WATER MANAGEMENT IN POTATO PRODUCTION

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

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ABSTRACT

WATER MANAGEMENT IN POTATO PRODUCTION

By

Ana F. Garay

The present acreage of irrigated potatoes is the largest among irrigated crops in Michigan. In terms of total amount of irrigation water used, potatoes rank second only to golf courses. The use of irrigation water on one of Michigan's best cash crops is not only going to be maintained but will probably be accentuated in the present decade.

Irrigation is being used primarily to supplement inadequate rainfall during the growing season. However, the wide usage of supplementary irrigation is not matched in knowledge, acceptance and use of modern irrigation management techniques required for more efficient use of the water applied.

This study was initiated to develop better irrigation management techniques in potato production. The experimental objectives and results were:

1. To determine the effect of time of initiation of irrigation on the quality and yield of tubers. In 1971, irrigations were started at 50, 60 and 70 days after

planting. In 1972, the initial irrigations were applied at 30, 50 and 70 days, respectively. In 1971, the plots irrigated at 50 days showed a significant yield increase compared to the plots receiving the initial irrigation at 70 days. Ample rainfall during the 1972 growing season eliminated any differential soil moisture effects and masked any yield differences due to the time of initiating irrigation.

2. To measure the effect of two levels of irrigation cooling. Intermittent, low volume sprinkler irrigation was applied in 1971 whenever the temperature was higher than 75 and 80°F. In 1972, temperature levels were changed to 80 and 85°F. Data from this experiment did not indicate any appreciable benefit from these cooling treatments.

3. To compare two quantities of water applied per irrigation. In 1972, a 1/2-inch irrigation was compared with a 1-inch irrigation. No significant yield or other visual differences were observed. During wet periods of the growing season the 1/2-inch irrigation resulted in water saving which could reduce nutrient leaching.

4. To evaluate the effect of periodic applications of small amounts of nitrogen fertilizer through the irrigation system. The 1972 data showed measurable yield increases with the periodic nitrogen application. In Kennebec potatoes the treatments resulted in an average increase

of 69 cwt/acre. For Russet Burbank potatoes the equivalent value was 71 cwt/acre.

5. To devise an accurate and simple scheme for scheduling crop irrigations. Irrigation frequency and quantity, precipitation gains, evaporative losses, soil type, and crop stages were considered and programmed into this scheme. Weather pan evaporation data were used to estimate soil water losses. A water balance chart was devised from this data for computing and graphically demonstrating the soil water status on a daily or weekly basis.

WATER MANAGEMENT IN POTATO PRODUCTION

By

Ana F. Garay

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INTRODUCTION

During the period 1961-70, Michigan produced an average 220 hundredweight of potatoes per acre and a total of 7.5 million hundredweight from 36,000 acres (16). Agricultural predictions indicate that for 1980 those figures will be 300, 24 and 80,000 (15) for yield, production and acreage, respectively. None of the other important crops in the state are expected to exhibit changes of such magnitude. The increase in yield is expected to come from the use of better quality and management of soil and from better management of the potato crop. Irrigation will have a major impact on this yield increase according to the same prediction study. Furthermore, it is estimated that most of the total projected increase of irrigation water use in Michigan will go to potato production. In fact, this trend is already evident. A recent survey of land irrigation (38) showed that in 1970 one-half of the 40,000 acres of potatoes were being irrigated. This figure represented 22% of the total agricultural irrigated acreage and ranks potatoes in the first place among all the irrigated crops. In terms of acre-inches of water applied potatoes were second only to turf, mainly golf courses.

Presently an average of 6 inches of irrigation water per year is being used for potatoes. If one-half of the projected increase in potatoes in 1980 is irrigated, as is the present acreage, then the potato crop is likely to become the major water user in the state. The need for careful use of our water resources, coupled with the fact that irrigation is a major cost in potato production, make it necessary to ascertain higher efficiency of water use. A rising increase in potato production is greatly dependent not only on an increase in irrigation acreage but also how efficiently this practice is carried out on each farm.

Because Michigan receives approximately 30 inches of precipitation per year, irrigation is used only on a supplemental basis. Although the practice of supplemental irrigation is widely accepted and used in potato production, there is no indication that the science of applying the proper quantity of water at the right time is practiced or even known among growers. A fixed amount of water at regular intervals is still the main basis for planning irrigation.

There are several reasons for advocating a more technical approach to irrigation management. First, the potato plant is sensitive to both a deficiency and an excess of soil water. The enhancement of soil moisture control may be best accomplished through a precise regulation of the time and amount of irrigation. Second, the variable nature of rainfall and atmospheric water demand precludes the use of predetermined and fixed irrigation needs. And third, if the use of irrigation water is going to be extended to uses other than supplying water to a crop, a more flexible approach to irrigation scheduling is needed.

For all these reasons a need for better irrigation management is evident. Specifically such management must consider not only local climatic conditions but also the special characteristics and properties of each soil. The potato variety and quality of the produce desired should also enter into the role of water management. All of these considerations must be integrated into a general water management plan for each farm.

This was a two year study dealing with various aspects of soil water management in potato production. The specific objectives were:

1. To determine the effect of the time of initiation of irrigation on the quality and yield of tubers.

2. To devise an accurate and simple scheme for determining the frequency and volume of crop irrigations. Soil-crop-climate data are considered in this scheme.

3. To measure the effect of two levels of irrigation cooling.

4. To measure the effect of two volumes of irrigation.

5. To evaluate the effect of periodic nitrogen applications through the irrigation system.

LITERATURE REVIEW

A. Water requirements of potatoes and responses to irrigation

1. Crop development and water needs

In considering the water requirement for potato growth three phases of the development of the plant should be taken into account according to Steineck (cited by Singh (30)), each one of which influences yield. The first phase corresponds to stolon formation which in normal years starts about 3 weeks after emergence and determines the potentiality for the setting of tubers. This is followed by the tuber setting stage approximately 4-5 weeks after emergence. The number of tubers as a component of yield depends on this phase. The next phase of tuber growth which lasts until maturity is the most important in determining the weight of a single tuber. The author concluded that a regular supply of water from the beginning of stolon formation to maturity is necessary to ensure high yields.

By restricting the water supply at different stages of development of the potato, several authors had intended to determine when the plant is most susceptible to water stress. De Lis et al. (5), working with the White Rose variety, found that withholding irrigations at any of the potato growth stages (with the exception of the one from planting to emergence) caused a decrease in tuber yield, but when the water stress occurred from stolonization to the beginning of tuberization, the yield decrease was greater. They concluded that the White Rose variety passes through the most critical water requirement period during this stage. In India, Hukkeri et al. (8) investigated the same problem, imposing an artificial moisture stress at equal periods of 20 days after planting. Their results showed that water stress during the period 0-20 days after planting did not affect the yield as much as the other stress periods. The stress during the stolon formation and elongation stage, coinciding with 20-40 days after planting period, resulted in the greatest yield reduction.

2. Tuber malformations as related to soil moisture

Several potato varieties have the tendency to produce misshapen tubers (knobs) under adverse growth conditions. A common observation was that their production is greater when drought periods occur during the growing season, and that irrigation has the effect of reducing or suppressing its occurrence (22, 31). Hence misshapen tubers generally were associated with water stress. However, observations (22,26) have been made in which water supplied by irrigation did not reduce the numbers of knobs and even increased their incidence. The abnormality apparently is more complicated than the simple water stress-misshapen tubers relationship.

Nichols and Ruf (17) conducted an experiment under controlled conditions in which they compared the reaction of Russet Burbank and Kennebec varieties to several levels of osmotic stress in the root medium. The stress was applied for continuous periods and for 2-day periods followed by sudden stress relief, both beginning at tuber set. The plants, stressed for short periods and then relieved, had more malformed tubers than the plants grown under continuous stress. Under the short period stress regime the incidence of malformed tubers increased with the level of stress. Under the continuous stress regime, however, no trend was observed. The control plants (no stress other than those imposed by the nutrient solution - about 0.7 atmospheres) had more misshapen tubers than the plants subjected to 1 and 5 atmospheres stress. Although Russet Burbank showed the greater reaction both varieties did react to the short period stress. In conclusion, water stress level did not increase significantly the occurrence of misshapen tubers but an irregular moisture regime did.

On the other hand Boadlaender et al. (2) carried out a glasshouse experiment under controlled temperature and drought conditions, in order to identify the environmental factor causing second growth in tubers. Their results showed that the high temperature level (82°F) induced second growth irrespective of the moisture level. Furthermore, the drought treatment alone did not induce second growth. Also Yamaguchi et al. (41) found that at high soil temperature (80-85°F) the tubers developed near the surface and were misshapen.

These studies seem to indicate that temperature is the primary factor in inducing malformation in tubers and an irregular water regime a contributing or predisposing factor.

3. Available water level and potato response

The three-year greenhouse experiment that Struchtmeyer (36) carried out with the Kathadin variety in Maine is a good illustration of the influence of the soil moisture level on yield of potatoes. Maintaining minimum levels of 15, 30, 50 and 75% of available water, he was able to show that the tuber yield decreased as the soil moisture level decreased. The same trend was obtained in each year of the investigation.

However the reports on field trials do not always show such consistent results. Wheaton et al. (39) grew potatoes in Michigan under 10, 40, 40-70, and 70% soil moisture levels during 1955, 1957 and 1958. The yields at the two higher moisture levels were the best, but none of them were consistently superior to the other soil moisture levels throughout the three years.

In another study conducted in East Lansing by Chase et al. (4) during 1965, 1966 and 1967 the 30, 45, 65 and 85% levels were compared against the non-irrigated control. The irrigated treatments increased yields from 17 to 35% for the Sebago variety and from 18-30% for the Russet Burbank, but no significant yield differences among the irrigated levels were observed. Specific gravity tended to decrease and percentage of knobby tubers increased with levels below 45% in Russet Burbank. The possible explanation for the similarity of response in the different levels in this study is, according to the authors, the small difference (1 atmosphere) in soil water tension between the highest and the lowest irrigation level.

Jensen and Middleton (11) suggested that no more than 30% of the soil water capacity be used by potatoes before the next irrigation. Notwithstanding occasional inconsistencies of results, a review of the literature on soil-moisture relationships for potatoes (16, 28, 29) shows that there is general agreement on the following points:

a. Potatoes are very sensitive to levels of soil water that prevent adequate aeration.

b. Potatoes respond negatively to low soil water levels which should never, as a practical rule, be allowed to drop below 50% of the soil available water.

B. Temperature requirements of potatoes and responses to irrigation cooling

1. Critical values of ambient temperature

Ora Smith (31) concluded that in many potato producing areas yield and quality of potatoes are kept below their maximum by the prevalence of high temperatures at some time during the growing season. Bodlaender (1) pointed out that the potato species originated in areas where the average temperatures are between 59°-65°F; hence these temperatures may also be the most favorable temperatures for potato development.

Controlled experiments in greenhouses and growth chamber in Pasadena and Wageningen reviewed by Bodlander (1) have shown that:

a. emergence was always accelerated by high temperatures. Two weeks difference was found between 55° and 72°F;

b. stem elongation reached its optimum at 65°, was very low at 48°F and stopped growing at 43°F;

c. the number of leaves formed was positively correlated with temperature;

d. tuber formation started earlier and the number of tubers formed were greater at low temperatures. High night temperatures decreased tuber yield more than high day temperatures. Higher yields were obtained with potatoes grown at 86°-63°F day-night temperatures than at the 73°-73°F regime;

e. maximum tuber weights were obtained at intermediate temperatures. Under summer conditions the optimum temperature was from 64 to 68°F.

Potato varieties respond differently in relation to temperature. Bodlaender (1) subjected seven potato varieties to temperature regimes of 61°, 72° and 81°F. Two of them had their maximum yield at 72°F and the remaining five at 61°F. However, the average decrease in yield from 61° to 72°F was only 3.5% as compared to 37% from 72° to 84°F.

Iritani (10) analyzed air temperature and potato yield data in Southern Idaho for an 11-year period. He found a negative correlation between yield and the accumulative June and August temperature below 48°F, which roughly corresponds to the early development of the plant and the tuber enlargement periods. A highly negative correlation was found between yield and temperatures above 85°F in July. This last period coincides with tuber initiation and early growth of the tuber.

