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EFFECT OF WATER STRESS AND PLANTING SYSTEM ON GROWTH, YIELD AND QUALITY OF SWEET POTATO

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ABSTRACT

Sweet potato (*Ipomoea batatas* (L.) Lam) is an important crop due to its cultivation as staple food for millions of small farmers as well as for poor people in Latin America, Asia, Africa and in many other parts of the world. This tuberous crop is susceptible to drought stress especially during the period of crop establishment as well as vine development and tuber initiation. Yield of the crop vary widely among farmers due to improper planting systems. This current study was aimed to investigate the influence of various irrigation intervals and planting systems on vegetative growth, storage root yield and quality of sweet potato (*Ipomoea batatas* (L.) Lam) cv. 'White star' under field conditions. Three irrigation intervals (7, 14 and 21 days for summer crop, and 14, 28 and 42 days for winter crop) and two planting systems (bed planting and ridge planting) were adopted in this study. Vine length, number of branches and average leaf area significantly reduced as the irrigation interval was increased. Ridge planting produced longer vines with greater leaf area in winter crop as compared to bed planting. Yield parameters (storage root length, storage root diameter, number and fresh weight of marketable roots per plant) were directly linked with vegetative growth especially in summer crop. Under water stress conditions, as vegetative growth decreased storage root yield was also reduced. However, yield attributes were not affected by the planting systems. Vitamin C content decreased with water stress, whereas total soluble solids (TSS) and leaf proline content significantly increased with water stress in summer crop. Ridge planting also resulted in increased leaf proline content in summer crop. It is concluded that for attaining good vegetative growth and storage root yield, sweet potato should be irrigated at an interval of 7 days during summer and 14 days during winter crop and planted on ridges.

Key words: irrigation regimes, *Ipomoea batatas*, planting systems, storage root yield, vegetative growth

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam) is a well-known storage root crop of the world. It belongs to family *Convolvulaceae*. The genus Ipomoea comprises of 500–600 species [Austin and Huamán 1996]. The origin of sweet potato is Central or Southern America and it has been grown for more than 5000 years [Rossel et al. 2001].

Millions of farmers are cultivating sweet potato as their staple food crop in Africa, Asia, and Latin America [Scott and Maldonado 1997]. Major consumers of sweet potato are the populations of developing countries which use over 98% of the world sweet potato production [Scott and Maldonado 1997, Loebenstein et al. 2009]. It can also be cultivated on less-fertile lands [Ray and Ravi 2005].

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Worldwide the production of sweet potato is 103.10 million tons which is produced on approximately 8.18 million ha of land with average yield of 12.60 tons ha^{-1}. Of this 75% is from China with an annual production of 70.74 million tons. In Pakistan, the total production of sweet potato is 13.07 thousand tons which is produced on an area of 1.47 thousand ha with average yield of 8.87 tons ha^{-1} [FAO 2015].

Sweet potato tubers as well as leaves are good source of nutrients. Raw storage root comprises of starch 20.12 g 100 g^{-1}, fiber 3 g 100 g^{-1}, protein 1.57 g 100 g^{-1}, and many essential minerals such as calcium, iron, magnesium, potassium, sodium, and phosphorus [USDA 2010]. It also provides a good amount of vitamin C (2.40 mg 100 g^{-1}) and ß-carotene (8.512 mg 100 g^{-1}), a precursor of vitamin A. The young leaves of sweet potato are a rich source of minerals and proteins and used as a vegetable in Africa as well as in East Asia [Mwanri et al. 2011]. Sweet potato has a perennial growth habit, however, it is commonly cultivated as an annual [Onwueme and Charles 1994, Norman et al. 1995]. The plant has a long stem ranging 0.5 m to 4 m which grows along the soil surface. Leaves are broad and arranged on the stem in alternate manner. Sweet potato has two types of roots: fibrous roots, which performs the function of water and nutrients absorption, while tuberous roots or storage roots, are used as storage organs where photosynthetic products, mainly starches and sugars, are stored. On average a sweet potato plant can produce 4–10 storage roots [Firon et al. 2009].

Appropriate planting systems are an imperative factor which markedly affects the growth and yield. Generally on shallow and compact soils, tuber and root crops do not give better production. The basic purposes of seedbed preparation in tubers crops are to (i) increase rooting depth, (ii) improve soil-water management and (iii) improve infiltration [FAO 2000]. Planting orientation and height of the ridge greatly affected the vine growth and yield of sweet potato.

