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Research Article

GROWTH AND YIELD CHARACTERS OF POTATO GENOTYPES GROWN IN DROUGHT AND IRRIGATED CONDITIONS OF NEPAL

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Abstract

This experiment was conducted to assess the genotypic variation for the growth, yield and yield components of potato grown under drought and irrigated conditions at Hattiban Research Farm, Khumaltar during the summer cropping season (Feb.-May) of the two consecutive years (2013 and 2014). The results revealed that canopy cover, stem height and number of leavers were more sensitive to drought and the effect was more pronounced in early cultivar Desiree. Stem height and leaf number of plant were more (36% and 45%, respectively) reduced in Desiree than other genotypes. Mean tuber number decreased by 55% under drought condition. Drought stress reduced marketable tuber number by 79% as compared to irrigated treatment. Drought stress reduced the marketable tuber yield from 70% to 87%. The clones CIP 392242.25 and LBr-40 had relatively lower yield loss, and less drought susceptibility index under drought indicating their tolerance to drought in field condition. Further experiment is recommended to study the physiological parameters of these genotypes under different water and soil conditions.

Keywords: canopy cover; drought; genotype; yield; drought susceptibility index

Introduction

Potato is an important non-cereal food crop of Nepal. In mid hills, it is mainly used as vegetables and grown in two times of the year i.e. summer and august, respectively. Summer is considered to be normal season for potato production in the hills. In mid-hills, the normal season potato faces the drought during tuberization period (NPRP, 2012). The planting of potato soon after harvesting the rice in rice-potato cropping system utilizes the residual moisture for tuber emergence. However, the drought condition exists thereafter during the tuberization and bulking period (NPRP, 2012). Drought stress occurs even in irrigated potato (Van Loon, 1981; Jefferies, 1993).

In the sub-tropical region, where potato production is only possible through irrigation but short periods of drought often arise because of inadequate irrigation techniques or shortages of water. Water stress may occur even in good irrigated condition because of high transpiration rate particularly during mid-day when root system cannot completely meet the water requirements of the plant (Minhas and Sukumaran, 1988). Drought stress affects the development and the growth of shoots, root and tubers (Lahlou *et al*., 2003). Reduced leaf growth and accelerated leaf senescence are common responses to water deficits condition (Monneveux, 1991). The effect of drought on tuber number has been studied by several researchers (MacKerron and Jefferies, 1986; Haverkort *et al*., 1991, Deblonde and Ledent, 2001; Lahlou *et al*., 2003). Potato crop may suffer significant yield reduction even under short periods of water depletion because of a relatively shallow root system and low capacity of recuperation after water stress (Iwama, 2008).

The drought effect on potato foliar characters affects tuber yield which had been studied by several researchers. Jefferies (1993) showed that the final size of individual leaves was reduced by drought but the magnitude of the effect differed significantly between cultivars. Drought reduced the number of green leaves (Deblonde and Ledent, 2001). Screening drought tolerance genotypes for breeding purposes need reliable parameters to assess the drought tolerance traits. In addition, the potato plant can follow different growth strategies to adapt drought condition. The potato genotypes developed so far may differ on their morphological characters, precocity and their variation for drought tolerance. The main objective of this study was to investigate the genotypic differences for their agro-morphological parameters and yield in drought and irrigated condition.

Materials and Methods

Five CIP clones (391598.75, 392242.25, 391011.47, 378711.7, and LBr-40), one German variety NPI-106, and a standard check represented by the Dutch cultivar Desiree, a very popular released variety of Nepal were used in the experiment. The experiment was conducted at Hattiban Research Farm, Khumaltar (27°40' N, 85° 20'E, 1340 m asl) during 2013-2014. The type of soil was sandy loam with medium organic matter content and soil pH was 5.5. The average, minimum and maximum temperature and rainfall were collected from Agrometeorological Station of Agronomy Research Division (ARD), Khumaltar within the distance of 1 km from the experimental field. Total rainfall during the cropping period was 314.7 mm and 199.4 mm in 2013 and 2014, respectively. Maximal temperature was higher in 2014 than 2013 (Table 1).