2. Critical values of soil temperature

Soil temperature has an important effect on potato plant development, especially on tuber initiation and growth. White Rose and Russet Burbank potatoes were grown by Yamaguchi et al. (41) at four soil temperatures: 50-55°, 60-65°, 70-75° and 80-85°F. A 5°F difference was maintained between day and night conditions. Both shoot emergence and foliar growth were optimal at 70°-75°F. Tuber initiation, tuber yield, specific gravity and starch content were highest at the two intermediate temperatures.

In a later study Eliot Epstein (6) used the Katahdin variety to measure the effect of temperature on three growth stages: planting-emergence, emergence-30 days after, and 30 days after emergence-maturity. During the third stage the yield increased up to 72°F and then sharply decreased at 84°F. Specific gravity started to decline at 72°F and the number of tubers was greatest at the lowest temperature. As was also reported by Yamaguchi, the shape of the tuber was affected at 84°F.

From all this information it appears that both air and soil temperatures above 70°-75°F are detrimental to potato yield and quality.

3. Irrigation cooling studies

In response to the problem of high temperatures with its corresponding high evaporative demand the effect of temperature reduction with sprinkling ("irrigation cooling", "mist irrigation" or "air conditioning") is being studied in potato crops with varying success.

In Muscatine, Iowa (9), the regular irrigation of 1" at 3-4 days intervals was compared with "mist" applications of 0.05" per hour from 11 A.M. to 4 P.M. when daytime air temperatures rose above 80°F in 1966 and 1967. In 1968 the applications were changed to 0.10" per hour when temperature rose above 85°F. Additional water was applied, as needed, to supplement soil moisture. The results of this three-year study showed that the response varied considerably between seasons. In 1966 and 1968 a significant response was obtained for all the varieties treated (Norland, Norgold, Viking and Kennebec) in contrast with very little or negative response in 1967. The degree of response differed according to the variety. The Kennebec variety was the most responsive with an average yield increase of 38%. The early maturing variety, Norland, gave the least response with a 9% average increase. The "mist" treatment also resulted in significant increases in the percent of total solids. In 1966 a substantial reduction in the amount of second growth was noted for Norgold and Kennebec. According to these data the practice of "mist" irrigation could be advantageous for some varieties, especially Kennebec.

Chase et al. (4) tested the effect of irrigation-cooling in Michigan on Sebago and Russet Burbank potatoes grown under four soil moisture levels plus a control. Irrigation cooling was applied when the air temperature rose above 85°F, at a rate of 0.08 inches per hour for a period of 2-3 hours. When the yields of all the irrigation-cooling treatments were averaged for the three year experiment and compared with yields from plots with no irrigation-cooling the values showed a 7% increase for Sebago and 3.5% increase for Russet Burbank. The yearly responses varied reflecting differences in temperature conditions. The highest response was obtained in 1966 which was characterized as unseasonably warm and dry with a yield increase of 12% in Sebago and 8% in Russet Burbank. The latter variety showed a trend toward increasing specific gravity. The responses obtained in this study were not large enough to make this practice profitable under Michigan conditions.

Sanders et al. (25, 26, 27, 28) have published a series of papers reporting the experimental results for a 3-year study (1967, 1968, 1969) in Minnesota in which they assessed the influence of irrigation methods on potato microenvironment and leaf water relations, growth and development, nutrient content of leaves and tuber quality factors. The methods compared were: no irrigation, mist irrigation, furrow irrigation and mist plus furrow irrigation. The mist irrigation consisted of low volume sprinkler application from 11:00-15:00 CDT at a rate of 0.11, 0.12 and 0.08 inches per hour in 1967, 1968 and 1969 respectively. The mist was applied for 8 seconds every 8 minutes when the temperature reached 72°F. The 3-year average yield value for the mist treatment was 4% lower than the furrow treatment and the mist plus furrow yield was 11% lower than the furrow value. The only year the mist treatment was superior to the furrow irrigation was during the "stressing" year of 1967 and then the difference was not significant. The authors also reported that misted plots yielded tubers which contained less dry matter and had more hollowheart and secondary growth. The modal ambient temperature depression by misting in the canopy was 5°F at 56 cm height, 3.2°F at 33 cm and 2.5°F at 10 cm when radiant energy flux was high (greater than 500 ly/day). At lower energy fluxes the depression temperatures were also lower.

C. Factors in scheduling potato irrigation

In a subhumid area, like Michigan, the two basic considerations in planning potato irrigations are the rate at which the crop depletes the soil moisture reservoir by evapotranspiration (ET) and the amount of this depletion that is replenished by precipitation. Irrigation must supply the deficit. A good farm irrigation program requires an accurate, rapid and simple procedure for calculating the daily water deficit. If the procedure is to be accurate, daily evapotranspiration data are needed. While precipitation is a discontinuous process, its measurement presents no problem. Evapotranspiration, on the other hand, is continuous, highly variable, and its actual measurement involves considerable work, time and usually sophisticated instrumentation. For this reason in practical irrigation management the measurement of pan evaporation is a convenient way of estimating the daily evapotranspiration.

Based on rate of evapotranspiration studies in Davis, California and on an evaluation of the literature concerning pan evaporation data Pruitt, (19, 20, 21) considers that the pan evaporation method, when well standardized, constituted a very useful tool in estimating evapotranspiration.

Stanhill (32, 33) in Israel tested eight different methods of estimating ET from climatic data and concluded that the methods based on open surface evaporation calculated by Penman's method or measured with standardized pan evaporation gave the most accurate results. He also pointed out that when time and cost are considered the pan evaporation method is the most satisfactory. Young (42) did a similar comparison in potato and tomato crops (Michigan) and reached similar conclusions in regard to the Penman and pan evaporation methods; however, he indicated that more work in determining the local correction factor for the pan evaporation method was needed.

For potatoes this factor changes with the stage of development of the crop as a consequence of the relatively low evapotranspiration during the early and late growth stages. Once a certain degree of development is reached though, several authors (19, 33, 34) have found a nearly constant linear relationship.

During his study Young (42) found that for the last part of June when the crop was not yet fully developed the measured ET was 0.07 inches per day compared to 0.23 inches per day for pan evaporation. For periods of a fully developed crop the values were 0.16 and 0.23 inches per day for ET and pan evaporation respectively. He used Bouyoucos block readings to calculate ET. Swan (37) in Wisconsin found an average measured evapotranspiration rate (lysimetric measurements) of 0.21 inches per day for periods when the surface cover was greater than 50%. The peak value was 0.24 inches per day.

In Carrington, North Dakota, Stegman and Olson (34) determined water use by potatoes with the soil moisture sampling method and summarized their 5-year data in relation to days after emergence. From emergence to 30 days after, the daily ET value rose from 0.08 to 0.20 inch per day. The average ET value for the 30-80 day period was 0.22 inch per day with a peak of 0.24 inch at 50-60 days. The soil moisture extraction pattern was also studied in this work showing that potato plants extracted 57% of the water from 0-12, 33% from 12-24, 8% from 24-36 and 2% from 36-48 inch depth.

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MATERIALS AND METHODS

A. Experimental site and crop management

The data were collected at the Montcalm Experimental Farm in Montcalm County, Michigan, during the growing seasons of 1971 and 1972.

The climatological summary (14) for the nearest weather station (Greenville) indicates a mean annual temperature of 47.6°F and a mean annual precipitation of 31.4 inches for the 1940-69 period. June, July and August have average monthly mean temperatures of 67.8, 72.2 and 70.6°F and an average mean precipitation of 3.1, 2.5 and 3.4 inches, respectively. Temperature extremes greater than 90°F occur 14 times during an average summer. During the crop season, May-October, the estimated class "A" pan evaporation equals 28 inches which is 10.5 inches greater than the average precipitation for the same period.

The soil is classified as a McBride sandy loam, 0 to 2% slope, and described (29) as a well drained soil with a weak fragipan development at 14-25 inches and a C horizon at more than 48 inches depth. Core samples were taken from the 0-24 inch layer to determine the moisture characteristic and bulk density values necessary for the calculation of

Table 1. Soil moisture retention at different depths and tension values on a McBride sandy loam soil.

Soil layer (inches)	Bulk* density	Percent weight of soil moisture at indicated tensions							
		Saturation	0.05 atm.	0.10 atm.	0.33 atm.	1 atm.	2 atm.	5 atm.	15 atm.
0-9	1.52	22.41	19.52	14.72	11.72	10.29	8.25	6.78	4.43
9-15	1.61	20.53	15.85	12.38	9.82	8.12	5.80	4.94	2.93
15-24	1.72	16.20	11.40	9.42	7.72	6.95	5.16	4.34	2.25

*Each bulk density and moisture value is an average of 6 replicates.

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available moisture capacity. These data are presented in Table 1. Using 0.1 atmosphere as the upper limit of available water, a value of 3.4 inches of water was stored in the soil for the 0-24 inch depth.

Two varieties of potatoes (Solanum tuberosum) were utilized in this study: the Kennebec (K) variety is a high yielding, rounded tuber of good quality; and the Russet Burbank (RB) variety is a long tuber with russetted and netted skin and high processing quality. The planting and harvesting date, plant spacing and fertilization information are given in Table 2.

Table 2. Planting and harvesting dates, plant spacing and fertilization

Year	Planting (date)	Harvesting (date)	Plant Spacing (inches)	Fertilization (lbs/A)*
1971	4/30	9/22	RB-14 K-12	a)175(33-0-0)+200(0-0-60) b)800(14-14-14)+16 Mg c) 70 N
1972	5/10	9/15 10/5 (N. exp.)	RB-14 K-12	a)200(0-0-60) b)800(14-14-14)+16 Mg c)120 N

*a) plowdown; b) plant; c) sidedress

The row width was 34 inches. The potatoes received regularly scheduled sprays along with other experimental potato plots for control of weeds, insects, and diseases.

B. Field layout of the experimental plots

1. 1971 experiments

In 1971 three aspects of water management in potatoes were studied: (1) the effect of timing of the initial irrigation (TI); (2) day versus night irrigation (DN), and (3) the effect of irrigation cooling (IC). The first two were combined in one experimental area which consisted of (4(TI) x 2(DN) x 2 varieties) 16 treatment combinations, in a split-split plot design with 4 replications.

The irrigation cooling experiment consisted of a check and two levels of irrigation cooling. When the temperature rose above 75°F, the plots corresponding to level 1 were sprinkler irrigated 5 minutes every 30 minutes, and when the temperature rose above 85°F the plots in level 2 received the same treatment. The treatments, with 3 replications each, were arranged in a completely randomized design.

Figure 1 shows the arrangement of the experimental plots in the field. Each plot contained ten rows and measured 28 by 25 feet. The two center rows of Kennebec and 2 rows of Russet Burbank were harvested for yield data. The other rows were considered as borders.

