THE EFFECT OF MOISTURE STRESS AT THREE GROWTH STAGES ON THE YIELD, COMPONENTS OF YIELD AND PROCESSING QUALITY OF EIGHT POTATO VARIETIES

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Abstract

A study was conducted over a three year period in southern Alberta to establish the yield and quality responses of eight potato varieties - Atlantic, Conestoga, Norchip, Niska, Shepody, Ranger Russet (Idaho clone), Ranger Russet (Amisk clone) and Russet Burbank to a single transient moisture stress (-80 kPa) at three growth stages in crop development (early, midseason and late). Early and midseason moisture stress had the greatest negative impact ($P<0.05$) on tuber yield. Of the eight varieties, Atlantic and Conestoga appear to be particularly sensitive to stress at these two growth stages. Midseason stress also appeared to reduce specific gravity. A year x stress interaction ($P<0.05$) for fry color suggests that the influence of moisture stress on fry color can be modified by other environmental factors. The results of the study demonstrate the importance of maintaining adequate soil moisture at all stages during crop development.

Compendio

Se condujo un estudio en un periodo de tres años al sur de Alberta, para establecer la respuesta en rendimiento y calidad de ocho variedades [Atlantic, Conestoga, Norchip, Niska, Shepody, Ranger Russet (clon de Idaho), Ranger Russet (clon de Amisk) y Russet Burbank], a un estrés temporal a la humedad (-80 kPa) en tres estados de crecimiento durante el desarrollo del cultivo (temprano, a media temporada y tardíamente). El estrés al comienzo y a mediados de la temporada tuvo el mayor impacto negativo ($P<0.05$) sobre el rendimiento en tubérculos. De las ocho variedades, Atlantic y Conestoga parecen ser particularmente sensibles al estrés en estos dos estados de crecimiento. El estrés, a mitad de temporada, parece que también disminuyó la gravedad específica. Una interacción año x estrés ($P<0.05$), para color de fritura, sugiere que la influencia del estres sobre éste puede ser modificada por otros factores ambientales. Los resultados del estudio demuestran la importancia de mantener una

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humedad adecuada en el suelo en todos los estados durante el desarrollo del cultivo.

Introduction

Potato is an important irrigated crop in Alberta and contributes significantly to the provincial economy and crop diversification. Seventy percent of the total acreage in Alberta and all the processing acreage is grown under irrigation in southern Alberta.

The potato crop is very sensitive to moisture stress as documented in reviews by Singh (14) and Harris (4). Irrigation protocols that maximize yield (1, 7, 9) as well as yield and quality responses associated with moisture stress (8, 12, 16) at specific growth stages have been determined. It is generally accepted that in southern Alberta Russet Burbank should be irrigated at a soil moisture tension of -40 kPa to -60 kPa (1, 9). Water stress in the early part of the season during tuber initiation has been reported to reduce tuber set (8, 12, 17, 18). Shock *et al.* (12) investigated the effect of early season moisture stress on Russet Burbank by delaying irrigation for up to 7 wk after planting. In this study, early stress increased US No. 1 and >284 g yield. In a study of the effects of transient drought stress at specific growth stages, Stark and McCann (16) demonstrated that the Russet Burbank crop was most sensitive to moisture 3 to 9 wk after tuber initiation. While Iritani and Weller (5) found that early season moisture stress reduced fry quality of Russet Burbank, Shock *et al.* (12, 13) report improved fry color associated with early season stress. Lynch and Tai (8) used a mathematical model to predict the impact of moisture stress on the components of yield of eight varieties and their data suggest important varietal differences in the response to moisture stress. Information on the response to moisture stress of varieties other than Russet Burbank in North America is limited.

Establishment of the influence of moisture stress during the growth and development of potato varieties is essential information to enable producers to make efficient irrigation management decisions on farms with several varieties as well as other crop species. This study was undertaken to establish the effects of a single transient moisture stress episode, at three growth stages, on the tuber yield and quality of eight commercially important chip and french fry varieties in S. Alberta.