The uniform sizes of well-sprouted tubers ranging from 25 to 50 g size from each variety were chosen for the trial. Before planting, the plot was well-leveled, rows were made and $NP_2O_5K_2O$ @ 100:100:60 $kgha^{-1}$ was placed, and the compost was mixed homogenously in the row. Then, sprouted tubers were placed manually in rows in upward direction. Tubers were planted at the spacing of 60 x 25 cm in two rows maintaining the plot sized 3 m^2. A split plot design with two factors (water status and cultivar) and three replicates were used. The drought treatments (T_1) in main plot and potato genotypes were placed in subplot. In drought plot, irrigation was applied once for emergence just after planting; then, drought treatment was applied after the emergence of tuber by withholding irrigation totally. Additionally, the water from rainfall was excluded by covering a strong plastic sheet just above the drought plot. The irrigated (T_2) plot was received water from rainfall and irrigation and it was applied by furrow system. Soil moisture content was determined using TRIME-PICo64/32 device at 10 cm depth in upper soil layer. When volumetric soil moisture content (%) dropped below 8%, irrigation was given to create ideal moisture condition (8-16%) but in drought plot, soil moisture content was maintained below 8% after tuber emergence to maintain dry or drought condition according to soil moisture scale mentioned by Zotarelli et al. (2010). In the both years, the trial was planted in February 1 and 10 and harvested in May 20 and 28, respectively.

Measurements

Canopy cover was estimated at 70 days after tuber planting. The proportion of the ground covered with green leaves was estimated using a 60 cm x 50 cm grid divided into 6 cm x 5 cm cells held over the central row (covering two plants) and percent cover was calculated as the number of cells at least half-filled by vegetation divided by the total number of cells. Stem height (cm) was measured from soil surface to the apex of the main stem. The number of green leaves was counted on five plants at 80 days after planting and it was averaged. The number of aboveground stems (AGS) was counted on five plants at the maximum growth of the plants when the plants touch each other's between the rows (NPRP, 2014). Leaf length was measured from 14^{th} to 19^{th} leaf on the main axis according to Deblonde and Ledent (2000). The internode length was measured between two internodes on the main axis. The number of harvested plants was counted before harvesting and all plants were harvested to assess the total tuber number $plant^{-1}$, marketable tuber $plant^{-1}$ (no.), marketable weight $plant^{-1}$ (g), and marketable yield (tha^{-1}). Total tuber $plant^{-1}$ was determined using the count of total number of tuber produced divided by the number of plants harvested in a specific plot. The tubers were graded into two categories; >25 g and < 25 g. Tubers <25 g category, and diseased, insect damaged, cracked, green, second growth, and early sprouted tubers were considered as non-marketable, and tubers of > 25 g with well-shaped tubers were considered as marketable tuber (NPRP, 2014). Drought susceptibility index was calculated as $(1-yield_{drought}/yield_{irrigated})$ / $(1-mean_{droughted}/mean_{irrigated})$ (Schafleitner *et al*., 2007).

Table 1: Monthly values of climatic data during the two growing periods, Khumaltar

Climatic variables	2013				2014			
	February	March	April	May	February	March	April	May
Maximal temperature (°C)	20.3	25.1	28.0	28.4	19.2	23.1	27.5	28.4
Minimal temperature (°C)	5.5	9.4	11.7	16.7	4.6	8.1	11.3	17.2
Mean temperature (°C)	12.9	17.2	19.8	22.5	11.9	15.6	19.4	22.8
Total rainfall (mm)	45.1	32.8	39.8	197.0	26.6	44.8	2.6	125.4
Number of rainy days	7	3	8	15	5	6	2	12

Statistical analysis

The data were analyzed using statistical software GenStat Discovery Edition 4 for Windows. All the measured data derived from the experiment were combined across the years and analyzed. In ANOVA, genotype and water status were considered as fixed effects, while year, and replication were considered as random effects. The genotype, treatment, year and their interaction effects were analyzed by combined ANOVA and pooled data over the years are presented.