2. 1972 experiments

The experimental treatments in 1972 were frequency of irrigation (2 FI levels); timing of initial irrigation (4 TI levels); irrigation cooling (2 IC levels) and peri

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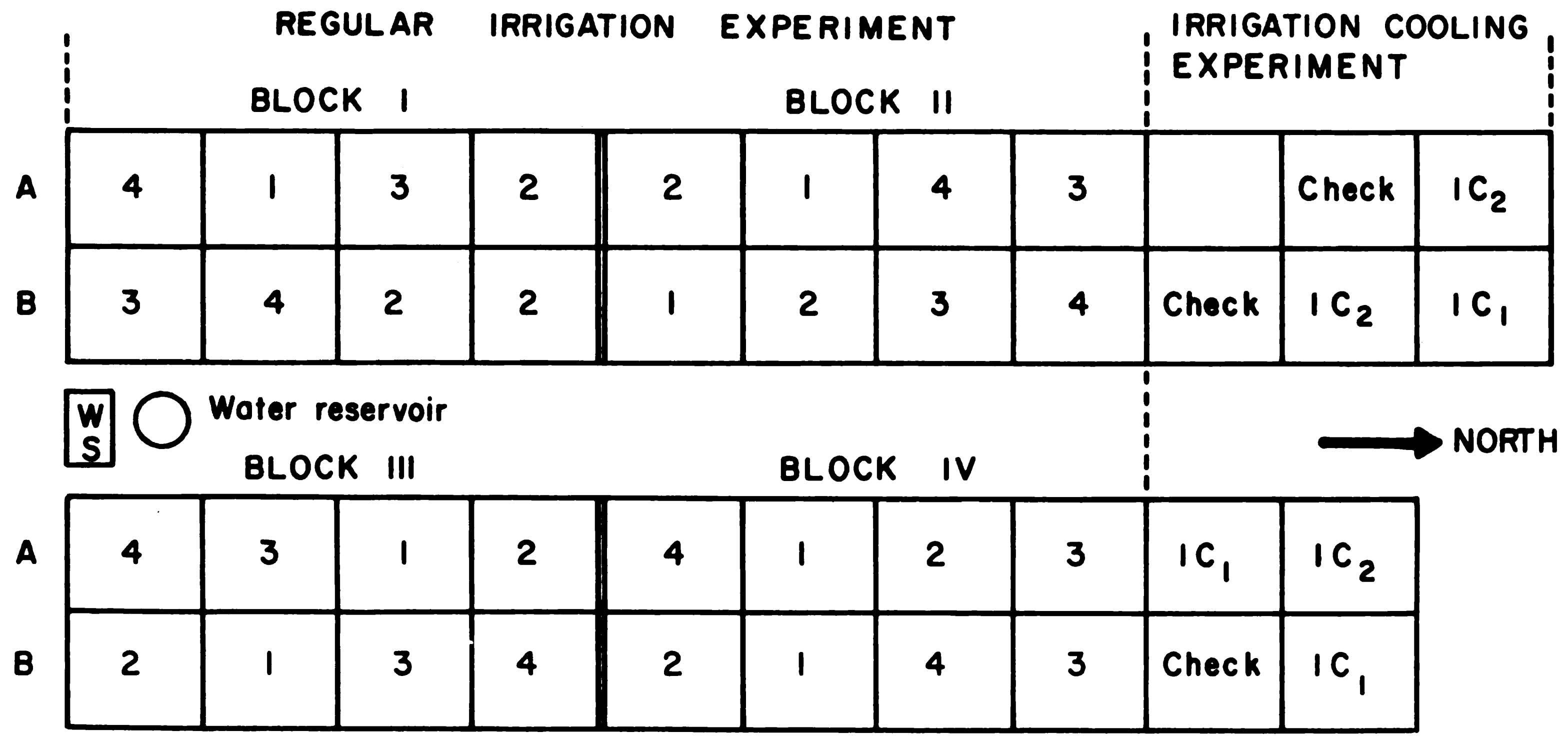
periodic applications of nitrogen fertilizer with irrigation water (2 N levels).

The two frequency of irrigation treatments were a 1/2-inch water application whenever the available soil moisture balance indicated that a deficit of 1/2 inch had occurred and a 1-inch water application whenever that deficit developed in the soil.

Instead of starting the (TI) treatments at 50, 60, and 70 days after planting as in 1971, the 1972 irrigation treatments were started at 30, 50 and 70 days after planting. These changes were considered and adopted after the 1971 data were analyzed. The (TI) treatments and check (no irrigation) were randomized within the irrigation frequency treatment plots.

In 1972, the criteria for IC at level 1 was changed from 75 to 80°F and from none specified to 65% or less relative humidity. For level 2 the only change was 80 to 85°F. The irrigation cooling was supplied at the rate of 1 gallon of water per 1/2 minute every 15 minutes. Because of changes in the method of application large amounts of water would have been applied under the 1971 criteria: hence the temperature levels were raised and a relative humidity value included for level 1 in 1972. All plots, including the check plot received a regular irrigation of 1 inch of water when needed.

REGULAR IRRIGATION EXPERIMENT IRRIGATION COOLING



TREATMENTS

A - Night irrigation   B - Day irrigation

1 - Irrig. starts at 50 days after planting
2 - " " 60 " " "
3 - " " 70 " " "
4 - Check (no irrigation)

IC_1 - Irrig. cooling, level 1
IC_2 - " " " 2
Check - No irrig. cooling

Figure 1. Layout of field experiments in 1971.

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The nitrogen fertilization treatments consisted of:

a. Treatment 1(N_1): 120 pounds of N per acre as 28% nitrogen solution applied at 20 pounds per week for six weeks in the irrigation water.

b. Treatment 2 (N_2): 60 pounds of N per acre as 28% nitrogen solution sidedressed and 60 pounds of N per acre as 28% nitrogen solution applied at 20 pounds per 2-week interval for 6 weeks in the irrigation water.

c. Check: 120 pounds of N per acre (60 pounds per acre as NH_4NO_3 and 60 pounds as a 28% nitrogen solution) sidedressed.

The treatments were arranged in a completely randomized design with 3 replications. Figure 2 represents the field arrangements of the experimental plots during 1972.

C. Irrigation system

1. 1971

In order to apply water to the plots according to indicated treatments and to irrigate the plots based on the water balance method, the experimental area required its own irrigation system independent of the general irrigation system of the farm.

The basic components of this system are listed below:

a. Water reservoir consisted of a portable swimming

	N_2	N_1	Check	IC_1	IC_2	Check	IC_1
N_2	N_1	N_2	N_1	Check	IC_2	IC_1	IC_2

BLOCK III | BLOCK IV

4	2	2	3	4	2	1	4
1	3	1	4	3	1	3	2

A B B A

BLOCK I | BLOCK II

3	2	2	1	4	1	3	4
4	1	3	4	3	2	1	2

B A B A

TREATMENTS

N-FERTILIZATION

N_1 - weekly application
N_2 - bi weekly "
Check

IRRIGATION-COOLING

IC_1 - level 1
IC_2 - " 2

REGULAR-IRRIGATION

A - frequency 1
B - " 2

IRRIGATION STARTS AT:

1 - 30 days after pl.
2 - 50 " " "
3 - 70 " " "
4 - Check

Figure 2. Layout of field experiments in 1972.

pool, 15 ft diameter and 4 ft height filled every other day from the farm irrigation system,

b. Centrifugal pump with 2 horsepower electric motor,

c. Aluminum irrigation pipes 4" diameter for main lines,

d. Garden hoses 25 and 50 feet long for the lateral lines,

e. Perforated rubber hoses used for irrigating (TI) and (DN) experimental plots,

f. Risers with rotating sprinkler heads for the irrigation cooling treatments.

Figure 3 shows the layout of the irrigation system and the use of the perforated hose for sprinkling a plot area. The perforated hose was taped on a 4" aluminun pipe which was held above the plants with stakes. These units could be moved from one plot to another.

The (IC) plots received normal irrigation from the farm irrigation system as adequate irrigation could not be provided with the (IC) equipment.

Because of continual leakage from the 4" aluminum pipe the main lines were replaced with 2" plastic pipe in mid-summer of 1971. The new system performed flawlessly and water loss problems were resolved.

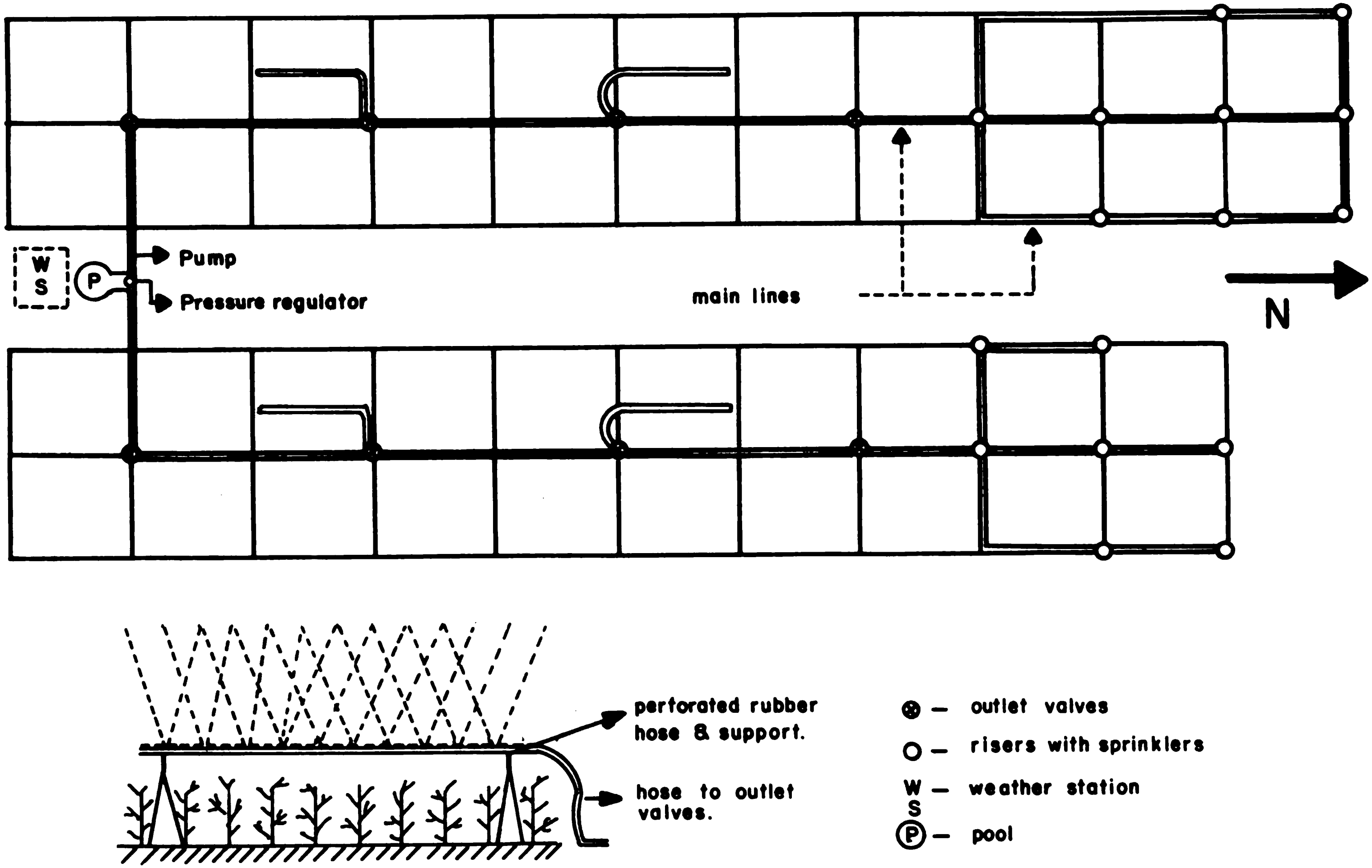

Figure 3. Irrigation system for the 1971 experiments.

2. 1972

To improve uniformity of water distribution, to minimize handling of equipment and to exercise better control of metering water, several changes were introduced into the system in 1972. A main line with a sufficient number of valves was placed along each tier. Each plot was equipped with an elevated, rotary sprinkler connected to the main line with a garden hose. The amount of irrigation applied to each plot was controlled with a metering device set for a specified volume of water. When this volume was delivered, the valve closed automatically.

For the irrigation cooling treatments a 15-minute clock timer was connected to the pump and was programmed to operate 1/2 minute every 15 minutes. Normal irrigations could be supplied when needed with the (IC) equipment and the farm irrigation system was not necessary.

The injection of liquid nitrogen fertilizer into the suction side of the irrigation pump simplified the procedure of applying the periodic nitrogen fertilization treatments. The fertilizer solution, diluted to 20 gallons in an open container, was drawn into the pump and mixed with the irrigation water. Gate valves in both suction lines were required to get the proper mix between the reservoir water and the fertilizer solution.

D. <u>Meteorological measurements</u>

A weather station was installed in the southwest corner of the experimental plot. The meteorological parameters measured and the instrumentation used are listed below:

1. <u>Temperature and relative humidity</u> - Daily records of the air temperature and relative humidity were obtained with a hygrothermograph, housed in a standard USWB shelter at 1.20 m height. Daily maximum and minimum temperatures were also recorded.
2. <u>Wind</u> - The 24-hour wind values were obtained with a circular-dial, 3-cup anemometer at 2 meters above the surface.
3. <u>Precipitation</u> - A non-recording, eight-inch diameter standard weather bureau precipitation gauge was used for this purpose.
4. <u>Evaporation</u> - Evaporation measurements were made with:
   a. A USWB-Class A evaporation pan (10 inches deep and 47 1/2 inches diameter) was accompanied by a five-digit odometer type, 3-cup anemometer to measure 24-hour wind values at 60 cm above the surface.
   b. A Lambretch drum recording evaporation gauge was housed in a standard instrument shelter.

e

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5. Net radiation - This parameter was measured with a ventilated and temperature compensated net exchange radiometer (Beckman and Whitley). This instrument was mounted 40 inches above the crop canopy in a plot adjacent to the weather station. Its output was recorded by a potentiometric recorder.