Materials and Methods

The study was carried out at the Vauxhall Research Substation of the Agriculture and Agri-Food Canada Research Centre at Lethbridge in 1990, 1991 and 1992. The substation is located on a Brown Chernozemic (sandy loam, Cavendish series) soil in an area with a mean growing-season (April-September) precipitation of 204 mm. In each year a new plot area, in close proximity to the previous year's experiment, was used.

Split-plot experiments were carried out with moisture stress treatments forming the main plots in a randomized complete block design with three replicates. Eight varieties - Atlantic, Conestoga, Norchip, Shepody, Ranger Russet I (Idaho clone), Ranger Russet A (Amisk clone), Russet Burbank and Niska formed the subplots. In 1990, 1991 and 1992, the moisture treatments consisted of a control, irrigated when the soil moisture tension reached -40 kPa, and moisture stress treatments in which irrigation was withheld until the soil moisture tension reached -80 kPa at five growth stages (2, 4, 6, 8 and 10 wk after 50% of the plants of the earliest emerging variety had emerged). The stress treatment was applied as a single stress episode after which the plots were irrigated as specified for the control plots. The growth stages were selected to ensure that the influence of moisture stress was assessed for all varieties at tuber initiation as well as at early and late tuber sizing.

Soil moisture was monitored by neutron probe (Campbell Pacific Nuclear Corp., Pacheco, CA) with aluminum access tubes located within the row. Since our objective was to subject the plants to a significant stress, rather than a precise stress level, we did not compensate for the influence of tuber water content on the neutron count(3). Development of moisture characteristic curves of a bulk soil sample obtained from the experimental area, plotted from porous plate data, allowed conversion of neutron probe readings to the equivalent soil moisture tension. Soil moisture tension was calculated for the upper 90 cm at 30 cm intervals. The 2 and 4 wk stress treatments were based on the mean of readings from the upper 60 cm of the soil profile, whereas for all other treatments the mean readings from the upper 90 cm were used to calculate soil moisture tension. Once the designated stress level was reached the plot was irrigated by overhead sprinkler to return the soil moisture level to field capacity. Moisture stress treatments were separated by a 7 m buffer strip and part-circle heads were used to ensure the integrity of adjacent treatments. Portable rainshelters (2), designed specifically for the project, were used to protect treatments undergoing moisture stress during precipitation events.

Elite II seed tubers of the eight potato varieties were used in all three years of the experiment. Prior to planting 150 kg ha^{-1} N, 65 kg ha^{-1} P and 50 kg ha^{-1} K (based on soil test) were broadcast and incorporated into the plot area, together with 4 kg a.i. ha^{-1} of EPTC for weed control. Minisprouted seed tubers were cut into approximately 60 g pieces and suberized at 15 C for 5 days prior to planting with an assisted-feed plot planter in mid-May. The varieties were grown in 15 hill plots with rows spaced 90 cm apart and individual plants 30 cm apart within the row. Rows adjacent to the treatment row were planted to a genotype (Norland) with a moderate vine size to avoid error due to competition associated with the differing vine sizes of the test varieties. After emergence, regular spraying with Fenvalerate was undertaken to control insect pests such as Colorado potato beetle. In all three years the plot area was fall irrigated in the year preceding the trial to ensure adequate moisture prior to emergence.

Foliage growth was terminated chemically with diquat in early September and harvested approximately 2 wk later. Stems were counted by pulling individual mainstems by hand from all plants in each plot prior to harvest. Plots were harvested mechanically in mid-September by a single-row plot digger in 1990 and 1991 and by a Grimme single-row harvester in 1992. Tubers were held in a 10 C storage prior to assessment of yield and quality traits. The following tuber yields and components of yield were measured on a plot basis: mainstem number; total tuber yield (kg) and number; >55 mm (marketable) yield (kg) and number; >88 mm (large) yield (kg) and number; mean tuber weight (g) (total tuber yield/total tuber number); tubers/stem (total tuber number/mainstem number).

Specific gravity was measured by weighing a 5 kg sample of tubers (55 mm-88 mm) in air and water. Fry color was assessed by frying 25 tuber slices from five tubers in corn oil after 6 wk storage at 10 C and rated from 10-100 by color chart (Agriculture and Agri-Food Canada). Reducing sugars were determined colorimetrically after 6 wk storage at 10 C using the procedure outlined by Sowokinos (15).