Results and Discussion

Growth parameters

Canopy cover

Highly significant genotype and treatment effects were observed in canopy cover (Table 2). The clone CIP 391011.47 had the highest (80%) canopy cover followed by NPI-106 (77%) and the lowest (49%) in Desiree. Mean canopy cover decreased 39.0% in drought treatments compared to irrigated treatment. The reduction of canopy cover in drought stress was also reported by other researchers (Ojala *et al*. 1990; Carli *et al*. 2014). The clone CIP 391011.47 had the highest canopy cover among the studied genotypes under drought and irrigated conditions. The genotype by treatment interaction was significant while year by treatment and year by genotype were not significant.

Stem height

Statistical analysis for stem height within years showed highly significant differences between genotype and treatment (Table 2). The clone LBr-40 had the tallest (58 cm) height and the lowest (37 cm) in Desiree. The mean stem height reduced by 25.9% in drought than irrigated treatment. Desiree, an early maturing variety was mainly affected by drought stress on stem height. The stem height reduction was 36% in Desiree but in the study of Deblonde and Ledent (2001), they found 25% reduction in stem height due to drought. The shorter vegetative cycle of the early genotype might be the cause of larger reduction of stem height in early bulking variety like Desiree. But Deblonde and Ledent (2001) reported that stem height strongly reduced in late cultivars than early cultivars which contradicts this findings. The stem height difference in irrigated condition among the cultivars mainly is due to genetic differences. The drought stress had less affected on stem height in clone LBr-40, a medium-late maturing variety. Ojala *et al*. (1990) reported that long term drought stress affects the stem height. The genotype by treatment interaction was non-significant while year by treatment was significant. The year by genotype and year by genotype by treatment interaction were non-significant in stem height.

Number of green leaves

The number of green leaves present on the plant was highly significant in genotype and treatment (Table 2). The highest number of green leaves was counted on NPI-106 (65) and the lowest in Desiree (43). The number of leaves decreased by 27.9% in drought as compared to irrigated treatment. The genotype by treatment interaction was non-significant while year by treatment and year by genotype were significant. In this study, the number of green leaves in Desiree reduced 45% in drought condition but in the study of Deblonde and Ledent (2001), they reported 25% reduction of green leaves number in Desiree. Fewer numbers of green leaves per plant in irrigated condition showed the lowest leaf number in drought condition in a medium-late maturing clone LBr-40.

Table 2: Canopy cover (%), stem height (cm), and number of leaves plant^{-1} for the different genotypes under drought and irrigated conditions (means of the two years)

Genotypes	Canopy cover (%)			Stem height (cm)			Leaves plant^{-1} (no.)		
	T_1	T_2	Mean	T_1	T_2	Mean	T_1	T_2	Mean
CIP 391598.75	51	93	72	44	62	53	55	72	64
CIP 392242.25	54	92	73	43	59	51	53	75	64
CIP 391011.47	63	98	80	39	53	46	57	68	63
CIP 378711.7	58	88	73	48	59	53	47	64	56
LBr -40	48	73	61	52	63	58	42	53	47
NPI -106	56	98	77	40	58	49	52	78	65
Desiree	38	61	49	29	45	37	31	56	43
Mean	52.5	86.1		42.2	57.0		48.0	66.6	
Genotype (G)			6.6**			0.8**			13.8*
Treatment (T)			2.4**			4.1**			9.5**
G x T			*			NS			NS
Year (Y) x T			NS			**			*
Y x G			NS			NS			*
Y x G x T			NS			NS			NS

NS, * and ** indicate non- significant, significant ($P \leq 0.05$) and highly significant ($P \leq 0.01$), respectively. T_1 = Drought, T_2 = Irrigated

Stem number

The genotype had highly significant effect on the main stem number (Table 3). The clone CIP 391011.47 had the highest stem number and LBr-40 had the lowest. The drought stress had highly significant differences on stem number. Drought stress reduced the total stem number by 5% than irrigated treatment. Lahlou *et al*. (2003) reported 28% reduction of total stem number caused by drought stress. Iritani (1968) reported that total stem number was influenced by drought stress. However, total stem number is affected by other factors like temperature (Haverkort and Harris, 1987) and growth regulators (Marinus and Bodlaander, 1978). Besides, the number of main stem produced plant^{-1} is a genotypic character (Nielson *et al*. 1989) and it is also affected by other factors such as length of the pre-sprouting period (Allen, 1978), size of seed tuber (Haverkort *et al*. 1991; Wurr, 1974) and physiological age (Iritani, 1968). Genotype by treatment interaction was not significant while year by treatment and year by genotype were significant.