In Pakistan, Sweet potato is an important vegetable which can be successfully grown with less fertilizer and water needs. It is a high yielding crop which requires less input and gives high profits to farmers. However, no attention has been given towards irrigation requirement and proper planting system of sweet potatoes. Therefore, this study was conducted in order to define the optimum water usage and proper planting pattern for attainment of vine growth as well as storage root yield of sweet potato in a semi-arid area of Pakistan.

MATERIALS AND METHODS

The current study was conducted at the experimental field, Department of Horticulture, Bahauddin Zakariya University, Multan, Pakistan (latitude 30.2570°N, longitude 71.5150°E, and 130.77 m altitude). The study was carried out during 2013–2015. In each year, two crops were raised one in winter season and other in summer season. During both years, winter crop was planted on 21st September and summer crop on 25th March. 'White star' is a high yielding cultivar of sweet potato which has a white to light tan skin with white flesh. Stem cuttings of sweet potato cultivar 'White star' from terminal portion of vines with a length of 30–35 cm were prepared for planting. Soil was analyzed for physico-chemical characteristics which are given in Table 1. At the time of land preparation, recommended fertilizer dosage i.e.

Table 1. Physico-chemical characteristics of soil before sowing the crop

Characteristics	Unit	Value
Texture	–	Sandy clay loam
pH	–	8.30
EC	dS m^{-1}	0.60
Organic matter	%	0.60
Available Phosphorous	ppm	7
Available potassium (ppm)	ppm	174

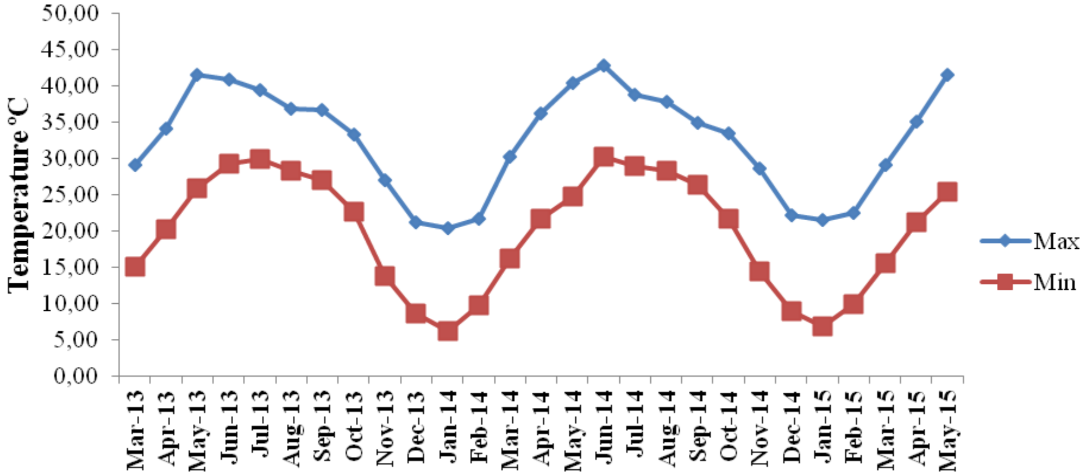

Fig. 1. Monthly maximum and minimum temperature at Multan during March 2013 to May 2015 (source: Pakistan Meteorological Department)

