Irrespective of the clone, Asterix produced the maximum average tuber size (32.97 g). Clones CIP 391004.18, CIP 396244.12

Table 7 Number of above ground shoots per plant in potato genotypes under nonstress and water stress conditions.

Genotype	At 60 DAP		
	Non stress	Water stress	Mean
CIP 391004.18	6.80 ± 0.61	6.50 ± 0.57	6.65 ± 0.40
CIP 393371.58	5.30 ± 0.35	5.30 ± 0.72	5.30 ± 0.42
CIP 396031.119	6.50 ± 0.77	6.30 ± 0.35	6.40 ± 0.45
CIP 396244.12	4.30 ± 0.35	4.30 ± 0.43	4.30 ± 0.24
Asterix	6.30 ± 0.61	6.40 ± 0.36	6.35 ± 0.36
Least significant difference _{0.05}	-		1.4
Significance of <i>F</i> -test			
Genotype (G)	**		
Environ. (E)	ns		
G × E	ns		

and CIP 393371.58 produced 26.96, 25.36, and 24.15 g tubers, respectively (no significant difference). Genotype CIP 396031.119 produced the minimum average tuber size (21.81 g). All the clones exhibited lower individual tuber weight under the water stress conditions. The maximum weight was recorded for CIP 396244.12 (17.61 g) which was similar to CIP 393371.58 (14.98 g) and Asterix (15.03 g) with a reduction of 30.55, 37.95 and 54.51%, respectively, in weight compared with the nonstress conditions. Genotype CIP 391004.18 produced the minimum average tuber size (11.73 g) with a 56.47% weight reduction.

Tuber fresh weight per plant

The fresh tuber yield per plant varied significantly among the clones according to the environment (Figure 1). Under normal conditions, Asterix yielded the highest (368.97 g) followed by CIP 396244.12 (349.11 g). Genotype CIP 391004.18 yielded the lowest (301.75 g per plant) which was similar to CIP 393371.58 (309.62 g).

However, in the water stress environment, CIP 396244.12 yielded the highest (182.37 g) followed by CIP 393371.58 (160.11 g) and CIP 396031.119 (157.40 g). There was no significant difference between CIP 393371.58 and CIP 396031.119. Genotype CIP 391004.18 produced the lowest (99.40 g). The lowest (47.76%) fresh yield reduction per plant compared to the corresponding control was recorded for CIP 396244.12, followed by CIP 393371.58 (48.29%) and CIP 396031.119 (49.75%). The highest reduction was recorded in genotype CIP 391004.18 (67.06%).

Harvest index

Water stress reduced the harvest index (HI) but the degree of reduction varied with the environment (Figure 2). The highest HI was observed in Asterix (0.85) which was similar to CIP 391004.18 (0.85) and the two lowest values were in CIP 393371.58 (0.81) and CIP 396031.119 (0.82) under the control conditions. The highest HI was observed in Asterix (0.86) followed by

Table 8 Tuber number per plant and average tuber size under nonstress and water stress conditions.

Genotype	Tuber number per plant		Average tuber size (g)	
	Non stress	Water stress	Non stress	Water stress
CIP 391004.18	11.25 ± 0.33	8.50 ± 0.73 (24.44%)	26.95 ± 1.17	11.73 ± 2.10 (56.47 %)
CIP 393371.58	12.87 ± 0.83	10.87 ± 0.50 (15.54)	24.15 ± 2.52	14.98 ± 1.46 (37.97 %)
CIP 396031.119	14.37 ± 0.57	13.25 ± 0.60 (7.79%)	21.80 ± 2.44	11.89 ± 2.27 (45.45 %)
CIP 396244.12	13.87 ± 0.87	10.37 ± 0.98 (25.23 %)	25.36 ± 3.77	17.61 ± 3.36 (30.55%)
Asterix	11.25 ± 0.47	9.63 ± 0.67 (14.4 %)	32.97 ± 4.93	15.03 ± 4.23 (54.41%)
Least significant difference _{0.05}		1.69		2.83
Significance of <i>F</i> -test				
Genotype (G)	**	**	**	**
Environ. (E)	**	**	**	**
G × E	**	**	**	**

Each value represents mean ± SE (n = 4).

Values within parentheses represent percentage reduction in number of tubers per plant and individual tuber weight. For water stress over nonstress conditions.

CIP 393371.58 (0.85), CIP 396244.12 (0.85) and CIP 391004.18 (0.84) and the lowest was in CIP 396031.119 (0.82) under the water stress conditions. Under the water stress conditions, increased HI was observed in CIP 393371.58, CIP 396031.119, CIP 396244.12, and Asterix, and a decreased HI was observed in CIP 391004.18.