Leaf length

Genotype and treatment had highly significant effect on leaf length (Table 3). The highest length was measured in CIP 378711.7 (19.8 cm) followed by LBr-40 while drought stress reduced the leaf length by 15.5% than irrigated treatment. The clone LBr-40 reduced the leaf length by 8% in drought stress. The reduction of leaf length caused by drought stress was also reported by Deblonde and Ledent (2001) in potato genotypes. Genotype by treatment interaction was not significant while year by treatment and year by genotype were significant.

Internode length

The genotype had significant effect in internode length of the plants. The internode length was reduced in Desiree variety as compared to other genotypes. But the treatment had highly significant effect on in internode length and drought stress decreased the internode length by 14.6% than irrigated treatment (Table 3). The clone CIP 391011.47 had reduced internode length by 7% due to drought stress. Genotype by treatment, year and treatment, and year by genotype were not-significant. The genotype with greatest internode length in irrigation condition had highest reduction in internode length in drought condition.

Table 3: Stem plant^{-1} (no.), leaf length (cm) and internode length (cm) for the different genotypes under drought and irrigated conditions (means of the two years)

Genotypes	Stem plant^{-1} (no.)			Leaf length (cm)			Internode length (cm)		
	T_1	T_2	Mean	T_1	T_2	Mean	T_1	T_2	Mean
CIP 391598.75	4	4	4	16.0	20.1	18.1	3.9	4.5	4.2
CIP 392242.25	4	4	4	15.7	19.5	17.7	4.1	4.4	4.3
CIP 391011.47	5	5	5	17.4	19.6	18.5	4.0	5.2	4.6
CIP 378711.7	4	4	4	16.9	22.6	19.8	4.4	5.4	4.9
LBr -40	3	3	3	18.8	20.5	19.7	4.5	5.4	4.9
NPI -106	4	4	4	16.0	18.8	17.4	4.2	4.8	4.5
Desiree	3	4	4	16.3	18.5	17.4	3.2	3.7	3.4
Mean	3.8	4.0		16.8	19.9		4.1	4.8	
Genotype (G)			0.5**			1.4**			0.7*
Treatment (T)			0.5**			1.0**			0.5**
G x T			NS			NS			NS
Year (Y) x T			*			**			NS
Y x G			*			NS			NS
Y x G x T			NS			NS			NS

NS, * and ** indicate non-significant, significant ($P \leq 0.05$) and highly significant ($P \leq 0.01$), respectively. T_1 = Drought, T_2 = Irrigated

Yield Attributes

Total tuber number

The statistical analysis of tuber number measured at final harvest is shown in Table 4. Genotype by treatment interaction for total tuber number was highly significant. NPI-106 had significantly highest and Desiree had lowest number of tubers plant^{-1} than other genotypes. The drought treatment reduced the total tuber number by 54.8% than irrigated treatment. Desiree was highly influenced by drought stress with regard to total tuber number and the clone LBr-40 had less affected by drought stress. This might due to the different tuberization behavior of the potato genotypes. Lahlou *et al*. (2003) also reported that tuber number had more affected in early variety. Except these genotypes, drought stress consistently reduced the total tuber number in other genotypes. The reduction of tuber number under drought stress on potato has been described by several authors (MacKerron and Jefferies, 1986; Haverkort *et al*. 1991; Lahlou *et al*. 2003; Carli *et al*. 2014). Genotype by treatment and year by treatment interaction were significant while year by genotype interaction was non-significant.