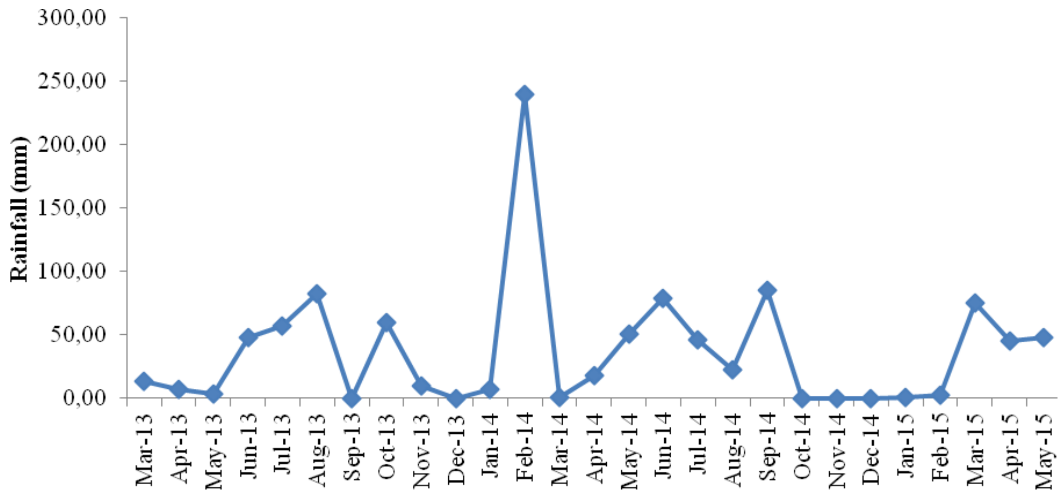

Fig. 2. Rainfall occurring at Multan during March 2013 to May 2015 (source: Pakistan Meteorological Department)

N = 50 kg ha^{-1}; P = 25 kg ha^{-1}; K = 50 kg ha^{-1} was applied. Experiments were laid out according to Randomized complete block design (RCBD) with split plot arrangement. Irrigation interval was kept as main plot factor while planting system was randomized in subplots. There were four replications of each experimental plot.

Irrigation interval. There were three irrigation intervals for each crop i.e. for summer crop 7, 14 and 21 days and for winter crop 14, 28 and 42 days.

Planting systems. Two planting systems were evaluated in the current study. i.e. bed planting system and ridge planting system. In case of bed planting system, raised beds were prepared 1 m wide and 3 m long and each side of the bed was used for planting of stem cuttings. Plant to plant distance (P-P) was maintained at 30 cm. In ridge planting system, ridges were made 0.5 m apart and 3 m long. One side of ridge was used for planting of cuttings with plant to plant distance = 30 cm. There were 30 plants in each plot and number of plants was equal in both planting systems.

Weather conditions. During summer season, rainfall happened more frequently during the crop period at various intervals and maximum monthly temperature was also higher. In winter season, monthly maximum and minimum temperatures remained lower as compared to summer (figs 1 and 2).

Parameters studied. Data were recorded on the following parameters of both the crops in each year.

Vine growth. The data of vine growth were recorded after five months of planting the cuttings. In each experimental unit, five plants were randomly selected for measuring physical parameters. Measuring tape was used to determine vine length. Number of branches per plant was counted. For the determination of leaf area, a digital plant canopy analyzer (Model LI-COR 3100, Lincoln, Nebraska, USA) was used.

Storage root growth and yield. After six months of planting, Storage roots were removed from the soil, sorted and graded according to different sizes. Marketable sized storage roots (>2.5 cm in diameter) were selected for collecting various yield related parameters. Ten storage roots of marketable size were selected randomly from each plot and storage root length was determined. Vernier Caliper was used for measuring storage root diameter. Number of marketable storage roots per plant was determined from five randomly selected plants. These were weighed for determining fresh weight of marketable storage roots per plant.

Vitamin C and total soluble solids (TSS). Storage roots were thoroughly washed and dried at room temperature. Ten storage roots of marketable size were selected from each experimental unit. These were peeled and their juice was extracted with electrical juicer. Vitamin C content of root's juice was determined through Indophenol's titration process as developed by Ruck [1963]. Total soluble solids (TSS) was determined through digital refractometer (PAL-1, Atago, Japan). Juice sample (1 or 2 drops) was placed on the refractometer prism plate with the help of a dropper and reading showed on LCD was noted in °Brix.

Leaf proline content. Leaf proline content was measured from fresh leaves taken from each experimental unit at same developmental stage. For proline determination, the protocol of Bates et al. [1973] was followed. Samples were analyzed with the help of UV-VIS spectrophotometer (UV-3000). Toluene was kept as blank.

Proline content in plant material was calculated by comparing with standard curve of proline and following formula was used to compute the values in fresh plant material.

$$\text{Proline } (\mu\text{moles g}^{-1}\text{ FW}) = \frac{\mu\text{g proline per ml} \times 4 / 115.5\ \mu\text{g}\ \mu\text{mole}^{-1}}{\text{gram sample} / 5}$$

Statistical analysis. Statistical software Statistix 8.1 (Tallahassee Florida, USA) was used for the statistical analysis of collected data. To compare the means, Least Significant Difference (LSD) test was applied at 5% level of probability [Gomez and Gomez 1984].

