Using Canopy Temperature Measurements to Evaluate Drought Tolerance of Potato Genotypes

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Abstract. Field studies were conducted in 1986 and 1987 to evaluate the potential of using canopy temperature measurements to evaluate the relative drought tolerance of potato genotypes. In both years, 14 potato genotypes representing a relatively wide range of *Solanum tuberosum* L. germplasm were grown under well-watered [irrigation $\approx$ 100% potential evapotranspiration (ET)] and stressed (irrigation $\approx$ 40% to 50% potential ET) conditions. Irrigation differences were imposed with a line source irrigation system. Canopy temperatures of the 14 genotypes were measured between 0900 and 1430 HR on 7 clear days during tuber bulking. A general linear relationship between canopy minus air temperature (ΔT) and air vapor pressure deficit (VPD) was determined for each year by regressing all ΔT data onto corresponding VPD values. The relative sensitivity of each genotype to changes in VPD was determined by regressing observed ΔT values onto the estimated ΔT from the general equation for that year. Genotypes with higher than average temperatures under well-watered conditions were generally less sensitive to changes in VPD than those with lower than average temperatures. Warmer genotypes under well-watered conditions were also generally less susceptible to drought than cooler genotypes. Thus, ΔT measurements from well-watered plots can be effectively used to assess the relative drought tolerance of potato genotypes.

Canopy temperature measurements have been widely used in recent years to study the drought response of various crops (Blum et al., 1989; Chaudhuri et al., 1986; Hatfield et al., 1987; Singh and Kanemasu, 1983; Stark and Pavek, 1987). This approach is based upon the close, inverse relationship between leaf temperature and transpirational cooling (Jackson, 1982). Negative correlations between canopy temperature and water use have been reported for corn (Mtui et al., 1981) and sorghum (Chaudhuri and Kanemasu, 1982).

Blum et al. (1989) used canopy temperatures of drought-stressed wheat genotypes to characterize yield stability under various moisture conditions. They found a positive correlation between drought susceptibility and canopy temperature in stressed environments. Genotypes that suffered greater relative yield losses under drought stress tended to have warmer canopies at midday. Similar results have also been reported for potatoes (Stark and Pavek, 1987).

Results from several recent studies indicate that ΔT from nonstressed environments can also be used to screen crop genotypes for drought susceptibility or yield stability. Singh and Kanemasu (1983) reported that the ratio of nonirrigated : irrigated yield of pearl millet genotypes was positively correlated with ΔT from the irrigated environment. Hatfield et al. (1987) found that cotton strains that had higher canopy temperatures in irrigated plots produced greater biomass in dryland plots.

Chaudhuri et al. (1986) used relationships between ΔT and corresponding air VPD measurements to characterize the response of sorghum and millet genotypes to changes in evaporative demand. They found that under well-watered conditions, warmer genotypes were generally less sensitive to changes in VPD than cooler genotypes. In addition, they found that the warmer genotypes were generally more productive under drought-stressed conditions.

Compared with most field crops, potatoes are considered to

be relatively drought-susceptible (Van Loon, 1981). Potato cultivars developed in North America and Europe are generally best adapted to cool, temperate zones. However, there currently is considerable interest in developing potato cultivars that will perform well in areas with hot, dry climates (Levy, 1986a, 1986b; Martin and Miller, 1983).

This study was conducted to determine whether ΔT and VPD data from well-watered potatoes can be used to characterize the relative drought susceptibility of potato genotypes.

Materials and Methods

Fourteen potato genotypes were grown in 1986 and 1987 at the Aberdeen Research and Extension Center, Aberdeen, Idaho, under well-watered (irrigation =100% potential ET) and stressed (irrigation $\approx$ 40% to 50% potential ET) conditions. The 14 genotypes represent a relatively wide range of *S. tuberosum* germplasm. Maximum vine size and leaf area for these 14 genotypes were fairly similar, with the exception of 'Frontier Russet' and 'Nooksack', which produced somewhat smaller vines. The experiments were conducted on a Delco silt loam (coarse-loamy, mixed, mesic Xerollic Calciorthid). All plots received a preplant application ($\text{kg}\cdot\text{ha}^{-1}$) 200 N, 80 P, and 80 K in 1986 and 1987.