The daily observations of max-min temperature, wind, evaporation and precipitation were made at 8:00 A.M. CST. Instrument arrangement in the weather station is shown in Figure 4.

E. Additional field instrumentation and measurements

Soil moisture tension: In eight selected irrigated plots soil moisture tension was monitored with sets of tensiometers placed at depths of 4, 10, 16 and 22 inches, giving a total of 32 tensiometers. In four of the non-irrigated plots Bouyoucos blocks were installed at the same four depths giving a total of 16 blocks.

Soil temperature: Three recording soil thermometers with dual probes were randomly installed at 4- and 12-inch depths. They were placed in plots corresponding to the (IC) experiment in 1971, and in a check plot and in plots of the (TI) experiment in 1972.

Soil moisture measurements: In 1972 soil moisture measurements were made at the 0-6, 6-12, 12-18 and 18-24 inch depth. These gravimetric soil moisture measurements were converted to volumetric values by multiplying the gravimetric measurements by the bulk density of the soil. The soil moisture stress associated with a particular moisture content was given by the tensiometric readings obtained at these same depths. The soil moisture values obtained between periods of rainfall were used to estimate the loss of soil water in that period and to relate soil water loss to the pan evaporation loss.

F. Irrigation scheduling procedure

Irrigations were scheduled by keeping a daily balance sheet of the water lost or gained by the soil. The daily pan evaporation values corrected by a crop canopy factor determined the estimated soil water losses and precipitation and irrigations the soil water gains. If precipitation exceeded the storage capacity of the soil, the excess was disregarded in calculating the balance of soil available water. When the balance indicated a deficit of 1 or 1/2 inch, depending on the treatment, that amount of water was applied to the respective plots. With certain modifications, the procedure followed the guidelines described by Jensen and Middleton for scheduling irrigation from pan evaporation data (11).

G. Harvesting procedure

Two rows of each variety were machine harvested from the center of each experimental plot. The Russet Burbank tubers were graded into four groups: (1) smaller than

Figure 4. Instrument layout for the weather station on the Montcalm County Experimental Farm.

1 7/8 inch; (2) between 1 7/8 and 10 ounces; (3) greater than 10 ounces, and (4) off-type tubers. For the Kennebec variety the off-type classification was not considered because of the absence of misshaped tubers. Also, because of a more round tuber shape, the maximum size was graded by linear measurement (3 1/4 inch maximum) rather than using the weight determination.

RESULTS

A. Weather conditions during the period of irrigation

The 1971 and 1972 growing seasons presented two well-defined and different weather patterns. Data to support this statement are shown in Table 3 and Figures 5, 6, 7 and 8. Though the mean daily temperatures for July and August were the same in 1971 and 1972, the mean maximum temperatures were higher and the mean minimum temperatures lower in 1971 when compared with the 1972 values. The most significant difference in regard to temperature is that observed during the last part of June which coincided, in both years, with the critical tuber setting stage of the crop. The mean daily temperature for this period was 12.4^{o}F higher in 1971 than in 1972 and temperatures above 95^{o}F were recorded for the last three days of June in 1971. On the other hand during the same period in 1972, a daily maximum temperature as low as 53^{o}F was recorded, and no daily maximum temperatures were higher than 85^{o}F.

These temperature differences were reflected in the average pan evaporation values of 0.30 inch/day for 1971 and 0.18 inch/day for the same period in 1972 (Table 3).

Table 3. Summary of weather conditions in June, July and August of 1971 and 1972.

Year	Month	Temperature means			Mean* relative humidity (%)	Precipitation totals (inch)	Mean daily wind movement (mi/day)	Pan evaporation	
		Max.	Min.	Daily				Total (inch)	Daily (inch/da.)
1971	June (19-30)	88.5	59.8	74.1	60.0	.38	73	3.6	0.30
	July	81.3	55.0	68.1	62.8	1.22	92	8.6	0.28
	August	80.5	53.3	66.9	63.0	2.67	93	6.7	0.22
	Totals or Averages					4.27	89	18.9	0.25
1972	June (15-30)	71.3	52.2	61.7	63.9	1.38	116	2.9	0.18
	July	78.7	57.3	68.0	60.8	3.33	88	6.7	0.22
	August	75.9	57.3	66.6	75.6	7.29	80	4.1	0.13
	Totals or Averages					13.0	90	13.7	0.17

*Correspond to the 8 A.M.-8 P.M. daily periods.

The highest daily pan evaporation value recorded, 0.50 inch, occurred on June 28, 1971.

In 1971 the total pan evaporation for June, July and August was 14.6 inches greater than the total precipitation, while in 1972 this difference was only 0.7 inch. This seasonal variation resulted because of an 8.7-inch increase in rainfall and a 5.2-inch decrease in pan evaporation in 1972.

Two items of interest are noted in the precipitation pattern of 1972 (Figure 8): the amount and timing of the rainfall during the stolonization and tuber setting phases, most critical with respect to yield, were sufficiently adequate to preclude any lack of soil water. Not only was the rainfall well timed to maintain an adequate water supply but many rainfalls were near or exceeded one inch of water.

In summary, the 1971 season was hot and dry with a low relative humidity, and the 1972 season was cool and wet with a high relative humidity.

The stolonization and tuber setting phases of the potato crop were affected by these two contrasting weather conditions. Table 4 illustrates this effect. The plants grew and developed faster in 1972. The plant vigor exhibited during the stolonization and tuber setting phases was due to the cool temperature and the ideal moisture conditions that prevailed during these growth stages.

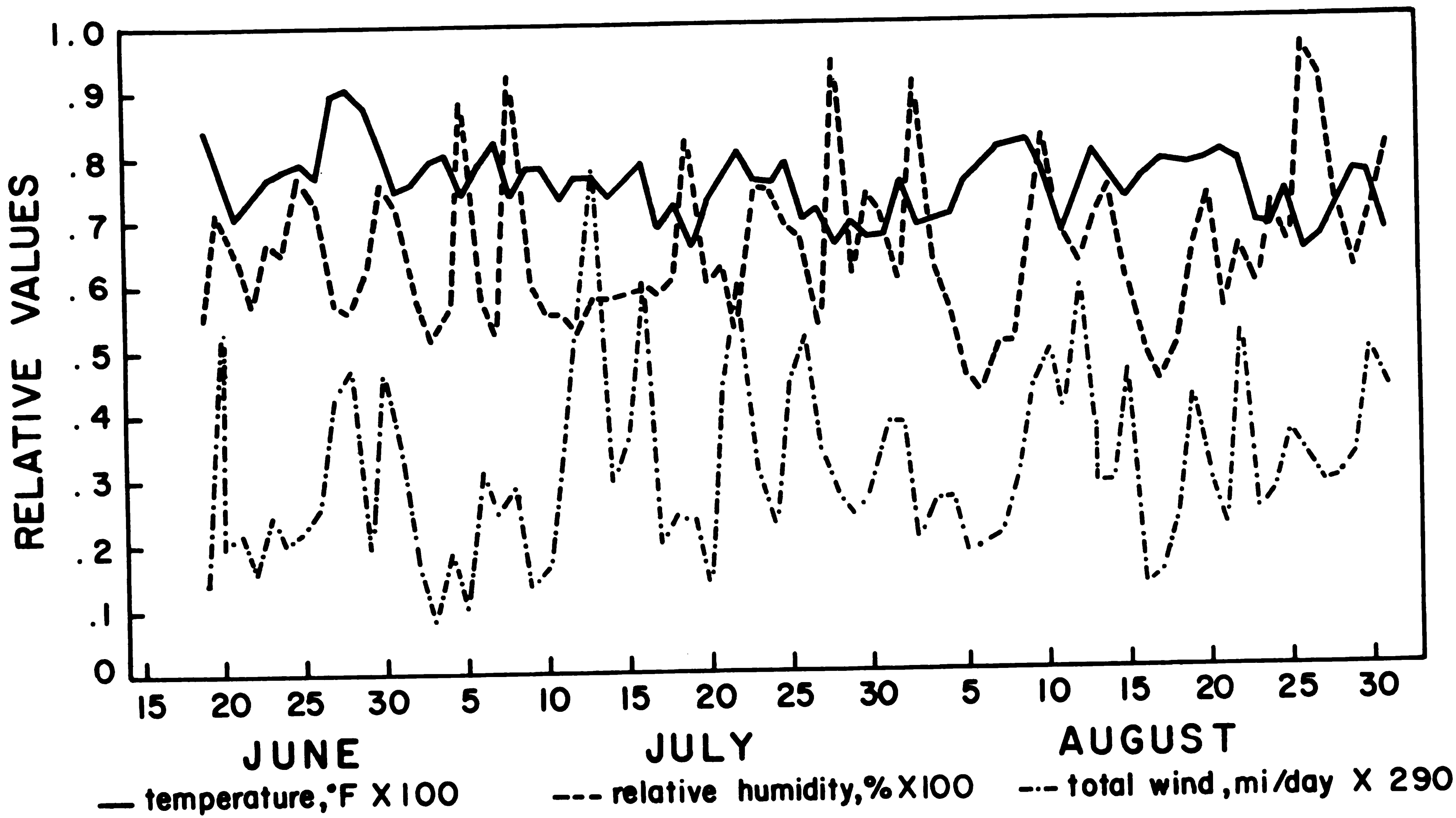


Figure 5. Mean daily temperature and relative humidity and daily total wind movement, 1971.

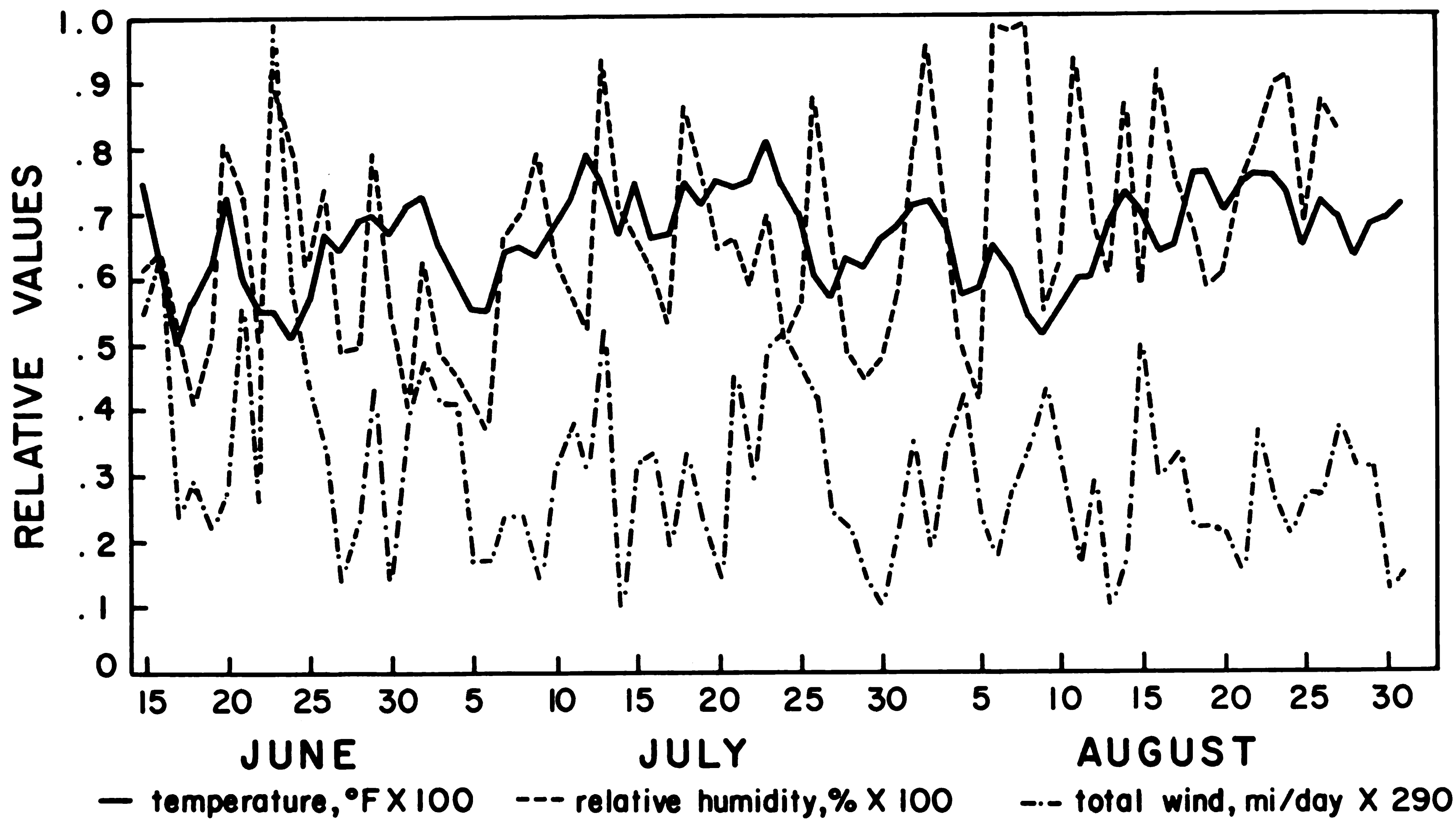


Figure 6. Mean daily temperature and relative humidity and daily total wind movement, 1972.