RESULTS AND DISCUSSION

Analysis of variance indicated that no statistically significant differences were observed between years and their interactions with the other two factors, therefore those are not presented and discussed.

Vine growth parameters

During summer crop, the vine length, number of branches and average leaf area were significantly affected by different irrigation intervals. Planting system alone could not affect these vine parameters. Instead, irrigation intervals in interaction with planting systems significantly affected the vine length, number of branches and leaf area. The maximum vine length (274 cm) was recorded in 7 days irrigation interval, followed by 14 days and 21 days irrigation interval. Regarding interaction, the maximum vine length (297 cm) was measured in ridge planting with 14 days irrigation interval, followed by bed planting system with 7 days irrigation interval and ridge planting system with 7 days irrigation interval (tab. 2).

The maximum number of branches per plant (10.4) was noted in 7 days irrigation interval, which considerably varied from the other two irrigation intervals. Concerning the combined effect of the two factors, the maximum numbers of branches per plant (10.5) was noted in plants on ridges which were irrigated after 7 days interval, followed by plants on beds which were irrigated after 7 days interval, plants on ridges which were irrigated after 14 days interval and plants on beds which were irrigated after 14 days interval. These four treatment combinations were statistically at par with each other. Bed planting with 21 days irrigation interval exhibited the lowest numbers of branches (6.3), per plant, followed by ridge planting with 21 days interval. These two treatment combinations were also at par with one another (tab. 2).

Average leaf area was significantly affected by the different irrigation intervals. The maximum leaf area (45.80 cm^2) was measured in 7 days irrigation interval, followed by 14 days and significantly decreased at 21 days irrigation interval. Regarding interaction between the two factors, the maximum leaf area (51.24 cm^2) was observed in ridge planting with 14 days irrigation interval, followed by bed planting with 7 days irrigation interval, and ridge planting with 7 days irrigation interval (tab. 2).

In winter crop, different irrigation intervals and planting systems had a profound effect on vine length. The maximum vine length (128.88 cm) was recorded in plants irrigated after every 14 days interval, which considerably differed from other two irrigation intervals.

Concerning the planting systems, longer vines were produced in plants on ridges than plants on beds. Irrigation interval markedly affected the numbers of branches per plant. The maximum numbers of branches (11.25) was counted in plants irrigated after every 14 days interval. The minimum number of

Table 2. Effect of different irrigation intervals and planting systems on vine growth of sweet potato

Irrigation interval (days)	Summer crop			Irrigation interval (days)	Winter crop		
	Bed	Ridge	Mean		Bed	Ridge	Mean
			Vine length (cm)				
7	280 a	269 ab	**274 a**	14	115.25 a	142.50 a	**128.88 a**
14	173 c	297 a	**235 b**	28	96.75 a	101.50 a	**99.13 b**
21	213 bc	106 d	**160 c**	42	91.00 a	127.50 a	**109.25 b**
Mean	**222 a**	**224 a**		Mean	**101.00 b**	**123.83 a**	
			Number of branches/plant				
7	10.3 a	10.5 a	**10.4 a**	14	10.15 ab	12.35 a	**11.25 a**
14	9.3 ab	9.8 a	**9.5 b**	28	10.95 ab	7.98 bc	**9.46 b**
21	6.3 c	7.0 bc	**6.6 c**	42	6.93 c	11.05 a	**8.99 b**
Mean	**8.6 a**	**9.1 a**		Mean	**9.34 a**	**10.46 a**	
			Average leaf area (cm^2)				
7	49.41 ab	42.20 abc	**45.80 a**	14	23.57 a	26.16 a	**24.86 a**
14	37.00 cd	51.24 a	**44.12 a**	28	20.11 a	21.84 a	**20.98 b**
21	40.87 bc	27.71 d	**34.29 b**	42	20.05 a	22.12 a	**21.08 b**
Mean	**42.42 a**	**40.38 a**		Mean	**21.24 b**	**23.37 a**	

Means sharing similar letter(s) in a group are statistically non-significant at $p < 0.05$

branches per plant was recorded at 42 days irrigation interval, followed by 28 days irrigation interval. These two irrigation treatments also stood statistically at par. Regarding the interaction between the two factors, maximum numbers of branches (12.35) was recorded in ridge planting irrigated after every 14 days interval, followed by ridge planting with 42 days interval, bed planting with 28 days and bed planting with 14 days irrigation interval (tab. 2).