Marketable tuber number

Genotype had highly significant differences on marketable tuber plant^{-1}. Except CIP 392242.25, marketable tuber number plant^{-1} was statistically similar in all the genotypes (Table 4). Similarly, treatment effect was highly significant on marketable tuber number and drought reduced the mean marketable tuber number by 79% as compared to irrigated treatment. The reduction by drought on marketable tuber number was 63.6% in CIP 392242.25, 66.6% in LBr-40, 80% in CIP 378711.7, 82% in CIP 391598.75 and CIP 391011.47, and 83% in Desiree (data not shown) in comparison with their respective irrigated treatment. The reduction of marketable tuber number under drought stress was varied from 64% to 83% and most of tubers under drought plots were observed as malformed, reduced size with defected tubers (data not shown). Schafleitner *et al*. (2007) had observed the malformed tuber in water deficit condition. Genotype by treatment interaction was significant. Likewise, year by treatment interaction was highly significant but year by genotype interaction was not significant.

Marketable tuber weight

Genotype had highly significant effect on marketable tuber weight (Table 4). The clones CIP 378711.7, CIP 391011.47, NPI -106 and CIP 392242.25 had the highest marketable weight averaged across years and treatment. The clone CIP 392242.25 had the highest weight in drought treatment while CIP 378711.7 had the highest weight in irrigated treatment across the years. The marketable weight reduced by drought treatment was 78.4% as compared to irrigated treatment. But the reduction of marketable tuber weight was highest in Desiree. Genotype by treatment interaction had highly significant while year by treatment and year by genotype interaction were not significant.

Table 4: Total tuber, marketable tuber number and weight (g) plant^{-1} for the different genotypes under drought and irrigated condition (means of the two years)

Genotypes	Total tuber plant^{-1} (no.)			Marketable tuber plant^{-1} (no.)			Marketable tuber weight plant^{-1} (g)		
	T_1	T_2	Mean	T_1	T_2	Mean	T_1	T_2	Mean
CIP 391598.75	8	18	12.9	2	11	7.0	98.4	484.1	291.3
CIP 392242.25	9	18	13.2	4	11	7.0	153.8	468.5	311.2
CIP 391011.47	8	17	12.3	2	11	6.0	122.0	580.3	351.1
CIP 378711.7	6	14	9.9	2	10	6.0	113.4	612.9	363.2
LBr -40	5	8	6.5	2	6	4.0	90.6	389.0	239.8
NPI -106	8	19	13.6	2	12	7.0	113.2	550.1	331.7
Desiree	3	8	5.7	1	6	4.0	44.6	323.3	184.0
Mean	6.6	14.6		2	9.5		105.1	486.9	
Genotype (G)			2.4**			1.8**			64.8**
Treatment (T)			1.5**			1.9**			44.2**
G x T			*			*			**
Year (Y) x T			**			**			NS
Y x G			NS			NS			NS
Y x G x T			NS			NS			NS

NS, * and ** indicate non-significant, significant ($P \leq 0.05$) and highly significant ($P \leq 0.01$), respectively. T_1 = Drought, T_2 = Irrigated

Table 5: Marketable yield (tha^{-1}), yield loss (%) and drought susceptibility index for the different genotypes under drought and irrigated conditions (means of the two years)

Genotypes	Marketable yield (tha^{-1})			Yield loss (%)	DSI
	T_1	T_2	Mean		
CIP 391598.75	6.6	32.3	19.4	80	0.62
CIP 392242.25	10.3	31.2	20.7	70	0.52
CIP 391011.47	8.1	38.7	23.4	79	0.62
CIP 378711.7	7.6	40.8	24.2	81	0.64
LBr -40	6.0	25.9	15.9	77	0.60
NPI -106	7.6	36.7	22.1	79	0.62
Desiree	2.9	21.5	12.2	87	0.68
Mean	7.0	32.5			
Genotype (G)			4.0**		
Treatment (T)			2.9**		
G x T			**		
Year (Y) x T			**		
Y x G			NS		
Y x G x T			NS		

NS, and ** indicate non-significant, and highly significant ($P \leq 0.01$), respectively. T_1 = Drought, T_2 = Irrigated, DSI = Drought Susceptibility Index

