EXCESS AND DEFICIENT WATER STRESS EFFECTS ON 30 YEARS OF AROOSTOOK COUNTY POTATO YIELDS[1]

G.R. Benoit and W.J. Grant[2]

Abstract

Potato production can be adversely affected by both deficient and excess water. A plant water excess (PWE) index is defined as the difference between actual evapotranspiration (AET), which is equal to the difference between rainfall and runoff, and potential evapotranspiration (PET), as computed by the Thornthwaite method, for those 5-day periods when AET exceeds PET. A growing season PWE index was equal to the accumulation of 5-day average PWE values and was calculated for each of 30 years of data. Similarly a plant water deficit (PWD) index was defined as the PET-AET for those 5-day periods when PET exceeds AET. Potato yields during the 30-year period were related to the combined effect of yearly water excess (PWE) and deficit (PWD) and can be described by the multiple regression relationship of

$$Y = 43.558 - 0.74527\ (PWD + PWE) + 0.031883\ (PWD \times PWE).$$

This model has a multiple r^2 value that indicates 46% of the yield variation can be accounted for by the combined yearly influence of deficient and excess water. The results suggest that maximizing potato production in the humid Northeast requires a water management system that includes both supplemental irrigation and drainage.

Resumen

La producción de papa puede ser afectada adversamente tanto por la deficiencia como por el exceso de agua. Un índice del exceso de agua en la planta (PWE) se define como la diferencia entra la evapotranspiración real (AET), que es igual a la diferencia entre la precipitación y el escurrimiento, y la evapotranspiración potencial (PET), tal como se calcula por el método de Thornthwaite, para aquellos períodos de 5 días en que AET excede a PET. El índice PWE en una estación de crecimiento fue igual a la acumulación de valores promedios PWE de 5 días y fue calculado para los datos de cada uno de los treinta años. De manera similar se definió un

[1]Contribution from the New England Plant, Soil and Water Laboratory, Agricultural Research Service, USDA, and the Maine Agricultural Experiment Station, University of Maine, Orono, Maine 04469.

[2]Soil Scientists, USDA, ARS, New England Plant, Soil and Water Laboratory, University of Maine, Orono, Maine 04469. Benoit presently stationed at North Central Soil Conservation Research Laboratory, Morris, Minnesota 56267.

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índice de deficiencia de agua de la planta (PWD) como PET-AET para aquellos períodos de 5 días en que PET excede AET. Los rendimientos de papa durante el período de 30 años fueron relacionados al efecto combinado de excesos anuales de agua (PWE) y de déficit (PWD) y puede describirse según una relación de regresión múltiple de

$$Y = 43.558 - 0.74527\ (PWD + PWE) + 0.031883\ (PWDxPWE).$$

Este modelo tiene un valor r^2 múltiple que indica que 46% de la variación del rendimiento puede atribuirse a la influencia anual combinada del agua en déficit y en exceso. Los resultados sugieron que para maximizar la producción de papa en al húmedo Nor-este se requiere un sistema de manejo de agua que incluya tanto riego suplementario como drenaje.

Introduction

For many years there has been great concern over the effect of water stress on crop production. Irrigation needs for maximum potato production have been of interest in humid areas where there is a probability of unfavorable distribution of precipitation. There has been much less interest on the effect of excess water on potato growth and tuber production.

Previously (1), we evaluated the relationship between accumulated 5-day plant water deficit (PWD) values for each of 30 growing seasons and the respective yearly potato yields in Aroostook County, Maine. Seasonal plant water deficits ranged from 11.94 cm to 28.72 cm. A highly significant negative correlation between PWD and potato yield was observed, with 32% of year to year variation in potato yield accounted for by PWD effects alone. The study verified prior work in that it demonstrated the potential benefit of properly timed supplemental irrigation (3, 4, 7, 8, 9, 11).

In the humid East and Northeast, plant growth restrictions can also occur as a result of plant water excess (10). Even those years with maximum water deficits may have extended wet periods that can cause water excess problems (pore aeration for example) that restrict plant growth during parts of the growing season. Total water stress related plant growth restrictions in the humid Northeast are likely the cumulative effect of both PWD and plant water excess (PWE) events during any one growing season. Bushnell (2) showed retardation and abnormal shapes of potato tubers attributed to poor aeration. Harkett and Burton (5) found that low oxygen near the seed piece interfered with tuber formation. Saini (10) found that oxygen diffusion rate of subsoil was highly correlated with marketable potato yield for several soils in New Brunswick. Holder and Cary (6) state that so much attention has been given to the effects of drought on the quality of Idaho Russet Burbank potatoes, that some growers may now overirrigate. They found that a wet treatment irrigated at a soil water potential of -30 to -40 kPa gave significantly more knobby and undersized tubers and a lower percentage of U.S. #1 tubers than dryer treatments.