The maximum average leaf area (24.86 cm^2) was exhibited by the plants irrigated after every 14 days interval which considerably varied from the other two irrigation intervals. Concerning planting systems, plants on ridges resulted in more leaf area as compared to plants on beds (tab. 2).

In the current study, irrigation interval had a profound effect on vine growth. Higher values of vine length, number of branches and average leaf area were recorded at irrigation interval of 7 days during summer crop and 14 days during winter crop. The vine growth decreased as the irrigation interval increased and plants were subjected to water stress conditions. Likewise, in another study, water stress had profound effect on vine length of sweet potato. Vine length significantly reduced as the plants were subjected to slight and severe water stress as compared to plants at no water stress [Laurie et al. 2014]. Similarly, Nedunchezhiyan et al. [2011] also observed a decreasing trend in vine length under water deficit conditions. In another study, drought reduced the number of branches per plant in sweet potato [Saraswati 2007]. High water deficit stress caused reduction in sweet potato shoot growth and photosynthetic activities which leads to lower storage root yield [Gajanayake et al. 2014].

Planting system also influenced the vine growth parameters in sweet potato. In ridge planting, vine length and leaf area were more than bed planting system especially in winter crop. More vegetative growth on ridges can be related with more water supplied through furrows present on both sides of a ridge, while in bed planting water is supplied to the plants by a single furrow. Hopkins [1999] stated that drought negatively affect the leaf metabolic processes, which causes reduction in leaf area of a plant. In another study, drought stress markedly affected the leaf photosynthesis in sweet potato, leading to reduced vine growth and hence low vine biomass [Kivuva 2013].

Storage root growth and yield

In summer crop, storage root growth (storage root length and diameter) and yield (number and fresh weight of storage roots per plant) were significantly reduced as the water stress increased. Storage root length (19.64 cm) was recorded maximum, when the plants were irrigated after every 7 days interval and it was found minimum (14.87 cm) when the plants were irrigated after 21 days interval, followed by 14 days irrigation interval. These two treatments were at par with each other (tab. 3). Thus, soil moisture directly affected the storage root length in sweet potato.

Irrigation interval negatively affected the storage root diameter. The maximum storage root diameter (3.9 cm) was exhibited in 7 days irrigation interval, followed by 14 days interval and 21 days interval. Concerning the interactive effect of irrigation interval and planting systems, the maximum storage root diameter (4.3 cm) was recorded in ridge planting with irrigation interval of 7 days, followed by ridge planting with 14 days interval and bed planting with 7 days interval. These three treatment combinations were statistically similar with each other (tab. 3). Above results indicated that vegetative growth particularly number of branches per plant had significant effect on storage root growth especially storage root diameter. The numbers of storage roots per plant decreased as the irrigation interval increased. The maximum number of storage roots per plant (2.7) was recorded in plants irrigated after 7 days interval, followed by 14 days irrigation interval. Regarding the interaction between irrigation interval and planting systems, ridge planting with 7 days irrigation interval (without water stress) showed the maximum numbers of storage roots (2.8), followed by ridge planting with 14 days and bed planting with 7 days irrigation interval (tab. 3).

Fresh weight of marketable storage roots per plant was markedly reduced as the plants were subjected to water stress by increasing irrigation interval from 7 to 21 days. While discussing the interactive effect of

Table 3. Effect of different irrigation intervals and planting systems on tuber growth and yield of sweet potato