For statistical analyses the stress treatments were combined into three stress periods and a control: 2 and 4 wk after emergence - early stress, 6 and 8 wk after emergence - midseason stress, 10 wk after emergence - late season stress. Since the 10 wk treatment was lost in 1991, two separate sets of analyses were carried out. The first set used all three years of data but only the early and midseason stress treatments while the other set used 1990 and 1992 data and all three stress treatments. For each data set, analyses of variance were carried out on yield, components of yield and quality data for individual years and over years to examine varietal and moisture stress responses (6). The model used for stress treatments, varieties and years was:

$$X_{ijkl}=\mu+y_i+b_{l(i)}+s_j+(sy)_{ji}+d_{ijl}+v_k+(vs)_{kj}+(vy)_{ki}+(vsy)_{kji}+e_{ijkl}$$

where μ = overall mean effect; $y_i(i = 1, \ldots, 3)$, $s_j(j = 1, \ldots, 3)$, $v_k(k = 1, \ldots, 8)$, $b_{l(i)}(l = 1, \ldots, 3)$ represent year, stress, variety and block effects, respectively; $(sy)_{ji}$, $(vs)_{kj}$, $(vy)_{ki}$ and $(vsy)_{kji}$ are interaction effects; and d_{ijl} and e_{ijkl} are the main and subplot random errors. The effects were tested using the appropriate error terms, assuming fixed effects for year, stress and variety. The General Linear Models (GLM) procedure of SAS (11) was used to carry out the statistical analyses.

Results and Discussion

The patterns of precipitation events over the three years were distinct (Table 1); 1990 was a dry season with precipitation concentrated in May

TABLE 1.—*Precipitation (mm) at Vauxhall during the 1990, 1991 and 1992 growing seasons.*

	Month					
Year	April	May	June	July	August	September
1990	17.4	68.7	23.2	43.4	14.6	5.2
1991	29.6	82.8	137.1	15.6	55.3	6.6
1992	17.8	36.8	76.2	74.6	36.4	58.0

and July; precipitation events in 1991 occurred more frequently in May, June and August than in other months of the growing season; 1992 was a wet season with precipitation evenly distributed over the growing season. In 1991, flooding in a part of the field resulted in the loss of the 10 wk treatment and in 1992 (July 29) hail caused defoliation of the crop and the loss of the 6 wk treatment (protected by the rainshelter whereas other treatments were defoliated). Crop recovery from the hail damage was remarkable and the mean marketable yield was similar to that attained in 1990 and 1991; 16.6 kg/plot in 1992 vs. 19.9 kg/plot and 14.8 kg/plot for 1990 and 1991, respectively. Observational data collected in 1990 and 1991 indicated that tuber initiation for all eight varieties occurred prior to the 6 wk after crop emergence treatment. In all years Conestoga emerged first but the interval between the first and the last variety to emerge did not exceed 5 days.

The use of shelters in moisture stress studies is essential to enable the imposition of moisture stress at defined times during the growth of the crop. However, the use of shelters modifies the micro-environment and it is important to be sure that the use of the shelter does not influence the result. In our study, the shelters were only deployed during periods of precipitation or imminent precipitation when the associated temperature elevation was likely small. The fact that frequency of precipitation events (Table 1) occurred at different times in the growing season during the three years that the study was conducted, and that this was not reflected in a significant stress x year interaction for yield or a component of yield supports the validity of our data (Tables 2 and 3). In a recent study (10), a similar conclusion was reached.