Marketable tuber yield and drought tolerance

Statistical analysis of final marketable tuber yield showed a highly significant effect of genotype, treatment, genotype by treatment interaction and year by treatment interaction (Table 5). The clones CIP 378711.7, CIP 391011.47, NPI-106 and CIP 392242.25 had highest marketable tuber yield averaged across the year and treatment. The clone CIP 392242.25 had highest tuber yield (10.3 tha^{-1}) followed by CIP 391011.47 and the lowest yield (2.9 tha^{-1}) in Desiree. Drought stress reduced the mean tuber yield by 78.4% than irrigated treatment. The yield loss caused by drought was 70% for CIP 392242.25, 77% for LBr-40, 79% for CIP 391011.47 and NPI-106, 80% for CIP 391598.75, 81% for CIP 378711.7, and 87% for Desiree in comparison with their respective irrigated treatment. The drought stress caused the greatest yield loss in Desiree. The early tuberization and bulking of variety might be cause of greater yield loss in Desiree as compared to mid-late maturing genotypes. Cavagnaro et al. (1971) had reported that drought stress decreased the tuber yield. In the study of Lahlou *et al*. (2003), they reported 11% yield reduction in Desiree, and 38 % in Remarka but in our study, 87% yield reduction was recorded in Desiree. Lahlou *et al*. (2003) had reported that drought stress reduced yield by 53% in Remarka genotype. The clone CIP 392242.25 had the lowest (0.52) drought susceptibility index followed by the clone CIP LBr-40 (0.60) indicating their drought tolerance and the highest (0.68) DSI for Desiree represented as drought susceptible genotype. But in the study of Schafleitner *et al*. (2007), they found the lowest (0.50) DSI in cv. Reiche and the highest (1.36) in cv. Achirana.

Conclusion

This study analyzed the agro-morphological characters and yield of potato genotypes under drought and irrigated condition. All the growth parameters including yield and yield components were sensitive to drought stress. The early maturing genotype Desiree was more affected than medium-late maturing genotypes by drought in terms of stem height, number of leaves plant^{-1}, total tuber number, marketable tuber number and weight, and yield. But drought stress consistently reduced the canopy cover, stem number, leaf length, internode length, yield components and final tuber yield but the magnitude of reduction varied according to the phenology of different genotypes. Drought reduced the marketable yield of all potato genotypes under the investigation in a genotype-dependent manner. The clones CIP 392242.25 and LBr-40 had showed lower yield loss and less drought susceptibility index under drought condition but further experiments are needed to evaluate the physiological response of these genotypes to different water, soil and climatic conditions for confirming this result.

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References

Allen E J (1978) Plant density, in: Harris PM (Ed.), The potato crop. The scientific basis of improvement, Chapman and Hall, London.DOI: 10.1007/978-1-4899-7210-1_7

Carli C, Yuldashev F, Khalikov D, Condori B, Mares V and Monneveux P (2014) Effect of different irrigation regimes on yield, water use efficiency and quality of potato (*Solanum tuberosum* L.) in the lowlands of Tashkent, Uzbekistan: A field and modeling perspective. *Field Crop Research* **163**: 90-99. DOI: 10.1016/j.fcr.2014.03.021

Cavagnaro JB, Lis De BR and Tizio RM (1971) Drought hardening of the potato plant as an after-effect of soil drought conditions at planting. *Potato Res*. **14**: 181-192. DOI: 10.1007/BF02361832

Deblonde PMK and Ledent JF (2000) Effects of moderate drought conditions on crop growth parameters and earliness of six potato cultivars under field conditions. *Agronomie* **20**: 595-608. DOI: 10.1051/agro:2000153

Deblonde PMK and Ledent JF (2001) Effects of moderate drought conditions on green leaf number, stem height, leaf length, and tuber yield of potato cultivars. *Eur. J. Agron*. **14**:1-41. DOI: 10.1016/S1161-0301(00)00081-2

Haverkort AJ and Harris PM (1987) A model for potato growth and yield under tropical condition. *Agric J. Meteorol*. **39**:271-282. DOI: 10.1016/0168-1923(87)90020-7

Haverkort AJ, Van de Waart M and Bodlaeander KBA (1991) The effect of early drought stress on numbers of tubers and stolons of potato in controlled and field conditions. *Potato Res*. **33**: 89-96. DOI: 10.1007/BF02358133

Haverkort, A. J. 2000. Management of nitrogen and water in potato production. Wageningen Academic Publications, pp. 353.