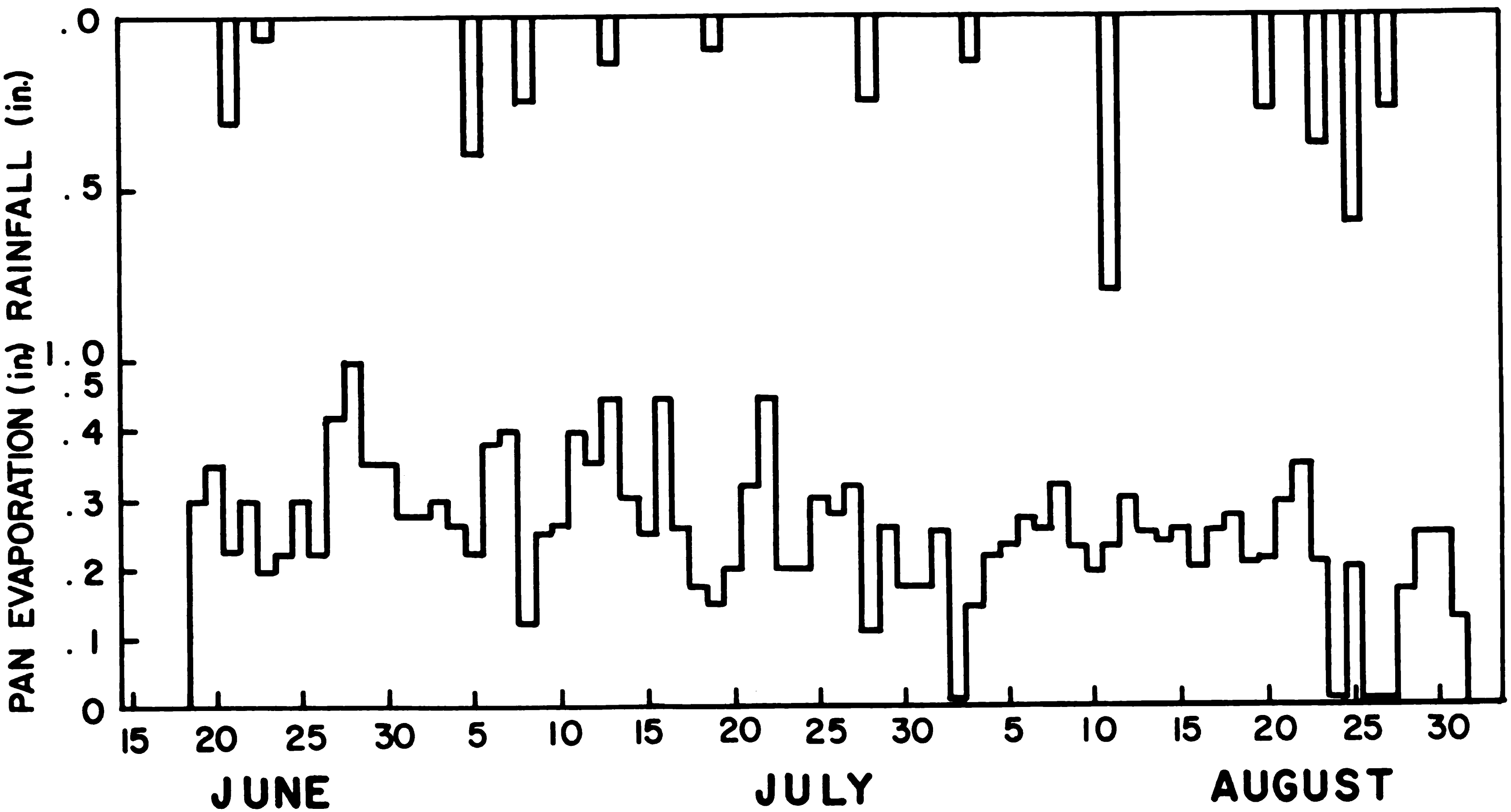


Figure 7. Rainfall and pan evaporation data, 1971.

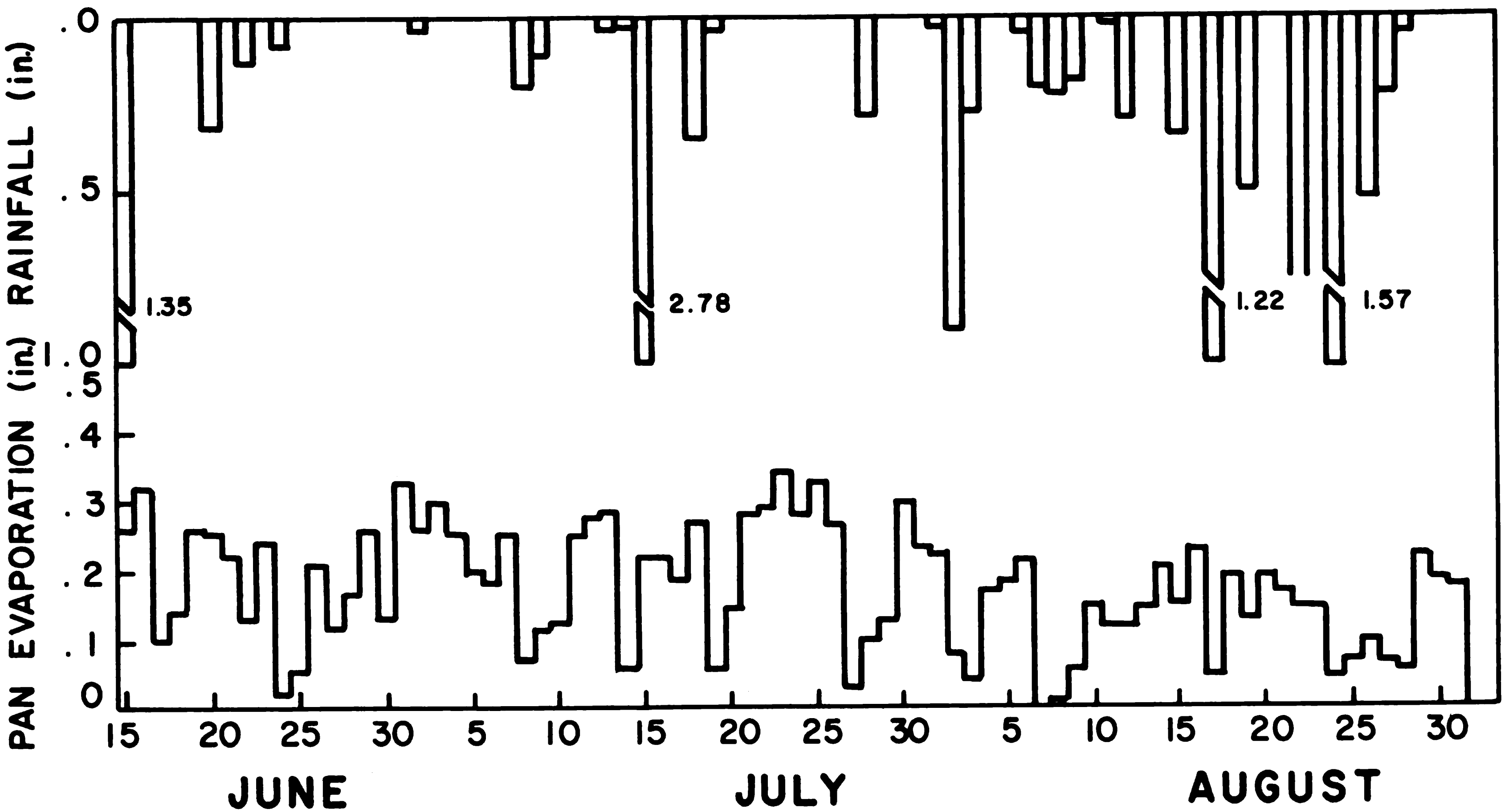


Figure 8. Rainfall and pan evaporation data, 1972.

Table 4. Crop development in 1971 and 1972, Russet Burbank variety.

	Days after planting	
	1971	1972
Plant emergence	30	20
50% surface cover	45-50	35-40
100% surface cover	65-70	55-60
Stolon initiation	40-45	25-30
Initiation of tuber set*	50-55	35-40
Completion of tuber set+	65-70	45-50

*Practically all plants examined exhibited either swollen stolon tips or up to 1/2-inch diameter tubers.

+Practically all plants examined exhibited tubers 1 1/2-inch diameter or less.

B. Timing of initial irrigation treatments

The amounts of water applied to Treatment 1, 2 and 3 in 1971 were 10, 8 and 6 inches respectively. In 1972 the same treatments were irrigated with 3.75, 2.75 and 1.0 inch of water.

During the warm and dry year of 1971 initiating irrigation at 50 days instead of at 70 days after planting produced a 42 cwt/acre yield increase in Russet Burbank and 43 cwt/acre increase in Kennebec (Table 5). Initial irrigation at 60 days gave intermediate yields. Knobbiness was reduced from 21.5% to 13.4% by the earlier irrigation in

Table 5. Effect of the timing of initial irrigation on yield, grade and specific gravity of Russet Burbank and Kennebec potatoes, 1971 and 1972.

		Russet Burbank				Kennebec				Standard error of difference‡
		Treat. 1	Treat. 2	Treat. 3	Check	Treat. 1	Treat. 2	Treat. 3	Check	
1971	Yield (cwt/A)*	334	302	292	179	329	306	286	166	19.2
	% U.S. No.1 tubers	51.7	55.1	53.6	45.0	75.5	74.2	77.4	78.9	4.6 n.s.
	% Knobby tubers	13.4	14.9	21.5	40.9	-	-	-	-	-
	Specific gravity	1.076	1.075	1.071	1.069	1.067	1.063	1.061	1.063	0.0066 n.s.
1972	Yield (cwt/A)†	340	337	327	344	387	425	387	366	27.2 n.s.
	% U.S. No.1 tubers	68.5	68.7	65.8	65.5	76.6	80.6	76.3	83.9	5.2 n.s.
	% Knobby tubers	10.8	12.4	14.4	13.0	-	-	-	-	-
	Spec. gravity	1.075	1.073	1.068	1.071	1.068	1.067	1.064	1.064	0.013 n.s.

*Averages of the Day and Night irrigation treatments in 1971.

†Averages of the 1" and 1/2" water applications in 1972.

‡To compare two treatment means within each variety.

Russet Burbank, and specific gravity showed a tendency to decrease with the later irrigations in both varieties. The percentage of U.S. No.1 tubers was not changed significantly by these treatments. The similarity of values for percentage of U.S. No.1 tubers and the significant changes in yield values are a consequence of the increase in oversize tubers in the earlier irrigated treatments. Hence, the earlier irrigations increased yields, produced larger tubers, gave higher specific gravities and tubers were less deformed.