Irrigation interval (days)	Summer crop Bed	Summer crop Ridge	Summer crop Mean	Irrigation interval (days)	Winter crop Bed	Winter crop Ridge	Winter crop Mean
Storage root length (cm)							
7	17.92 a	21.36 a	**19.64 a**	14	16.25 a	15.80 a	**16.03 a**
14	15.13 a	15.02 a	**15.08 b**	28	15.80 a	13.30 a	**14.55 a**
21	15.59 a	14.14 a	**14.87 b**	42	14.18 a	17.35 a	**15.76 a**
Mean	**16.21 a**	**16.84 a**		Mean	**15.41 a**	**15.48 a**	
Storage root diameter (cm)							
7	3.5 ab	4.3 a	**3.9 a**	14	3.55 ab	2.85 ab	**3.20 a**
14	3.2 b	3.6 ab	**3.4 ab**	28	3.15 ab	2.60 b	**2.88 a**
21	3.1 b	2.2 c	**2.6 b**	42	2.73 ab	3.78 a	**3.25 a**
Mean	**3.3 a**	**3.3 a**		Mean	**3.14 a**	**3.08 a**	
No. of marketable storage roots per plant							
7	2.6 ab	2.8 a	**2.7 a**	14	3.45 a	2.93 a	**3.19 a**
14	1.7 bc	2.7 a	**2.2 ab**	28	2.08 a	1.70 a	**1.89 b**
21	1.9 bc	1.5 c	**1.7 b**	42	2.38 a	3.40 a	**2.89 a**
Mean	**2.1 a**	**2.3 a**		Mean	**2.63 a**	**2.68 a**	
Fresh weight of storage roots / plant (g)							
7	229 a	292 a	**260 a**	14	328.00 a	189.75 a	**258.88 a**
14	113 b	250 a	**182 b**	28	193.50 a	113.25 a	**153.38 a**
21	93 b	52 b	**73 c**	42	134.50 a	349.00 a	**241.75 a**
Mean	**145 a**	**198 a**		Mean	**218.67 a**	**217.33 a**	

Means sharing similar letter(s) in a group are statistically non-significant at $p < 0.05$

irrigation interval and planting systems, the maximum fresh weight of storage roots (292 g) was exhibited by the plants on ridges and irrigated after 7 days interval, followed by ridge planting with 14 days interval and bed planting with 7 days interval. These three treatment combinations behaved statistically alike. The minimum fresh weight of storage roots per plant (52 g) was determined in ridge planting with 21 days irrigation interval, followed by bed planting with 21 days interval and bed planting with 14 days interval. These three treatment combinations were also statistically at par with each other (tab. 3).

Fresh weight and number of storage roots reduced as the irrigation interval increased. In previous studies, number of storage roots per plant decreased in potato [Khalel 2015] and sweet potato [Saraswati 2007] as the plants were subjected to water deficit conditions. Kivua [2013] also stated that drought stress reduced the number of marketable sized storage roots in different sweet potato cultivars.

In case of winter crop, length and fresh weight of storage roots were not influenced by either the individual or combined effect of irrigation interval and planting systems. The reason might be the low temperature prevailing during winter and water stress could not be developed. However, the interactive effect of irrigation interval and planting systems significantly affected the storage root diameter (tab. 3).

The maximum number of marketable tubers per plant (3.19) was recorded in plants irrigated after 14 days intervals, followed by 42 days and 28 days interval. There was no significant effect of planting systems on the number of storage roots. The combined effect of the two factors on number of storage roots was also found non-significant (tab. 3).

Vitamin C and total soluble solids (TSS)

In summer crop, irrigation interval had significant effect on vitamin C content. Plants irrigated after 7 days interval showed the maximum vitamin C content (2.86 mg 100 ml^{-1} juice), followed by the plants irrigated after 21 days interval and 14 days interval. Concerning the combined effect of the two factors, plants on ridges which are irrigated after every 7 days interval had the maximum vitamin C content which markedly differed from all other treatment combinations.

Total soluble solids (TSS) was the maximum (11.1 ºBrix) in plants irrigated after 21 days interval which markedly differed from other two irrigation treatments. Regarding the interactive effect of the two factors, TSS was the maximum (11.5 ºBrix) in bed planting system with 21 days interval (tab. 4). Results of our study revealed that TSS increased with water stress. In previous studies deficit irrigation in tomato [Favati et al. 2009] and mandarin [Navarro et al. 2010] caused higher TSS as compared to plants at no water stress.

In winter crop, the interactive effect of planting systems and irrigation interval markedly influenced the vitamin C content. Plants which were irrigated after 14 days interval and planted on beds, exhibited the maximum vitamin C content (2.43 mg 100 ml^{-1} juice) while it was found minimum (1.59 mg 100 ml^{-1} juice) in plants irrigated after 42 days interval and were planted on beds. These two treatments were statistically different from all other treatment combinations. Vitamin C content of storage roots declined with water stress in both summer and winter crops.