A line-source sprinkler system (Hanks et al., 1976) was used to apply different amounts of water to $8 \times 12\text{-m}$ plots of each genotype. Plots were arranged in a randomized complete-block design with six replications (three on each side of the line source). Potato rows were planted with a 0.91-m row spacing and were oriented parallel to the line source so that row positions could be associated with specific irrigation environments. Rows designated as well-watered and stressed environments were located 1.4 and 10 m from the line source, respectively. Evapotranspiration was estimated from changes in soil water content in the well-watered plots. Gravimetric soil water content for the 0 to 60-cm depth was determined at 2- to 3-day intervals throughout the growing season. Available soil water content in the well-watered plots was consistently maintained above 65%. Stressed rows received a total of 212 and 193 mm of irrigation + pre-

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Abbreviations: DSI, drought susceptibility index; ET, evapotranspiration; AT, canopy - air temperature; VPD, vapor pressure deficit.

precipitation in 1986 and 1987, respectively, while the well-watered rows received 464 and 470 mm, respectively.

Canopy temperatures of the 14 genotypes were measured in the well-watered rows between 0900 and 1430 HR on 7 clear days each year during tuber bulking. Canopy temperature was measured with a hand-held infrared thermometer (Teletemp Model AG-42, Fullerton, Calif.) calibrated regularly with a blackbody source to within $\pm 0.3^\circ\text{C}$. The instrument was held so as to view the crop at an angle of 30° from the horizontal at right angles to the rows at a distance of 2.0 m from the sample row. This procedure was followed to minimize the influence of soil exposure. Each canopy temperature measurement was the average of six readings (three from each side of the row). Air temperature and VPD were determined concurrently with each set of six canopy temperature measurements using an aspirated psychrometer held ≈ 1 m over the crop canopy. Each set of measurements took ≈ 2 min to complete and individual readings usually were within $\pm 0.2^\circ\text{C}$. Air temperatures during the sampling periods ranged from 18.3 to 33.4°C , while VPD ranged from 1.22 kPa to 4.68 kPa. ΔT typically was -1.0 to -2.5°C during the midmorning hours and increased to -4.0 to -6.5°C during the midafternoon. Wind speeds during the measurement periods were negligible (< 2 m/s).

A general linear relationship between ΔT and VPD was determined for each year by regressing all AT data for each of the 14 genotypes on to corresponding VPD values in kilopascals. The general equation for all genotypes was $\Delta T = 0.36 - 1.41 \text{ VPD}$ ($r^2 = 0.70$) in 1986; and $\Delta T = 0.56 - 1.76 \text{ VPD}$ ($r^2 = 0.83$) in 1987. The relative sensitivity of each genotype to changes in VPD was determined by regressing observed ΔT values onto the estimated ΔT ($\hat{\Delta T}$), determined from the general equation for all genotypes for the corresponding VPD value. Genotypes having slopes (represented by $\Delta T/\hat{\Delta T}$) > 1.0 or < 1.0 are interpreted as having greater or lesser sensitivity to changes in VPD compared to the average response for all genotypes (Chaudhuri et al., 1986). Examples of two genotypes having above or below average sensitivities to changes in VPD are presented in Fig. 1.

The single-row plots were mechanically harvested on 3 Oct. 1986 and 22 Sept. 1987. A drought susceptibility index (DSI) was subsequently determined for each genotype using the relationship presented by Fischer and Maurer (1978), $\text{DSI} =$

$(1 - Y_d/Y_w)/(1 - Y_d/Y_w)$ where Y_d = fresh tuber yield~under drought, Y_w = fresh tuber yield~under full irrigation, Y_d = mean Y_d for all genotypes, and Y_w = mean Y_w for all genotypes. This index provides a measure of relative drought tolerance based on minimization of yield loss under drought. Values > 1.0 indicate greater than average drought susceptibility while values < 1.0 indicate 'greater than average drought resistance.