Adequate amounts and distribution of rainfall during the earlier part of the irrigation period of 1972 eliminated any differential moisture stress between the treatments and masked any yield differences due to the time of initiating irrigation. It is interesting to observe though, that even under these circumstances, specific gravity tended to be greater with the earlier irrigations, and this increase was statistically significant.

C. Day irrigation versus night irrigation treatment

These treatments did not produce any significant difference in the crop yield characteristics under consideration. Table 6 shows these results. Night irrigation had a negative effect on the percentage of U.S. No.1 tubers in Russet Burbank variety but this effect was not statistically significant. No differential disease incidence was observed in the experimental plots subjected to these treatments.

Table 6. Effect of day versus night irrigation on yield, grade and specific gravity of Russet Burbank and Kennebec potatoes, 1971.

		Day Irrigation				Night Irrigation				Standard* error of difference
		Treat. 1	Treat. 2	Treat. 3	Check	Treat. 1	Treat. 2	Treat. 3	Check	
Russet Burbank	Yield (cwt/A)	327	300	295	198	342	304	290	160	29.3 n.s.
	% U.S. No. 1 tubers	54.9	60.2	56.5	44.6	48.6	50.0	50.7	45.3	6.75 n.s.
	% Knobby tubers	12.4	14.3	19.9	41.4	14.5	15.5	23.2	40.5	-
	% Oversize tubers	27.7	19.7	15.7	4.4	31.3	30.0	19.6	3.3	5.16 n.s.
	Spec. gravity	1.075	1.073	1.072	1.069	1.076	1.074	1.070	1.068	0.09 n.s.
Kennebec	Yield (cwt/A)	354	288	280	185	304	324	291	147	29.3 n.s.
	% U.S. No.1 tubers	75.6	74.3	77.0	79.7	75.5	74.2	77.9	78.3	6.75 n.s.
	% Oversize tubers	16.1	13.9	13.7	3.9	14.1	11.2	17.0	2.9	5.16 n.s.
	Spec. gravity	1.063	1.067	1.062	1.059	1.067	1.065	1.062	1.063	0.09 n.s.

*Comparison of irrigation means within same treatment and variety.

These results were considered sufficiently conclusive to exclude this objective in the 1972 experiments.

D. Frequency of irrigation treatments

Irrigations of 1/2 inch of water resulted in some benefit as compared to irrigations of 1 inch of water per application in 1972. Table 7 shows that a higher yield resulted for Russet Burbank when it was irrigated at 1/2 inch as compared to 1 inch per application. Several of the irrigations were followed by heavy precipitation and the 1/2-inch treatment received less than 3.0, 2.5 and 0.5 inches of irrigation for Treatments 1, 2 and 3. These data suggest that the plots receiving 1 inch were depressed more by excessive water. The Kennebec variety did not suffer a similar yield decrease with the heavier application but the percentage of U.S. No.1 tubers and the specific gravity were less. All the differences observed were not statistically significant.

E. Irrigation cooling treatments

Treatment 1 of the irrigation cooling experiment had 34 days of irrigation cooling resulting in a total of about 2.3 inches of water applied in 1971. Treatment 2 had 14 days with 1.0 inch of total water applied. In 1972 the comparable figures were 30 days with 2.6 inches of water for Treatment 1 and 10 days with 0.7 inch of water for Treatment 2.

Table 7. Effect of the frequency of irrigation on yield, grade and specific gravity of Russet Burbank and Kennebec potatoes, 1972.

		1" Application				1/2" Application				Standard* error of difference
		Treat. 1	Treat. 2	Treat. 3	Check	Treat. 1	Treat. 2	Treat. 3	Check	
Russet Burbank	Yield (cwt/A)	324	312	317	354	356	362	338	335	39.7 n.s.
	% U.S. No.1 tubers	68.3	69.1	68.6	69.4	68.7	68.3	63.0	61.5	7.13 n.s.
	% Knobby tubers	11.1	12.6	12.5	12.8	11.5	11.4	14.4	14.2	-
	% Oversize tubers	11.5	10.6	8.1	8.4	12.2	11.0	10.7	12.4	6.07 n.s.
	Spec. gravity	1.076	1.072	1.068	1.071	1.075	1.073	1.069	1.070	0.0018n.s
Kennebec	Yield (cwt/A)	371	430	362	346	403	421	412	385	39.7 n.s.
	% U.S. No.1 tubers	74.6	73.7	77.9	88.4	78.6	80.1	74.8	79.3	7.13 n.s.
	% Oversize tubers	19.1	18.8	16.2	6.4	17.2	16.0	21.5	17.6	6.07 n.s
	Spec. gravity	1.067	1.066	1.064	1.063	1.069	1.068	1.065	1.064	0.0018n.s

*Comparison between application means within same treatment and variety.

The effect of irrigation cooling on yield, grade and specific gravity of potatoes in 1971 and 1972 is shown in Table 8. A yield increase, larger tubers and a greater specific gravity were obtained in 1971 by irrigation cooling. Russet Burbank and Kennebec responded similarly. A large variability in the check plots in 1971, thought to be a consequence of poor irrigation distribution from the farm irrigation system, suggests that these data be used with discretion.

No significant responses between treatments were obtained in 1972. The ample rainfall and cool temperature did not permit a good test of the cooling effect during this growing season. Contrary to expectations, Treatment 2 (irrigation cooling at 85°F) gave a higher yield than Treatment 1 (irrigation cooling at 80°F). Again more water applied for cooling at 80°F may have been responsible for the lower yield. The results in this regard were consistent in both years. The tendency of specific gravity to increase with irrigation cooling was also consistent in both years.

F. Partitioning of nitrogen fertilization treatments

The yield, grade and specific gravity response to partitioning the nitrogen fertilizer is depicted in Table 9. Both varieties, Russet Burbank and Kennebec, gave significant yield increases with later applications of nitrogen.

Table 8. **Effect of irrigation cooling treatments on yield, grade and specific gravity of Russet Burbank and Kennebec potatoes, 1971 and 1972.**

		Russet Burbank			Kennebec		
		Treat.1	Treat.2	Check	Treat.1	Treat.2	Check
1971	Yield (cwt/A)	316	375	266	315	324	265
	% U.S. No.1 tubers	59.5	66.4	63.5	75.5	75.3	83.5
	% Knobby tubers	9.4	8.7	10.1	-	-	-
	% Oversize tubers	20.0	25.0	14.8	16.1	15.2	6.8
	Spec. gravity	1.076	1.075	1.073	1.064	1.065	1.061
1972	Yield (cwt/A)	360	379	341	371	393	392
	% U.S. No.1 tubers	68.0	66.5	62.2	78.5	77.6	77.2
	% Knobby tubers	9.5	11.8	17.2	-	-	-
	% Oversize tubers	12.7	11.1	11.2	15.7	17.2	16.0
	Spec. gravity	1.076	1.075	1.074	1.067	1.066	1.065

Table 9. Effect of partitioning the nitrogen fertilization on yield, grade and specific gravity of Russet Burbank and Kennebec potatoes, 1972.

	Russet Burbank			Kennebec			Standard* error of difference
	Treat.1	Treat.2	Check	Treat.1	Treat.2	Check	
Yield (cwt/A)	401.7	427	343	480	442	392	20.6
% U.S. No.1 tubers	56.7	61.5	62.2	71.4	71.1	77.2	3.7 n.s.
% Oversize tubers	9.7	14.4	11.1	23.8	23.8	16.0	4.8 n.s.
% Knobby tubers	24.1	18.0	17.2	-	-	-	-
Spec. gravity	1.068	1.072	1.074	1.068	1.065	1.065	.002 n.s.

*To test difference of treatment means within each variety.

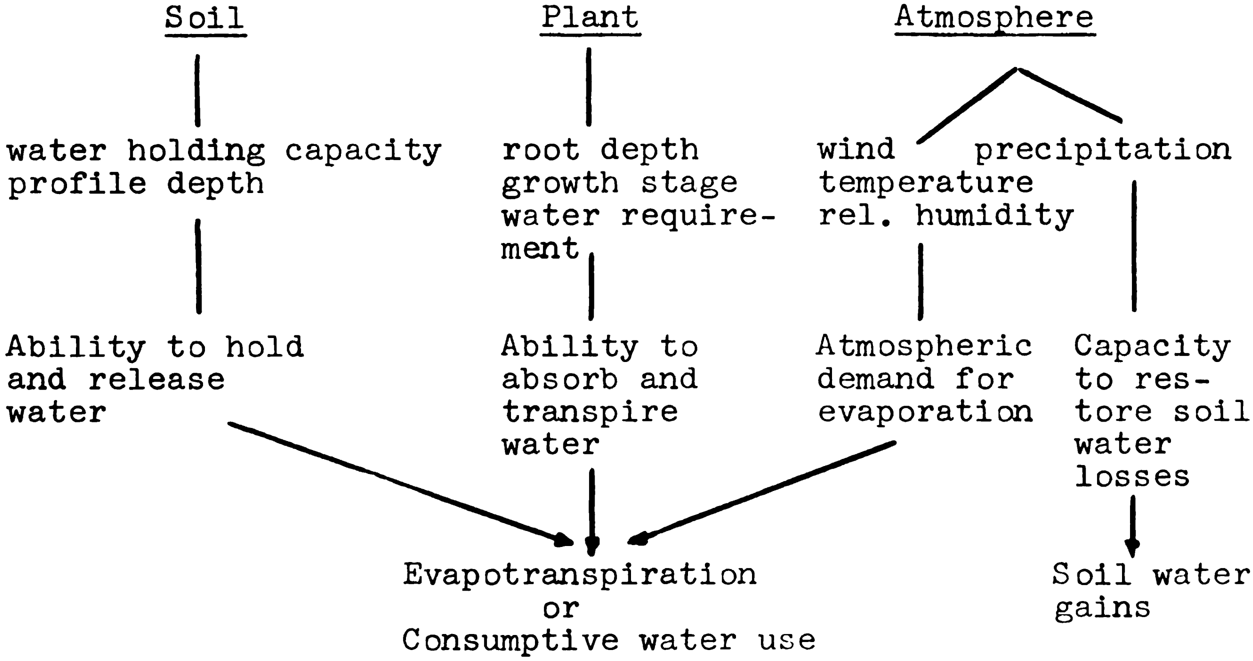
However, the 1972 data alone, do not give a clear indication as to the optimum amount and frequency of later nitrogen applications.

G. Crop factor for pan evaporation values

From gravimetric soil moisture data and estimated soil moisture data inferred from tensiometer readings, the evapotranspiration was calculated for selected time periods in absence of rains or irrigations in 1972. These values were used to calculate the evapotranspiration/pan evaporation (ET/PE) ratio. For June 26-30 the ratio was 0.63; for July 3-7, 0.74; for July 10-13, 0.89; and for July 22-24, 0.68. The average value was 0.73. The infrequency of rainless periods, the short time span over which measurements were made, the inability to measure water loss resulting from deep percolation and the variability of the measured soil moisture contributed to the variability of the above ratios and prevented the precise monitoring of this ratio as crop development progressed.

H. Procedure for scheduling potato irrigations

To devise an accurate and simple procedure for determining the amount of water and frequency for potato irrigations, soil, crop and atmospheric factors were taken into consideration according to the following scheme:



Pan evaporation losses, soil water gains and the soil water storage capacity were the basic parameters used in the calculation of the "soil available water balance". The steps for evaluating these parameters as used in this particular experiment were as follows:

1. Soil available water capacity calculation
   a. Soil type . . . . McBride sandy loam
   b. Effective root depth . . . . . 24 inches
   c. Water retained by the 24" layer at 1/10 bar . . . . 4.7 inches
   d. Water retained by the 24" layer at 15 bars . . . . 1.3 inches
   e. Soil available water capacity (c-d) . . . . 3.4 inches

2. Adoption of soil moisture level and volume of irrigation criteria

a. Amount of available water allowed to be depleted before irrigation . . . . 1.5 inches

b. Amount of water applied per irrigation . . . . 1.0 inches

3. Soil water gains assessment

   a. Precipitations record (P)

   b. Irrigations record (I)

4. Soil water losses estimation

   a. Pan evaporation (PE) measurements

   b. Evapotranspiration/Pan evaporation (ET/PE=CF) adapted to crop growth stage

   c. Evapotranspiration (ET) calculation using the correction factor (CF) in ET = CF x PE

5. Computing daily net gains or losses of soil water with (P + I) - ET = Soil water gain or loss

6. Graphing the soil available water balance chart on a daily basis.

The graphical representation of the daily soil available water balance on a chart has proved to be a useful tool in planning potato irrigations. Figures 9 and 10 show the available water balances kept for Treatment 1 of the (TI) experiment in 1971 and 1972. The two horizontal lines enclose an approximate 50% of the soil available water range. The actual soil moisture was maintained within these limits. In this particular case the percentage value is roughly equivalent to 1.5 inches.