The analyses of variance for the yield data for the first data set (1990-1992) is presented in Tables 2 and 3. For both data sets, there were significant ($P<0.05$) moisture effects of stress treatments on total and marketable yield and tuber number per mainstem. While tuber number per mainstem was reduced both by early and midseason stress, the greatest reduction

TABLE 2.—*Mean squares from analyses of variance to study effects of stress (S), variety (V), year (Y) and their interactions for total tuber yield and the components of yield (1990-1992).*[1]

Source of variation	DF	Total yield (kg/plot)	Stems/ plot	Tubers/ stem	Average tuber weight (g)
Y	2	308	1611	1.60	2.4
Block (Y)	5	78	126	0.83	17.5
S	2	143**	38 NS	5.67*	2.0 NS
SxY	4	9 NS	47 NS	1.15 NS	1.7 NS
Error A	10	25	20	1.14	3.3
V	7	98**	689**	2.87**	32.6**
VxS	14	58*	10 NS	0.30 NS	5.7 NS
VxY	14	58*	216**	1.13**	5.6 NS
VxSxY	28	39 NS	25 NS	0.43 NS	4.9 NS
Error B	209	32	29	0.36	4.6

[1]Analysis using stress treatments E=early; M=midseason; C=control;
*,** $P<0.05$, $P<0.01$; NS $P>0.10$.

TABLE 3.—*Mean squares from analyses of variance to study effects of stress (S), variety (V), year (Y) and their interactions for tuber yield and tuber number (1990-1992)*[1].

Source of variation	DF	Yield (kg/plot)		Tuber number/plot	
		Marketable	Large	Marketable	Large
Y	2	352	55.7	17323	703
Block (Y)	5	55	29.1	830	108
S	2	106*	24.7 NS	1969*	291†
SxY	4	9 NS	4.9 NS	422 NS	31 NS
Error A	10	25	20.3	345	97
V	7	119**	261.4**	600**	2024**
VxS	14	44*	8.5 NS	127 NS	19 NS
VxY	14	46*	36.1**	531**	243**
VxSxY	28	28 NS	8.9 NS	200 NS	33 NS
Error B	209	25	9.6	164	34

[1]Analysis using stress treatments E=early; M=midseason;
C=control; **, *, † $P<0.01$, $P<0.05$, $P<0.10$; NS $P>0.10$.

TABLE 4.—*Effect of early and midseason moisture stress on yield, components of yield and specific gravity measured over three years (1990-1992).*

Variable	Moisture stress treatment[1]		
	Early	Midseason	Control
Mainstem number/plot	36.2	35.5	34.8
Tuber number/stem	2.62**	2.88	3.14
Average tuber weight (gm)	183	184	186
Marketable tuber number/plot	64.2**	65.2*	73.6
Large (>88 mm) tuber yield (kg/plot)	6.3	5.4	6.3
Large (>88 mm) tuber number/plot	16.3	13.6*	17.0
Specific gravity	1.087	1.086*	1.089

[1]*, ** stress treatments that are significantly different from the control at the 5% and 1% significance levels, respectively, using the least significant difference (LSD) test.

($P<0.05$) occurred in the early season stress treatment (Table 4). This result is consistent with published data (8, 12, 18). For the first data set, stem number and average tuber weight were not affected by the stress treatments while for the second data set early stress increased ($P<0.05$) stem number. In both data sets, large (>88 mm) tuber number (1990-1992 $P<0.10$; 1990/1992 $P<0.05$) was negatively impacted by midseason stress. The year x stress x variety interaction was significant ($P<0.01$; data not shown) in both data sets for average marketable tuber weight and for average tuber weight in the second data set. This result likely reflects the differences in growing environment over years and the genetic capacity to capitalize in terms of bulking rate.

The variety x stress interaction was significant ($P<0.05$) for total and marketable yield in the analysis of the first data set. For Atlantic ($P<0.05$) and Conestoga ($P<0.01$), the greatest reduction in marketable yield occurred with the early season stress treatment (Table 5) and was associated with reduced tuber number. Midseason stress for both these varieties also caused a marked (Atlantic $P<0.05$ and Conestoga $P<0.01$) yield reduction (Table 5). While the total and marketable yields for most of the other varieties were also negatively impacted by early and midseason stress, the effect was not significant ($P>0.10$). In contrast, early season stress appeared to improve ($P<0.10$, Table 5) the total yield of Norchip. Similar results for Russet

TABLE 5.—*Effect of early and midseason moisture stress on total and marketable yield (kg/plot) of eight varieties measured over three years (1990-1992).*