Results

Drought susceptibility index values ranged from 0.86 to 1.16 in 1986 and from 0.88 to 1.08 in 1987 (Table 1). The results for 1986 and 1987 indicate that 'Russet Burbank', 'Red Pontiac', NDA1725-1, and A76147-2 are relatively drought susceptible ($\text{DSI} > 1.0$), while A79368-2, 'Monona', A79239-7, DTO-28, A7411-2, and 'Nooksack' are relatively drought resistant ($\text{DSI} < 1.0$).

Mean ΔT values for the 14 potato genotypes ranged from -2.87 to -4.21°C in 1986 and from -2.93 to -4.12°C in 1987. The mean ΔT for all genotypes was -3.52 and -3.46°C in 1986 and 1987, respectively. Mean ΔT values for the 14 genotypes were linearly related to slopes from regressions of ΔT on $\hat{\Delta T}$ in both 1986 and 1987 (Fig. 2). Genotypes with higher than average temperatures were generally less sensitive to changes in VPD than genotypes with lower than average temperatures. 'Red Pontiac', 'Frontier Russet', NDA1725-1 and A76147-2 consistently exhibited above average sensitivity to changes in VPD (slopes > 1.0), while 'Lemhi Russet', A79368-2, 'Monona', A79239-7, DTO-28, and A7411-2 were relatively insensitive to VPD (slopes < 1.0).

Mean ΔT and slopes of ΔT on $\hat{\Delta T}$ ($\Delta T/\hat{\Delta T}$) were not significantly correlated with stressed yield or well-watered yield (Table 2). However, mean ΔT was negatively correlated with DSI in 1986 and 1987, and $\Delta T/\hat{\Delta T}$ was negatively correlated with DSI in 1987.

The relationship between mean ΔT and DSI was linear for both years of the study (Fig. 3). Drought susceptibility of the different genotypes decreased as ΔT increased. 'Red Pontiac', 'Frontier Russet', NDA1725-1, and A76147-2 consistently had lower than average canopy temperatures, while A79368-2, 'Monona', A79239-7, and A7411-2 were consistently warmer than average. With the exception of 'Frontier Russet', the yield responses of these two groups consistently fell within the drought susceptible and drought tolerant categories, respectively. The other six genotypes exhibited greater variability in the relationship between mean ΔT and DSI.

Discussion

Results of this study show that canopy temperature measurements from well-watered plots can provide an indication of relative drought susceptibility for different potato genotypes. However, genotypes with canopy temperatures that were well above or below average were easier to characterize than those with intermediate temperatures. For example, the relatively high drought susceptibility of 'Red Pontiac', NDA1725-1, and A76147-2 could be readily distinguished by comparing their relatively low temperatures with those of the other genotypes. At the other extreme, the comparatively high canopy temperatures of 'Monona' and A79368-2 gave a clear indication of their high degree of drought resistance. The drought responses of genotypes with intermediate temperatures were more variable.

Warmer potato genotypes were also less sensitive to changes in VPD than cooler genotypes. However, correlations between

Fig. 1. Linear regressions of observed ΔT onto estimated ΔT at a given VPD for two potato genotypes in 1986. The dashed line indicates the 1:1 relationship for all 14 genotypes.

Table 1. Yield of 14 potato genotypes under stressed (Y_d) and well-watered (Y_w) conditions and corresponding DSI and mean ΔT values in 1986 and 1987.

Genotype	Yield (t·ha ⁻¹)							
	1986				1987			
	Y_d	Y_w	DSI ^z	ΔT	Y_d	Y_w	DSI	ΔT
1. Russet Burbank	15.8	37.1	1.16	-3.83	16.1	33.9	1.02	-3.25
2. Lemhi Russet	22.1	46.6	1.06	-3.45	18.5	37.5	0.98	-3.35
3. Frontier Russet	17.6	32.4	0.94	-3.68	15.3	32.8	1.04	-4.12
4. A79368-2	22.4	39.8	0.89	-2.98	15.8	29.5	0.90	-3.00
5. Monona	21.6	37.1	0.86	-2.87	15.9	29.0	0.88	-2.93
6. Kennebec	22.2	47.0	1.07	-3.59	22.4	42.7	0.94	-3.26
7. A79239-7	17.7	34.5	0.98	-3.32	16.0	32.5	0.99	-3.24
8. DTO-28	22.3	41.8	0.94	-3.38	18.7	35.3	0.92	-3.53
9. Red Pontiac	22.3	46.5	1.06	-3.93	20.3	42.8	1.05	-3.85
10. NDA1725-1	23.2	51.5	1.13	-4.21	19.1	42.3	1.08	-4.06
11. A76147-2	22.8	46.8	1.05	-3.88	20.7	43.5	1.02	-3.59
12. Bintje	18.5	35.9	0.99	-3.41	15.5	33.2	1.04	-3.62
13. A7411-2	21.4	37.4	0.88	-3.30	16.1	32.3	0.97	-3.05
14. Nooksack	19.0	33.3	0.87	-3.42	16.6	32.7	0.97	-3.60
Mcan	20.7	40.5		-3.52	17.6	35.7		-3.46
LSD _{0.05}	4.9	3.5	0.08		3.8	3.1	0.05	