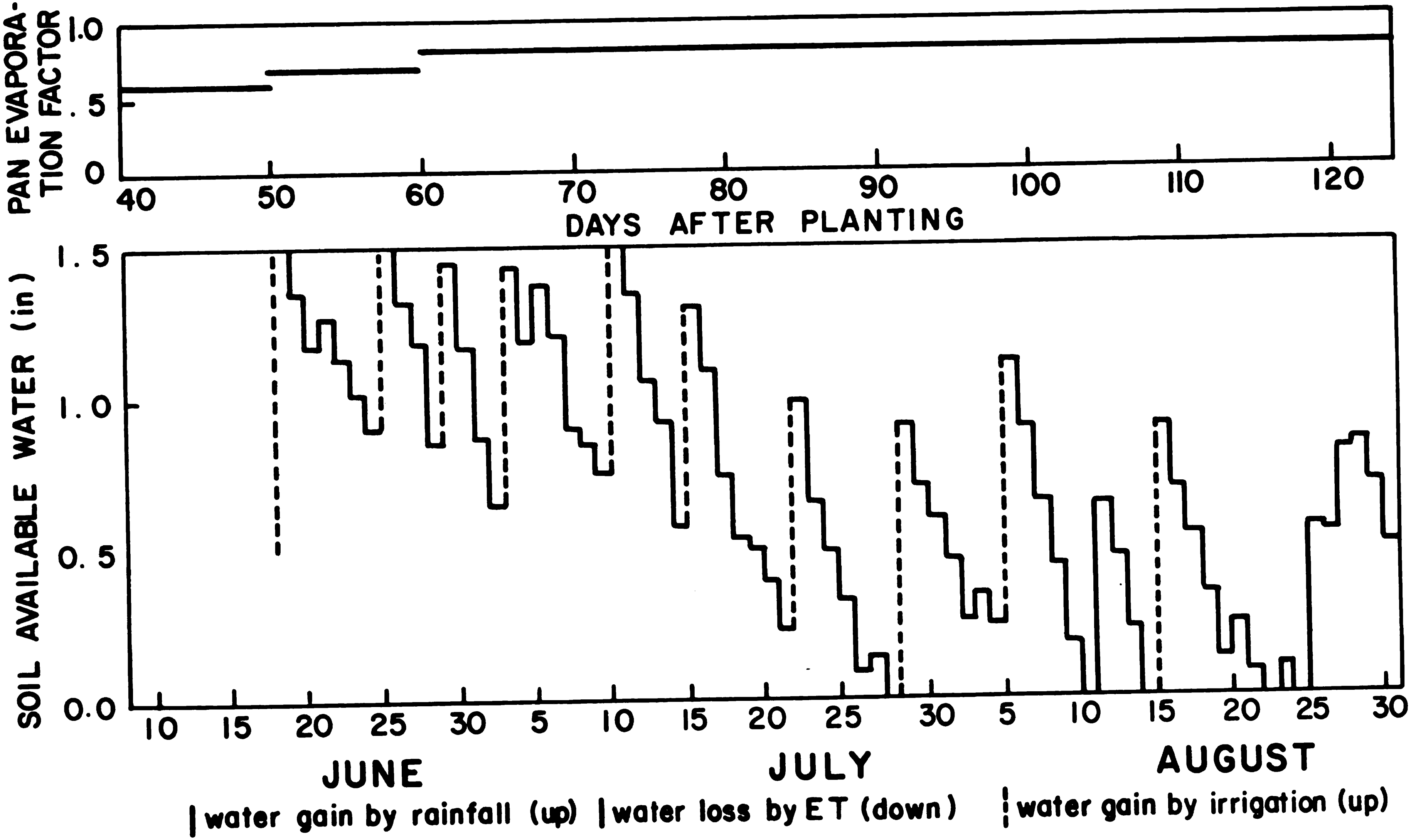


Figure 9. Water balance chart for scheduling potato irrigations (Treatment 1), 1971.

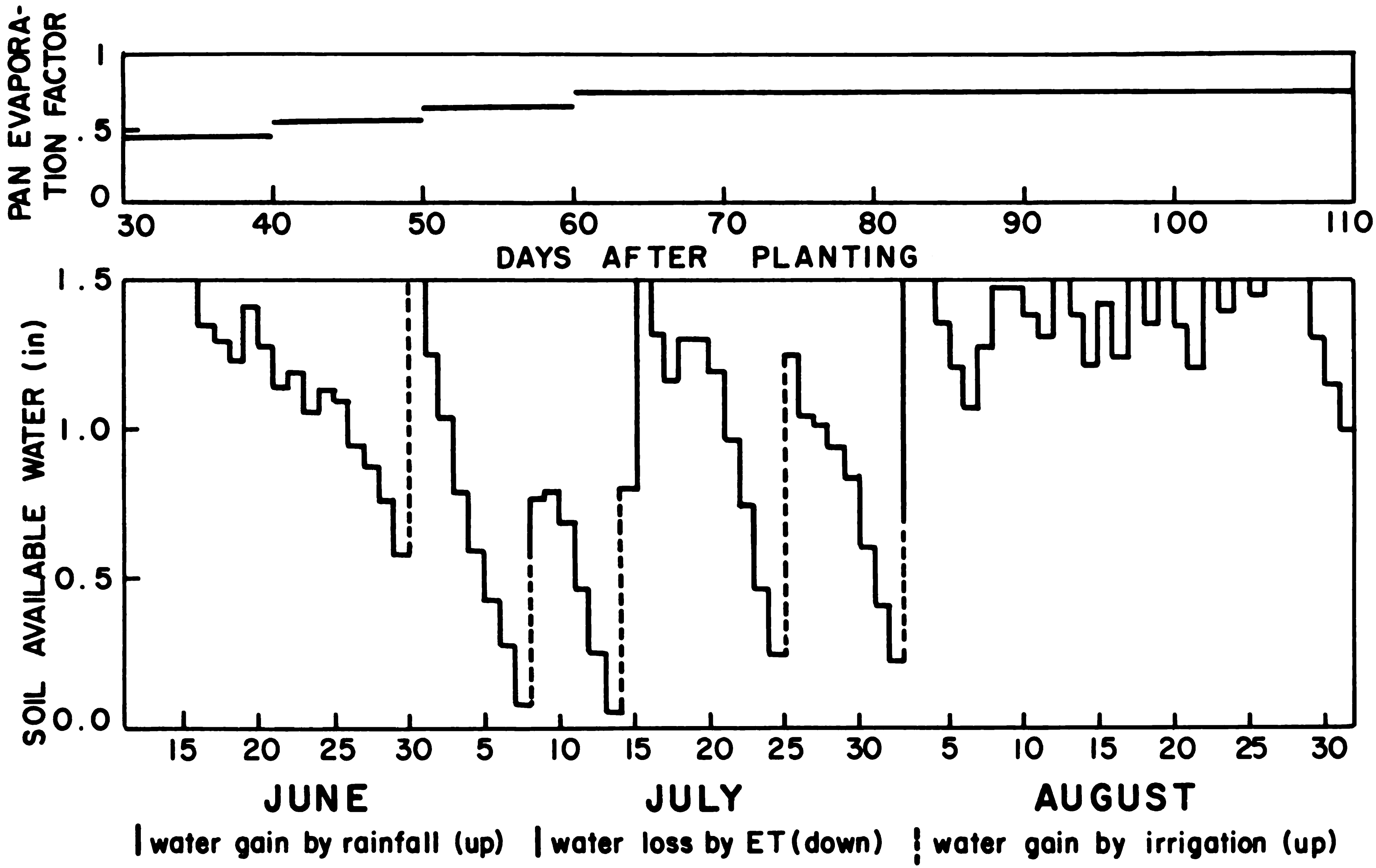


Figure 10. Water balance chart for scheduling potato irrigations (Treatment 1), 1972.

Starting from a known point from the time of planting the daily soil water status was graphed by drawing a vertical line on the indicated day, downward if the balance indicated a loss of water and upward if the balance indicated a water gain. The gain or loss is proportional to the length of the line. The ending of the vertical line for the first day was the beginning of the vertical line for the next day. Lines for successive days were connected for ease of record keeping as shown in Figures 9 and 10. An excess of water causing the vertical line to move beyond the upper boundary was not drawn beyond the boundary line. This water was lost as gravitational water because the storage capacity of the soil had been exceeded. Irrigation was recommended when the line approached the lower boundary; however irrigations could be scheduled at any available soil water deficit.

A practical and convenient way of starting the balance procedure from a known point was to start the soil water reservoir at its highest level. This was established in the field by doing the first irrigation with enough water to assure that field capacity had been reached or exceeded. From then on the irrigations were scheduled by the "soil available water balance" method. Frequently, the soil was sufficiently wet in the spring at planting time that such irrigations were not required.

The pan evaporation factors, indicated by the horizontal lines in Figures 9 and 10, were adopted after considering the values reported in the literature by other investigators (35, 37, 42), the crop development data reported in Table 4 and the ET/PE ratios calculated for this experiment.

I. Comparison of measured pan evaporation with evaporation estimates

Days giving a considerable range in evaporative potential were selected for calculating the free water surface evaporation using Penman's equation. Measured net radiation, mean temperature, mean relative humidity and wind velocity were used as input data. Computations were made for the 6 A.M. - 8 P.M. period. Table 10 shows these results as well as the direct transformation of net radiation into equivalent evaporation at 68^{o}F. Total solar radiation and net radiation are also included. Because of the cloudiness of most of the days the integration of these parameters from the recorded graph involves a certain degree of uncertainty. However, pan evaporation values within the range of .15-.25 inch showed a remarkable agreement with Penman's estimated values (correlation coefficient = 0.95). Smaller pan evaporation values did not show a consistent relationship as some were underestimated while others were overestimated. On the other hand, the estimates were consistently and significantly lower than the measured pan evaporation values when the latter were higher than .25 inch. Advective energy may contribute to this discrepancy. Also

Table 10. Comparison of pan evaporation values and other evaporation estimates for selected days in 1972.

Date	Solar radiation (Langleys/ day)	Positive net radiation* (Langleys/ day)	Pan Evaporation† (in./da.)	Evaporation Estimates Net Rad.‡ (in./da.)	Evaporation Estimates Penman (in./da.)
8-02	121	37	.04	.02	.02
6-24	-	166	.06	.11	.10
8-27	210	101	.06	.07	.06
7-18	285	166	.06	.11	.09
8-04	175	109	.07	.07	.07
7-27	458	248	.10	.16	.14
7-08	-	233	.115	.155	.12
7-09	-	169	.125	.11	.10
7-19	414	276	.14	.18	.16
8-14	292	203	.15	.135	.115
8-21	374	256	.15	.17	.16
8-22	392	233	.15	.15	.13
8-31	429	203	.15	.135	.115
8-20	428	291	.17	.19	.17
8-30	440	299	.18	.20	.18
7-16	420	339	.185	.23	.20
7-29	431	293	.19	.20	.18
8-19	505	297	.195	.20	.20
8-13	524	311	.21	.21	.21
7-15	536	340	.22	.22	.22
8-28	512	317	.22	.21	.18
7-30	506	334	.23	.22	.20
7-10	-	404	.25	.27	.24
6-19	-	400	.255	.27	.24
6-18	-	431	.26	.29	.24
7-28	530	312	.26	.21	.20
7-17	534	385	.27	.26	.24
7-20	542	375	.28	.25	.24
7-23	456	319	.28	.21	.22
7-21	520	385	.29	.26	.24
7-24	574	377	.33	.25	.25
7-22	606	417	.34	.28	.27
		Total	5.98	6.00	5.50

*Computed with 6 A.M. to 8 P.M. data.