	Total yield[1]			Marketable yield[1]		
Variety	Early	Midseason	Control	Early	Midseason	Control
Atlantic	16.0*	17.0†	21.1	14.1*	14.9	18.6
Conestoga	13.2**	15.0**	23.3	11.7**	13.1**	20.0
Norchip	19.4†	14.2	15.4	16.2	11.2	12.9
Niska	17.4	17.4	19.6	15.5	15.1	16.9
Ranger Russet (A)	17.5	17.2	19.1	15.9	15.4	17.3
Ranger Russet (I)	17.1	21.5	19.7	15.5	18.9	17.3
Russet Burbank	15.6	14.0	16.2	13.6	11.5	14.6
Shepody	19.9	20.9	21.7	18.4	19.1	19.5

[1]†, *, ** stress treatments within a variety that are significantly different from the control at the 10%, 5% and 1% significance levels, respectively, using the least significance difference (LSD) test.

Burbank are reported by Shock *et al.* (12). The variety x stress interaction was not significant in the analysis of the second data set. Late season stress treatment reduced marketable tuber yield from the control, but the response was less severe than that recorded for the early and mid-season stress treatments (means of 16.6 ($P<0.10$), 15.9 ($P<0.05$), 15.9 ($P<0.05$) and 18.2 kg plot^{-1} for the late, mid, early and control, respectively).

Specific gravity and fry color are important components of processing quality. In the analysis of both data sets, midseason moisture stress reduced ($P<0.10$) specific gravity (Tables 4 and 6). In the analysis of variance of both data sets, the year x stress interaction for chip color was significant ($P<0.05$) (Tables 6 and 7). In 1990 the early, and in 1992, mid-season stress reduced ($P<0.05$ and $P<0.10$, respectively) fry color. However, in 1991, the fry color was not influenced by stress treatment. This result is similar to that reported by Iritani (5) but not consistent with data reported by Shock *et al.* (12, 13) who found that early season stress improved fry color. The year x stress interaction recorded in our study suggests that the growing environment influences the response of fry color to moisture stress. Fry color was highly correlated (r=-0.70**) with reducing sugars in all three years that the study was conducted.

Conclusions

Previous research (8), as well as our current study, indicate differences in moisture stress response among varieties. In this study, all varieties were

TABLE 6.—*Mean squares from analyses of variance to study effects of stress (S), variety (V), year (Y) and their interactions for specific gravity and fry color (1990-1992).*[1]

Source of variation	DF	Specific gravity	Fry color[2]
Y	2	0.00120	16461
Block (Y)	5	0.00005	121
S	2	0.00025†	241 NS
SxY	4	0.00005 NS	302*
Error A	10	0.00011	72
V	7	0.00054**	1784**
VxS	14	0.00004 NS	60 NS
VxY	14	0.00003 NS	191**
VxSxY	28	0.00001 NS	83 NS
Error B	209	0.00003	68

[1]Analysis using stress treatments E=early; M=midseason; C=control; *, **, † $P<0.01$, $P<0.05$, $P<0.10$; NS $P>0.10$.
[2]Fry color scored on a 10-100 scale (100 being best) - Agriculture and Agri-Food Canada Color Chart.

TABLE 7.—*Effect of early, midseason and late season moisture stress on fry color in 1990, 1991 and 1992.*[1]

Treatment	Fry color[2,3] 1990	1991	1992
Early	61.2*	57.1	38.6
Midseason	64.1	49.8	36.2†
Late	70.8	-	42.9†
Control	67.7	53.1	39.6

[1]The stress x year interaction for fry color was significant ($P<0.05$) in the ANOVA for 1990-1992 as well as for 1990 and 1992.
[2]Fry color was scored on a 10-100 scale (100 being best) - Agriculture and Agri-Food Canada Color Chart.
[3]†, * stress treatments are significantly different from the control at the 10% and 5% significance levels, respectively, using the least significance difference (LSD) test.

negatively impacted by moisture stress imposed at all stages during the growing season. In the first data set, the variety x moisture stress interaction was significant. Atlantic and Conestoga, under southern Alberta conditions, appear to be more sensitive to early and midseason transient moisture stress than the other 6 varieties included in the study. On the other hand the total yield of Norchip appeared to be improved by early season moisture stress. This was an unexpected result and should be confirmed before recommendation as a production practice. Our data support the conclusion of Stark and McCann (16) that transient moisture stress in the late season has less impact on marketable tuber yield than stress in the early and midseason.