Our objective was to develop a PWE index and to evaluate the combined effect of yearly PWD and PWE on Aroostook County potato production over 30 years.

Methods

In our previous work (1), PWD for any particular crop season (31 May to 27 September) was computed from the equation

$$PWD = \Sigma\ (\overline{PET}-\overline{AET})\ N \qquad [1]$$

for those 5-day periods where PET > AET.

In Eq. [1] PWD = total seasonal plant water deficit (cm);

N = the number of days in a time period (5 in this instance);

$\overline{PET}$ = average potential evapotranspiration (cm/day) as calculated by the Thornthwaite method for each 5-day time period (12);

$\overline{AET}$ = average actual evapotranspiration (cm/day) for the same time period and is computed by the equation $\overline{AET} = \overline{R} - (\overline{SF}-\overline{BF})$ with $\overline{R}$, $\overline{SF}$, and $\overline{BF}$ equal to average precipitation (cm/day), average total stream flow (cm/day), and average base stream flow (cm/day), respectively, during a 5-day period for the potato producing area of the Aroostook River watershed. The simplifying assumption was made that all precipitation (R) not appearing as part of streamflow infiltrated the soil and was used in the evapotranspiration process.

For the present study, Eq. [1] was modified to yield a total seasonal plant water excess (PWE) index (cm) computed as

$$PWE = \Sigma|\ \overline{PET}-\overline{AET})|\ N \qquad [2]$$

for those 5-day periods where $\overline{PET} < \overline{AET}$. In this case $\overline{AET}$ could be redefined as "available evapotranspiration" in that it is water that could be used by a plant if needed but is in excess of the needs established by $\overline{PET}$.

PWE and PWD values for the 30 years from 1946-1975 inclusive were related singly and in various combinations through a simple and multiple correlation analysis to the Aroostook County potato yield. Interactive effects were evaluated by using a stepwise multiple regression analysis that yields a best fit statistical equation composed only of those parameters that make a significant contribution to the equation's prediction ability.

Results and Discussion

As in our previous work, the intent here has been to evaluate the singular effect of total water stress on potato production in Aroostook County, Maine. Only the effects of water deficits (PWD) and water excess (PWE) or related water availability or use indices alone or in various combinations have been considered. No attempt has been made to evaluate other yield influencing parameters.

Over the 30-year period 1946-1975, potato yields ranged from 23.07 to 32.26 t/ha (Table 1) in Aroostook County, Maine. During that period, growing degree days (GDD), precipitation (R), PWD, PWE, PET, AET, and AET/PET were highly variable (Table 1). Simple correlation of yield with GDD, PWD, AET and AET/PET yielded significant r values (5% probability level). No significant simple relationship was found between yield and R, PWE, PET, PWD-PWE, PWE/PWD or PWD × PWE. However, PWD + PWE was significantly and negatively correlated with yield.

Obviously, many of these parameters are related to each other and may have interactive effects on yield. Parameters that have no significant effect alone may interact with others to make a significant contribution in a mul-

TABLE 1. — *Potato yields (t/ha) as related to some climatic stress indices over a 30-year period, Aroostook County, Maine.*