†24-hr values.

‡Latent heat of vaporization value used = 590 g-cal/g.

night evaporation, not accounted for in the estimates, can contribute a measurable amount to pan evaporation when the relative humidity is low and the air movement is significant. A comparison of the pan evaporation data with the equivalent evaporation from net radiation also showed good agreement (correlation coefficient 0.91).

DISCUSSION

A. Timing of initial irrigation

The critical stolonization and tuber setting stages of the two potato crops in this experiment occurred in weather conditions entirely different and extreme of those normally encountered in Montcalm County area. It can be expected then that the plant developmental stages would also lie between the two time periods observed in this study (Table 4). Generally, stolonization takes place at 30-40 days and tuber setting at 40-50 days after planting.

The 1971 data showed the beneficial effect of starting the initial irrigation at 50 days as compared to irrigations starting at later times. At 50 days tuber setting had already begun. In 1972 the intent was to start the first irrigation at 30 days during the stolonization period. The rainfall pattern for 1972 invalidated this test; it was not possible to test the desirability of starting the irrigation earlier in the season during the stolonization period. However, two literature reports (4, 6) clearly indicate the importance of maintaining a good soil moisture level during the early plant development period. Consequently, it appears, even in the absence of supportive 1972 data, that irrigation of potatoes at the stolonization stage may be of practical and economic benefit if unseasonably dry and warm weather conditions exists.

B. Day versus night irrigation

The lack of an increase in disease incidence in the plots receiving night irrigation permit the grower to make use of night irrigation without the fear of significant adverse results. Night irrigation also has two advantages: (1) water loss from wind and evaporation is reduced and (2) number of days required to irrigate a field may be reduced by one-half. The night irrigated plots of Russet Burbank produced more oversized tubers, less U.S. No.1, and more knobby tubers. Though the sum of U.S. No. 1 and oversized tubers was similar in both types of irrigation, the data suggest that day irrigation promoted uniformity in tuber size.

It should be noted that day irrigations were generally applied in the morning from 9 to 10:30 or in the afternoon from 5:30 to 6. If these irrigations had been applied around noon, evaporative cooling could have been effected.

C. Frequency of irrigation

Although increasing the yield of Russet Burbank potatoes, the 1/2-inch irrigations did not increase the percentage of large tubers over that found in the 1-inch irrigations in this variety. The total percentage of U.S. No.1 and oversized tubers (Table 7) was increased up to 8% in relation to the check plot. The same comparison for the one-inch treatments showed an increase of only 2%. In the same experiment, the Kennebec variety did not show a differential response to the two frequencies under consideration.

These results suggest that significant yield improvement from applying water at different frequencies is not likely. However, varieties, very sensitive to soil moisture fluctuations like the Russet Burbank may experience some benefit. On the other hand, using less water per irrigation constitutes an assurance against overirrigation and excessive nutrient leaching. Such water savings can eventually be very significant.

D. Irrigation cooling

Potatoes were irrigation cooled under high air temperatures comparable to conditions cited in the literature (1, 5, 17, 23) as being primarily responsible for yield reductions. Even though a lower temperature was established in the plant canopy, the crop yield did not reflect this more favorable environment. This view is reinforced by the observation that these yields were similar to yields obtained from Treatment 1 of the TI experiment. The inconsistency of the check plots in 1971 was attributed to the non-uniform distribution of the water received from the farm irrigation system.

Table 8 shows the reduced yield observed in both years for plots receiving the greater amount of irrigation cooling (Treatment 1). The result was not expected based on findings in the literature. However, the results do agree in general with the more recent investigations of Sanders et al. (26, 28). It appears that not all the water applied was being evaporated but that part of it reached the soil and added to the already sufficient soil water supplied by normal irrigation.

The most likely reason for this absence of response is that irrigation cooling, as applied in this study, did not achieve a temperature depression of sufficient magnitude to produce sensible physiological changes in potatoes. Assuming that temperatures above 70-75^{o}F are detrimental to potato yield and quality (see page 11) and that cooling treatments are generally applied when air temperature reaches 80 to 85^{o}F, it is clear that a consistent temperature decrease of the order of 5-10^{o}F is necessary if substantial yield improvements are to be expected.

Sanders et al. (25) reported a modal ambient temperature depression by misting of 5^{o}F in days of radiant energy higher than 500 ly/day; 4^{o}F in days with 300-500 ly/day; and 1^{o}F for days with radiant energy lower than 300 ly/day. These changes were observed at 22 inches above ground; at lower heights temperature depressions were smaller. The maximum cooling effect, measured during days of high solar radiation, was of the order of 9-12^{o}F for all heights within the canopy. This work was done in Minnesota.

During the study reported here, ambient temperature measurements at 10 and 20 inches above ground were made within the canopy of a check and an IC treated plot. Measured temperature differences averaged from 3.0 to 4.2°F at 10 inches and 2.1 to 3.2°F at 20 inches during periods in which irrigation cooling was being applied.

After testing the validity of a mathematical model to predict microenvironmental modification by small droplet evaporation, Nurnberger (18) calculated the expected maximum cooling effect under different initial conditions. With an initial temperature and relative humidity equal to 86°F and 25% respectively, the predicted maximum cooling would be of the order of 15°F. Decreasing initial temperature and increasing initial relative humidity results in smaller temperature depressions. Although this prediction was made for the tested conditions of uncropped soil and very small water drops, its application to a crop canopy condition and a larger water size drop was not established. The data, nevertheless, provide an indication of the degree of modification to be expected by irrigation cooling under similar initial ambient conditions. It shows that to get significant cooling the initial temperature has to be high and the relative humidity very low. Those conditions, especially the relative humidity referred to are seldom realized in humid areas such as Michigan.

It seems then, that in Michigan's weather pattern it is unrealistic to expect any substantial, consistent, or economical response in potatoes from IC induced temperature changes.

E. Scheduling of irrigations

Potatoes require a high moisture level at practically all stages of plant growth. They also require, especially among those varieties with a tendency to produce malformed tubers, uniformity in the soil water regime. As a result, there is a need to keep the level of soil moisture within a rather narrow range of available water. To avoid both deficiency and excess of water as well as drastic changes in the soil moisture condition, an accurate, simple and rapid method is needed for farmers to keep an accounting of soil moisture. Such a soil available water balance will permit the farmer to establish the soil moisture status and plan irrigations as needed. The soil available water balance based on the soil water storage capacity and the soil water loss estimated from pan evaporation data and crop development, as used in this study, serves as a valuable aid in irrigation management.

The information available indicates that 0.8 is a reasonable factor for the conversion of pan evaporation to evapotranspiration when the crop develops a full canopy. However, a precise determination of this factor and its changes with crop development is not possible without considering percolation through the soil profile. Such water losses are serious only when the entire soil profile is wetted. If pan evaporation data is the only measure for estimating irrigation needs under such conditions, then serious errors can arise.

The observed good agreement of the pan evaporation values with the estimations based on meteorological data confirms once more (7, 20, 32) that the U.S. Weather Bureau Class A pan is a reliable means of estimating the atmospheric demand for water. For most purposes the pan measurements have the advantage of being less time-consuming and expensive than other estimation methods or direct measurement procedures.

Once provided with rainfall and evaporation data several alternatives for handling the information to determine the time and amount of irrigation can be followed. Some of these are:

a. Balance sheet. A numerical daily account of soil moisture is kept by subtraction of the amount of soil water used and addition of the amount of rainfall or irrigation water supplied. Irrigation is scheduled on the basis of the allowed soil moisture depletion. For the McBride sandy loam soil this depletion was established as 1 1/2 inches.

b. Accumulative water chart. This procedure was designed and used for corn irrigations by Woodruff (40). For the daily evaporative loss he used an empirical value of 0.16 inch/day. This value, together with the rainfall or irrigation are used to chart the daily change in soil water status. Basically the chart consists of two inclined parallel lines, with a slope equal to the average soil water use. The top line represents the upper limit of soil water capacity and the lower one the minimum soil moisture level allowed. Horizontal line increments are drawn for each day and vertical lines are drawn upward representing rainfalls or irrigations. The result is a stair-shape line which graphically accumulates the water added and indicates the need for irrigation by its proximity to the lower line.

c. Water balance chart. This procedure, followed in this study, is a modification of Woodruff's method. It differs from the Woodruff method in two ways.

1. The lines are not plotted on a diagonal; hence no accumulative loss of water is kept. Because an oblique line is removed from the plot this modification adds simplicity to the graphing procedure and facilitates its comprehension.

2. The daily evapotransporative loss of water varies with development of the plant canopy and with the daily or weekly atmospheric conditions. More accuracy in estimating the soil moisture level is gained in this way.

These procedures offer the possibility of scheduling irrigations, both in time and amount, at any point within the established range of available soil moisture, thus providing the necessary flexibility and planning for a practical and efficient farm operation. With one of the soil moisture accounting procedures, the farmer is not restricted to a fixed soil moisture level or frequency of irrigation. These management operations can be varied as the growing season proceeds in response to a weather situation or to the periodic nitrogen application needs of his crop.

Irrigation cooling may also enter into the irrigation plan. This study showed that for most years no substantial potato yield increase can be expected from irrigation cooling under Michigan's climatic conditions. Consequently it will not be economical to introduce the practice on a regular basis. This conclusion, however, does not invalidate the observation that under some stressing atmospheric conditions measurable increases in terms of yield, grade and specific gravity have been obtained from irrigation cooling. As a consequence, it is thought that a partial irrigation at noon hours of days, when temperature and relative humidity values are conducive to an effective evaporation cooling, may be of some benefit to the crop.

In conclusion, the approach proposed here for water management of potatoes is that of planning the amount of water to be applied to a soil, the frequency and time of the day for these water application, the irrigation cooling requirements, the periodic application of nitrogen and other collateral uses of the irrigation water. These plans should be integrated to meet changing weather and soil moisture conditions. This implies that the water management plan must be flexible, and this can only be accomplished if a precise record of the soil moisture status is kept by the farmer on a routine basis. The water balance chart procedure provides an easy means of achieving these goals.

The U.S. Weather Bureau obtains daily pan evaporation data from six sites in Michigan. These sites are Dearborn, East Lansing, Germfask, Lake City, Lupton and South Haven. The use of the water balance method would be greatly facilitated if pan evaporation data, like rainfall data, were made available to the growers on a regular basis by newspaper, radio and other means of communication.

CONCLUSIONS

1. Two years of a potato irrigation experiment were characterized by different weather patterns: 1971 was warm and dry and 1972 cool and wet. The greater and most significant climatological difference took place during the earlier part of the two growing seasons.
2. In 1971 the Russet Burbank variety responded to irrigation with a 98% yield increase and the Kennebec variety with a 66% increase. In 1972 no response to irrigation was obtained. A slight yield depression, attributed to excess water was observed in Russet Burbank.
3. Initiating the crop irrigation at the beginning of tuber setting period (50 days after planting) instead of 20 days later increased the yield 14% in Russet Burbank. Kennebec gave a similar response. Knobbiness was reduced from 21 to 13% in Russet Burbank. Specific gravity was increased by the same amount in both varieties. These results were observed in 1971. No significant differences were detected in 1972. Specific gravity did show a tendency to increase with the earlier irrigations in both varieties.

4. Night irrigation did not increase disease incidence. Yield, grade and specific gravity were not significantly affected by night irrigation as compared to day irrigation.
5. Half-inch versus one-inch applications per irrigation did not give significant improvements of yield and quality of tubers. Yet the smaller application gave a higher yield with Russet Burbank. Yield depression with the one-inch application was attributed to short term water excess.
6. Yield data from the irrigation cooling experiment showed no increase as a result of this practice. This study like earlier investigations indicates no substantial benefit from this practice in humid areas.
7. Partitioning the nitrogen fertilization through periodic applications with irrigation water gave significant increases in 1972.
8. The evapotranspiration/pan evaporation value of 0.8 is acceptable for potatoes with good canopy development.
9. Penman's estimation of evaporative water loss showed very good agreement with pan evaporation values in the intermediate range of atmospheric conditions.

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