The significance of the year x stress x variety interaction for average tuber weight and average marketable tuber weight suggest that differences between results obtained by Shock *et al.* (12) and data from our study likely reflect differences in the growing season between Klamath Falls (Oregon) and Vauxhall (S. Alberta) and the capacity of a variety to compensate for the reduced tuber set caused by early season moisture stress. In addition, our study investigated the effect of a single transient stress, while Shock *et al.* (12) studied the impact of a prolonged early stress on yield and quality. The significance of the year x moisture stress interaction suggests that the effect of early and midseason moisture stress on fry color is modified by other factors in the environment.

The results of this study demonstrate that, ideally, producers in S. Alberta should schedule irrigation to ensure adequate levels of soil moisture throughout the growing season. In situations where water is limited, and, in particular, for varieties sensitive to transient moisture stress such as Atlantic and Conestoga, our data indicate that moisture stress in the early and midseason will cause a greater reduction in yield and quality than where stress occurs late in the growing season.

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Literature Cited

1. Dubetz, S. and K.K. Krogman. 1973. Comparison of methods of scheduling irrigations of potatoes. Am Potato J 50:408-414.

2. Farries, B.C., D.R. Lynch and N. Foroud. 1994. A portable rainshelter for moisture stress studies. Am Potato J (submitted).

3. Foroud, N., D. R. Lynch and T. Entz. 1993. Potato water content impact on soil moisture measurement by neutron meter. Plant and Soil 148:101-106.

4. Harris, P.M. 1978. Water. Pp. 244-277. *In:* The Potato Crop ed. P.M. Harris. Chapman and Hall, London. 730 pp.

5. Iritani, W.M. and L. Weller. 1973. The development of translucent end tubers. Am Potato J 50:223-233.

6. Kempthorne, O. 1952. The design and analysis of experiments. John Wiley and Sons, New York. 631 pp.

7. Larsen, D.C. 1984. Simplifying potato irrigation scheduling - The Idaho program. Am Potato J 61:215-227.

8. Lynch, D.R. and G.C.C. Tai. 1989. Yield and yield component response of eight potato genotypes to water stress. Crop Sci 29:1207-1211.

9. MacKenzie, R.C. 1987. The effect of water and nitrogen on the yield and quality of potatoes. pp. 21-24. *In:* Proc. of the 15th Annual Meeting of Prairie Potato Council, Calgary, AB.

10. Martin, R.J., P.D. Jamieson, D.R. Wilson and G.S. Francis. 1992. Effects of soil moisture deficits on yield and quality of Russet Burbank potatoes. New Zealand Journal of Crop and Horticultural Science 20:1-9.

11. SAS Institute Inc. 1989. SAS/STAT® User's Guide, Version 6, 4th Ed., Vol 1, 2. Cary, NC: SAS Institute, Inc. 1686 pp.

12. Shock, C.C., J.C. Zalewksi, T.D. Stieber and D.S. Burnett. 1992. Impact of early-season water deficits on Russet Burbank plant development, tuber yield and quality. Am Potato J 69:793-803.

13. Shock, C.C., Z.A. Holmes, T.D. Stieber, E.P. Eldredge and P. Zhang. 1993. The effect of timed water stress on quality, total solids and reducing sugar content of potatoes. Am Potato J 70:227-241.

14. Singh, G. 1969. A review of soil-moisture relationship in potatoes. Am Potato J 46:398-403.

15. Sowokinos, J.R. 1978. Relationship of harvest sucrose content to processing maturity and storage life of potatoes. Am Potato J 55:333-344.

16. Stark, J.C. and I.R. McCann. 1992. Optimal allocation of limited water supplies for Russet Burbank potatoes. Am Potato J 69:413-421.

17. Struik, P.C. and G. Van Voorst. 1986. Effects of drought on the initiation, yield and size distribution of *Solanum tuberosum L.* cv. Bintje. Potato Res 29:487-500.

18. Loon, C.D. van. 1981. The effect of water stress on potato growth, development, and yield. Am Potato J 58:51-69.