Table 4. Effect of different irrigation intervals and planting systems on some biochemical parameters of sweet potato

Irrigation interval (days)	Summer crop Bed	Summer crop Ridge	Summer crop Mean	Irrigation interval (days)	Winter crop Bed	Winter crop Ridge	Winter crop Mean
			Vitamin C content (mg 100 ml^{-1} juice)				
7	2.34 b	3.38 a	**2.86 a**	14	2.43 a	1.87 b	**2.15 a**
14	2.47 b	2.34 b	**2.41 b**	28	1.86 b	1.88 b	**1.87 a**
21	2.66 b	2.32 b	**2.49 ab**	42	1.59 c	2.10 b	**1.85 a**
Mean	**2.49 a**	**2.68 a**		Mean	**1.96 a**	**1.95 a**	
			Total soluble solids (ºBrix)				
7	10.0 b	10.7 b	**10.3 b**	14	11.23 a	11.35 a	**11.29 a**
14	10.5 b	10.3 b	**10.4 b**	28	12.55 a	11.60 a	**12.08 a**
21	11.5 a	10.7 b	**11.1 a**	42	12.95 a	12.08 a	**12.51 a**
Mean	**10.7 a**	**10.5 a**		Mean	**12.24 a**	**11.68 a**	
			Leaf proline content (µmoles g^{-1} FW)				
7	14.71 c	26.69 b	**20.70 b**	14	35.23 a	39.98 a	**37.60 a**
14	20.27 bc	22.92 bc	**21.59 ab**	28	45.78 a	38.45 a	**42.11 a**
21	17.76 bc	43.22 a	**30.49 a**	42	36.20 a	40.90 a	**38.55 a**
Mean	**17.58 b**	**30.94 a**		Mean	**39.07 a**	**39.78 a**	

Means sharing similar letter(s) in a group are statistically non-significant at $p < 0.05$

In potato tubers vitamin C content reduced as the plants were subjected to water stress conditions [Carli et al. 2014]. However, contradictory results have been observed by Rautenbach [2010], who reported that vitamin C content in sweet potato storage roots increased in water stress conditions. Studies conducted by Love et al. [2003] and Burgos et al. [2009] showed that vitamin C content was much more dependent on genotype than prevailing environmental conditions.

In winter crop, total soluble solids (TSS) remained unaffected by the irrigation interval, planting systems and their interaction.

Leaf proline content

In summer crop, leaf proline content was the maximum (30.49 µmoles g^{-1} FW) in plants irrigated after 21 days interval, followed by 14 days interval. Concerning planting systems, plants on ridges exhibited more leaf proline content as compared to plants on beds. The interactive effect of the two factors revealed that the plants on ridges which were irrigated after every 21 days interval showed maximum leaf proline content (43.22 µmoles g^{-1} FW) (tab. 4). In winter crop, although difference was statistically not significant, perhaps due to environmental factors especially low temperature. However, leaf proline content was found to be increased greatly at mild water stress and slightly at severe water stress as compared to normally watered plants (tab. 4). Similar observations were recorded in other crop plants including sweet potato. Under a hydroponic system, Rodríguez-Delfín et al. [2011] reported increase in free proline content of sweet potato cultivars ‘Huambachero’ and ‘Untacip’, when plants were subjected to water deficit conditions. In another study *Solanum melongena* plants showed increase in free proline content at severe drought conditions [Sarker et al. 2005].

CONCLUSIONS

In sweet potato, vegetative growth, storage root yield quality was affected by the irrigation interval and planting system. It is concluded from the results that maximum vegetative growth and storage root yield was exhibited in plants irrigated after 7 days interval during summer crop and 14 days during winter crop. Plants on ridges produced maximum vegetative growth and more storage roots as compared to bed planting. Vitamin C content decreased with water stress, whereas total soluble solids (TSS) and leaf proline content significantly increased with water stress. In Multan conditions for summer crop irrigation interval should be managed according to rainfall pattern. For winter crop, 14 days irrigation interval with ridge planting method could be followed both for vine and storage root growth.

AUTHORS CONTRIBUTION

Muhammad Saqib carried out the experiments, Muhammad A. Anjum conceived and supervised the experiments, Sajjad Hussain and Muhammad F. Khalid analyzed data and wrote manuscript.

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