$$^z\text{DSI} = (1 - Y_d/Y_w)/(1 - Y_d/Y_w)$$

Fig. 2. Relationships between mean ΔT and the slope from regressing ΔT on ΔT for 14 potato genotypes grown in 1986 (top) and 1987 (bottom). Numerical designations refer to the 14 genotypes as presented in Table 1.

Table 2. Simple correlations of stressed yield, well-watered yield, and DSI values with mean ΔT values and slopes of regressions of ΔT^z on ΔT^y ($\Delta T/\Delta T$).

Yield variable	1986		1987	
	ΔT	$\Delta T/\Delta T$	ΔT	$\Delta T/\Delta T$
Stressed yield	-0.02	-0.05	-0.20	0.24
Well-watered yield	-0.53	0.30	-0.47	0.49
DSI	-0.78**	0.42	-0.73**	-0.66**

^z ΔT = canopy - air temperature.

^y ΔT = estimated ΔT from the general equation for all genotypes at a given VPD.

**Significant at $P = 0.01$.

VPD sensitivity ($\Delta T/\Delta T$) and DSI were not as high as those between mean ΔT and DSI. Therefore, the more straightforward approach of measuring ΔT in well-watered plots appears to be a more effective means of assessing potato drought susceptibility than comparing ΔT vs. VPD relationships.

The close relationship between ΔT and DSI is consistent with the results of Hatfield et al. (1987) and Chaudhuri et al. (1986) who found that cotton, sorghum, and millet genotypes that had the warmest canopies under well-watered conditions generally produced the greatest biomass or yield under drought-stressed conditions. Hatfield et al. (1987) proposed that genotypes with high water-conserving ability will transpire less under optimal soil water conditions, thereby reducing transpirational cooling and increasing canopy temperature. The resulting lower crop water use should allow these genotypes to conserve more water for use during periods of drought.

Some investigators have used canopy temperatures from drought-stressed plots to assess genotypic response to drought (Blum et al., 1989; Stark and Pavek, 1987). In these studies, the most drought-resistant genotypes usually had the lowest canopy temperatures during periods of drought, apparently due to a greater ability to conserve or extract soil water.

There are, however, several advantages in using ΔT data from nonstressed environments to characterize genotypic response to drought. From a management standpoint, it is much easier to standardize soil water levels under irrigated conditions

Fig. 3. Relationship between mean ΔT and the drought susceptibility index for 14 potato genotypes grown in 1986 (top) and 1987 (bottom). Numerical designations refer to the 14 genotypes as presented in Table 1.

than under nonirrigated conditions. As soil water deficits increase, variability in soil texture and water-holding capacity will become an increasingly important source of variation that may mask genotypic differences. Differences in ΔT among genotypes also tend to narrow with increasing water stress, making it more difficult to use this variable to screen for drought resistance (Singh and Kanemasu, 1983). Furthermore, data can be collected from existing irrigated breeding plots, thereby avoiding the establishment of a parallel set of nonirrigated plots or the use of rain shelters.

It should be noted that the index used in this study to describe

drought susceptibility is based on differences in fresh tuber weight and does not reflect differences in tuber quality. The quality and marketability of certain cultivars are often greatly affected by the timing and duration of water stress (Lynch and Tai, 1989; Miller and Martin, 1987). Consequently, additional research is needed to evaluate relationships between canopy temperature and tuber quality characteristics.

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