Year	Yield	GDD	Precip.	PWD	PWE	PET	AET	AET/PET
	t/ha		cm	cm	cm	cm	cm	
1946	24.08	2,416	30.91	19.81	9.14	39.34	19.53	0.50
1947	23.52	2,646	35.97	23.88	13.33	42.32	18.44	0.44
1948	25.87	2,482	31.93	20.70	9.78	40.36	19.66	0.49
1949	30.91	2,604	39.85	19.68	13.84	42.06	22.38	0.53
1950	32.26	2,237	31.80	14.73	4.95	38.12	23.39	0.61
1951	30.24	2,429	44.55	16.51	10.29	40.11	23.60	0.59
1952	25.42	2,703	32.33	22.99	6.60	43.26	20.27	0.47
1953	26.54	2,481	21.72	23.37	3.30	40.49	17.12	0.42
1954	23.07	2,230	62.61	18.03	21.46	37.82	19.79	0.52
1955	28.45	2,552	31.06	25.78	13.84	41.81	16.03	0.38
1956	31.81	2,133	33.17	11.94	7.24	37.29	25.35	0.68
1957	30.91	2,357	39.45	14.10	11.56	39.34	25.24	0.69
1958	28.00	2,260	48.84	15.11	19.94	38.07	22.96	0.60
1959	27.22	2,610	39.29	21.34	14.10	44.40	23.06	0.52
1960	25.65	2,564	32.79	18.80	7.37	41.63	22.83	0.55
1961	28.11	2,694	45.42	18.80	15.49	42.11	23.31	0.55
1962	29.68	2,301	39.93	17.02	9.91	38.35	21.33	0.56
1963	30.24	2,498	36.09	21.59	8.76	40.72	19.13	0.47
1964	30.69	2,294	25.55	18.80	3.05	39.62	20.82	0.52
1965	26.66	2,413	29.62	18.80	8.00	38.74	19.94	.051
1966	26.88	2,412	24.74	22.61	6.22	38.99	16.38	0.42
1967	26.66	2,733	42.21	18.29	13.97	44.17	25.88	0.59
1968	26.32	2,552	21.62	25.78	5.71	41.10	15.32	0.37
1969	25.20	2,470	44.60	16.89	16.13	40.21	23.32	0.58
1970	26.66	2,809	35.71	22.99	10.41	44.17	21.18	0.48
1971	29.12	2,479	29.01	16.76	3.05	40.72	23.96	0.59
1972	29.12	2,498	46.99	18.80	16.38	41.12	22.32	0.54

Year	Yield	GDD	Precip.	PWD	PWE	PET	AET	AET/PET
1973	23.52	2,795	31.60	25.53	6.98	44.45	18.92	0.43
1974	29.12	2,507	33.27	18.80	8.00	41.71	22.91	0.45
1975	24.64	2,710	28.45	24.89	5.59	43.31	18.42	0.43
Simple R value		-0.45*	-0.03	-0.57*	-0.17	-0.35	-0.47*	0.55* [†]
Range	23.07–32.26	2,133–2,809	21.62–62.61	11.94–25.98	3.05–21.46	37.29–44.45	15.32–25.88	0.37–0.68

*Significant at 5% level.

tiple regression equation. Our stepwise multiple regression analysis resulted in the yield equation.

$$Y = 43.558 - 0.74527\ (PWD + PWE) + 0.031883\ (PWD \times PWE).$$

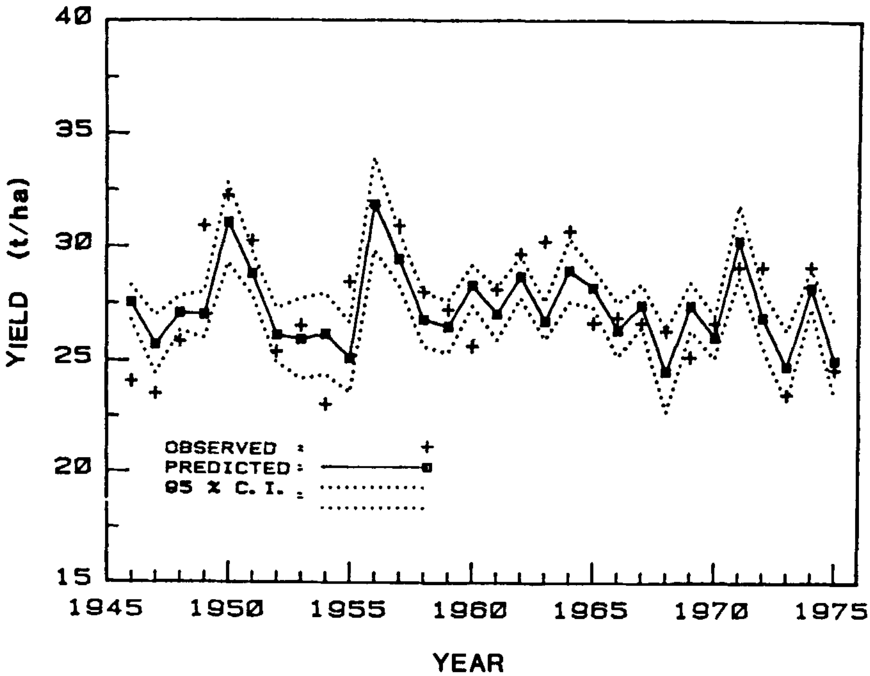

FIG. 1. Actual Aroostook County potato yields over a 30-year period compared to values predicted from the equation

$$Y = 43.558 - 0.74527\ (PWD + PWE) + 0.031883\ (PWD \times PWE).$$

The dotted lines represent the 95% confidence intervals about the predicted values. The multiple correlation coefficient = 0.677.