Tuber dry matter

The tuber dry matter increased under the water stress conditions compared with the control (Figure 3) which varied among the clones in both environments. The highest percentage of dry matter was recorded in CIP 396244.12 (21.10%) under the control conditions. Under the water

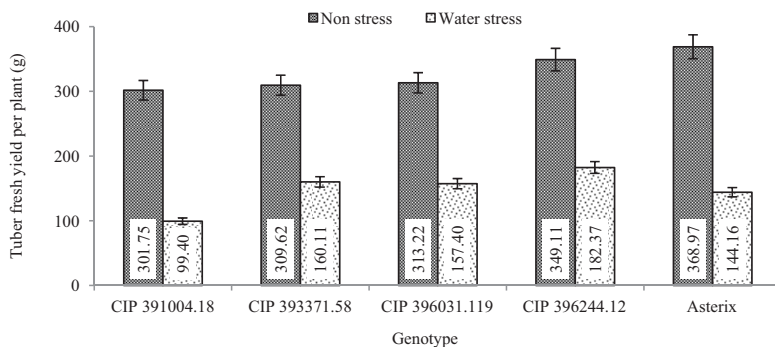


Figure 1 Tuber fresh weight per plant of five potato genotypes under nonstress and water stress conditions. Error bars represents mean $\pm$ SE of the genotypes at the same level of treatment.

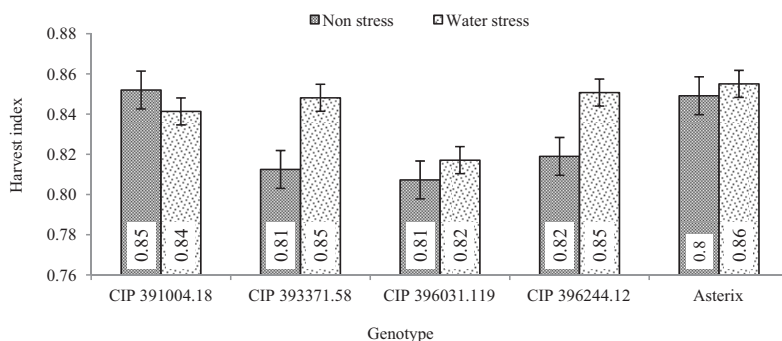


Figure 2 Harvest indexes of five potato genotypes under nonstress and water stress conditions. Error bars represents mean $\pm$ SE of the genotypes at the same level of treatment.

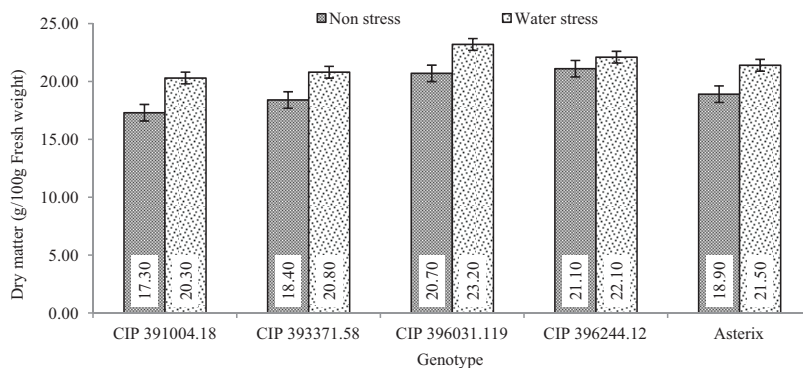


Figure 3 Tuber dry matter of five potato genotypes under nonstress and water stress conditions. Error bars represents mean $\pm$ SE of the genotypes at the same level of treatment.

stress conditions, the highest tuber dry matter percentage was observed in CIP 396031.119 (23.20%). Genotype CIP 391004.18 produced the lowest in both environments (17.30 and 20.30%, respectively). Comparing the control and water stress situations, the highest difference in tuber dry matter (-3.00) was found in CIP 391004.18 whereas the least difference was in CIP 396244.12 (-1.00) followed by CIP 393371.58 (-2.40), CIP 396031.119 (-2.50) and Asterix (-2.60). The main reason for the increased tuber dry matter in the water stress environment may have been due to the utilization of water in the tuber for its physiological activities. In the present study, it was observed that the shrinkage of tubers was more pronounced in the water stress environment than in the control, which indicated the loss of water from tubers due to water stress.

CONCLUSION

Water stress had an adverse effect on plant canopy development and reduced tuber yield. The highest growth index (GI) was found in tolerant clones and the lowest was in susceptible clones. Thus, GI at an early stage of growth may be a useful tool for screening potato clones for water stress tolerance. Water stress created variation in the number of viable leaves, the number of fallen leaves and the leaf area per plant. An increase in the stress period resulted in greater leaf fall. The water stress tolerant clones produced the lowest number of fallen leaves with minimum leaf area reduction. Water stress also lowered the tuber number per plant in the tolerant potato clones but produced larger tubers. The largest reduction in yield (greater than 60%) was in the susceptible clones; the tolerant clones showed comparatively less yield reduction (less than 50%). Less difference in the percentage tuber dry matter was found in the water tolerant potato clones; this parameter is a good indicator for water stress tolerance in potato. According to the findings of the present study, clones CIP 396244.12 and CIP

393371.58 have a high degree of tolerance to water stress.

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