Iritani WM (1968) Factors affecting aging (degeneration) of potato tubers used as seed. *Am Potato J*. **45:** 111-116. DOI: 10.1007/BF02862871

Iwama K (2008) Physiology of the potato: new insights into root system and repercussions for crop management. *Potato Res*. **51**:333-353. DOI: 10.1007/s11540-008-9120-3

Jefferies RA (1993) Responses of potato genotypes to drought. I. Expansion of individual leaves and osmotic adjustment. Ann. Appl. Biol. **122**:93-104. DOI: 10.1111/j.1744-7348.1993.tb04017.x

Jefferies RA (1995) Physiology of crop response to drought. In: Haverkort AJ, MacKerron DKL (Eds.), Potato Ecology and Modelling of Crops under Conditions Limiting Growth. Kluwer Academic Publishers, Dordrecht, pp. 61-74. DOI: 10.1007/978-94-011-0051-9_4

Lahlou O, Ouattar S and Ledent JF (2003) The effect of drought and cultivar on growth parameters, yield and yield components of potato. *Agronomie*, **23**: 257-268. DOI: 10.1051/agro:2002089

Lynch DR and Tai GCV (1989) Yield and yield component response of eight potato genotypes to water stress. *Crop Sci*. **29**:1207-1211. DOI: 10.2135/cropsci1989.0011183X002900050024x

MacKerron DKL and Jefferies RA (1986) The influence of early soil moisture stress on tuber numbers in potato. *Potato Res*. **29**:299-312. DOI: 10.1007/BF02359959

Marinus JK and Bodlaander BA (1978) Growth and yield of seed potatoes after application of gibberellic acid to the tubers before planting. *Neth. J. Agric. Sci*. **26**: 354-365.

Minhas JS and Bansal KC (1991) Tuber yield in relation to water stress as different stages of growth in potato (*Solanum tuberosum* L.) *Ind Potato Assoc*. **18**: 1-8.

Minhas JS and Sukumaran NP (1988) Diurnal changes in net photosynthetic rate in potato in two environments. *Potato Res*. **31**: 375-378. DOI: 10.1007/BF02357871

Monneveux PH (1991) What strategies for genetic improvement to water deficit winter cereals? The plant breeding for adaptation to arid environment, AUPELF-UREF (Ed.) John Libbey Eurotext, Paris pp. 1965-1968.

Nielson M, Iritani WM, and Weiler LD **(**1989**)** Potato seed productivity; factors influencing eye number per seed piece and subsequent performance. *Am. J. Potato Res.* **66**: 151-160. DOI: 10.1007/BF02853676

NPRP (2012) Annual Report, 2068/69 (2011/2012). National Potato Research Programme, NARC, Khumaltar, Lalitpur, Nepal.

NPRP (2014) Field book for standard evaluation of potato and sweet potato germplasm (Eds. BB Khatri and BP Luitel), National Potato Research Programme, NARC, Khumaltar, Lalitpur, Nepal.

Ojala JC, Stark JC and Kleinkopf GE (1990) Influence of irrigation and nitrogen management on potato yield and quality. *Am. Potato J.* **67**:29-43. DOI: 10.1007/BF02986910

Schafleitner R, Gutierrez R, Espino R, Gaudin A, Perez J, Martinez M, Dominguez A, Tincopa L, Alvarado C, Numberto G and Bonierbale M (2007) Field screening for variation of drought tolerance in *Solanum tuberosum* L. by agronomical, physiological and genetic analysis. *Potato Res*. **50**:71-85. DOI: 10.1007/s11540-007-9030-9

Van Loon CD (1981) The effect of water stress on potato growth, development, and yield. *Am. Potato J*. **58**:51-69. DOI: 10.1007/BF02855380

Wurr DE (1974) Some effects of seed size and spacing on the yield and grading of two main crop potato varieties. *J. Agric. Sci.* **82**:37-45. DOI: 10.1017/S0021859600050206

Zotarelli L, Dukes MD, and Paranhos M **(**2010**)** Minimum number of soil moisture sensors for monitoring and irrigation Purposes. http://edis.ifas.ufl.edu.