This equation has a multiple r^2 value of 0.46 indicating that 46% of the total variation in potato yields over the 30-year period of concern can be accounted for by the effect of plant water stress caused by the combined yearly influence of deficient and excess water.

Predicted potato yield values for the 30 years of record follow the same general trend as the observed values (Figure 1) with most observed values falling within the 95% confidence interval band. Tests for model significance indicate that the probability that the model is not valid is less than 0.01%.

The model predicts a top potato yield of 43.6 t/ha for a year with zero values for both PWD and PWE. Any deviation from a zero value for either variable will result in reduced yield (Figure 2). The effect on potato yield of increasing PWD or PWE depends on the interaction on one variable with the other. For instance, an increasing PWD causes decreased yields with a constant zero PWE and increased yields with PWE at a constant 30 cm. Maximum yields with 30 cm of excess water occur with a PWD value of 30 cm. Holding PWD constant and varying PWE, yields the same type of result as discussed for constant PWE values. Holding either PWD or PWE constant at a value of 22 to 24 cm and letting the other vary over the 0- to 30-cm range results in no real change in yield.

Each growing season in Aroostook County, Maine, has periods of both excess and/or deficient water even though on a yearly total basis, AET is al-

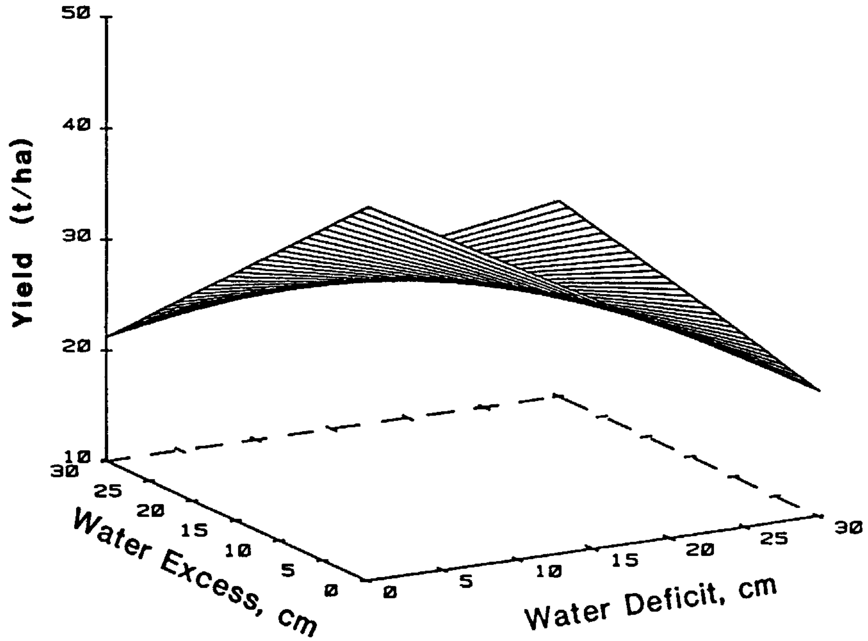

FIG. 2. Response surface showing the combined effect of PWD and PWE on potato yields.

ways less than PET. Over the 30 years of study, PWD had an average value of 19.77 cm and ranged from 11.94 to 25.98 cm. PWE had an average of 10.15 cm and ranged from 3.05 to 21.46 cm (Table 1). PWE exceeded PWD only during 1954 and 1958.

The effect of seasonal PWD on potato yields over a 30-year period was reported earlier (1) and indicated the need for supplemental irrigation at some point for each year. The present work shows that potato yields vary as a result of total plant water stress in any growing season. Such stress can be considered to be the combined interactive effect of the seasonal sum of both PWD and PWE with the work reported here indicating that these two parameters account for 46% of the variation in potato yields. The results suggest that maximizing potato production in the humid Northeast requires a total water management system that includes both supplemental irrigation and drainage.

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