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The effects of irrigation frequencies and rates and time of nitrogen fertilizer application on the yields, grades and N status of Russet Burbank potatoes were determined on a sandy soil near Hermiston, Oregon.

Increasing the frequency of irrigation from 72 to 48 to 12-hours did not result in increases of yields or improved grades of tubers during the growing season.

Optimum yields and grades were obtained when 196 lbs. N/A was applied in a single fertilizer application with 88 lbs. N/A in the soil as nitrate-N. This N treatment corresponded to 0.58, 0.42, 0.46, 0.32 and 0.17 percent petiole nitrate-N on July 6, July 21, August 4, August 24 and September 9 sampling dates, respectively.

Split N fertilizer applications resulted in higher petiole nitrate-N levels during the growing season, similar total yields and lower

yields of U.S. No. 1 tubers than treatments in which all of the fertilizer was applied at planting. The higher petiole nitrate-N levels delayed tuber maturity and subsequently the split N applications were influenced by the high soil and air temperatures in July and August and formed increased yields of off-shape tubers. This emphasizes the importance of adequate N early in the growing season in order to prevent delayed vine and tuber growth and the importance of even assimilation of nutrients by the tubers in later stages of development.

Potato Yield and Grade as Influenced by Nitrogen Fertilizer and Irrigation Frequency

by

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POTATO YIELD AND GRADE AS INFLUENCED BY NITROGEN FERTILIZER AND IRRIGATION EFFICIENCY

INTRODUCTION

In recent years there has been a substantial increase in potato production on sandy soils in the Hermiston-Boardman area of Oregon. This increase has been made possible with the development of irrigation water on previously undeveloped desert land. At present there are about 6, 000 acres of potatoes under irrigation. Potentially there are 100, 000 acres of irrigable land yet to be developed. With favorable market conditions increases in potato production should continue to take place as large acreages of this new land are developed.

The Hermiston-Boardman area produces potatoes that are sold to fresh produce markets throughout the country. In fresh market potatoes, the production of tubers of desirable size and smoothness can be more important than total yield. Producers need information concerning the management of these sandy soils with respect to irrigation and nitrogen (N) fertilizer use and how they affect the desirable grades and yields of potatoes. At present, there is little uniformity among potato producers as to the frequency of irrigation. Center pivot irrigation systems permit considerable flexibility in irrigation frequency. Some producers irrigate as frequently as every six hours while others irrigate every 48-hours. Solid-set and side-roll irrigation systems provide less flexibility primarily due to the labor involved and generally two to four day irrigation intervals are common with these two systems. Potato producers have sought increased yields and grades by applying N fertilizer during the growing season. Although N fertilization practices are not uniform most producers believe split N applications are necessary on these sandy soils to obtain optimum grades and yields of tubers.

Research has shown that irrigation and N fertilization practices can have an affect on the grades and yields of tubers. Most research studies to date have been conducted in areas differing from the Hermiston-Boardman area with respect to soil type and climatic conditions. The low water holding capacities of these sandy soils and the different climatic conditions present in the area may require different management practices. Additional information is needed under conditions in the Hermiston-Boardman area to determine the influence of irrigation frequencies on N fertilization and how both of these affect the yields and grades of tubers.

PURPOSE

The purpose of this study was to determine the influence of irrigation frequencies and rates and time of N fertilizer application on the N status, yields and grades of Russet Burbank potatoes. The N status includes petiole nitrate-N, soil nitrate-N, soil ammonium-N and N utilization by the potato crop.

LITERATURE REVIEW

Nitrogen Requirements of Potato Plants

Nitrogen was the nutrient most closely associated with increased yields of White Rose potatoes, in more than 80 experiments conducted over 16 years in California (Lorenz *et al.* 1954). The annual rate of N application needed to produce the highest total yield was variable. In Riverside County (Tyler *et al.* 1961), in sandy soils where the organic matter level in the soil had not been appreciably increased by plant residues, the highest total yields (23.6 tons/A) of Kennebec, White Rose and Russet Burbank potatoes were obtained when 240 lbs. N/A was applied. Where the soil organic matter had been increased and therefore contributed to the N present for crop removal, the highest total yields were reported when 60 lbs. N/A was applied. McKay, MacEachern and Bishop (1966), reported that maximum total yields of Kennebec potatoes were obtained when N was applied near 200 lbs./A in Canada. In the Ontario area of Oregon the highest total yields of Russet Burbank potatoes were obtained when 260 lbs. N/A was present (160 lbs./A applied and 100 lbs./A as nitrate-N in the soil) (Jackson 1970).

Lorenz (1954) found that the percentage of U.S. No. 1 White Rose potatoes was seldom affected by applied N fertilizer, except when the total yield of unfertilized plots was very low. In these cases the tubers had not reached sufficient size to place them in the U.S. No. 1 size A grade. Hanley, Jarvis and Ridgman (1965), reported that N fertilization increased the number of Majestic tubers and yields of all grades and increased the weight of individual tubers slightly.

Other workers report that excess N present for crop assimilation delays tuber maturity and lowers quality of potatoes (Terman et al. 1951; Doll and Thurlow 1965).

Nitrogen Assimilation by Potato Plants

Lorenz (1954) reported that the rate of NPK assimilation in potatoes is closely associated with tuber growth. They stated that from 30 to 60 days after planting, most of the nutrients are assimilated in the tops, but this usually amounts to less than 10% of the total nutrients absorbed during the growing season. As tuber growth commences, the tubers account for most of the nutrient absorption, and by harvest more than two-thirds of the total nutrients assimilated are found in the tubers. Nitrogen assimilation closely approximated dry matter accumulation according to Soltanpour (1969), in Russet Burbank potatoes in Colorado. He showed that 60 days after planting, 35% of the total N was absorbed. The remaining 65% was absorbed between 60 to 88 days after planting. After 88 days almost all of the N assimilated by tubers was due to translocation of stored N from the tops which amounted to 48% of the maximum N uptake by the tubers. At final harvest (15.0 tons/A total yield), 76% of the plant N was in the tubers. This is compared to 70% of the plant N in the tubers as reported by Jackson and Haddock in Utah (1959). Hawkins (1946) stated that the percentage of N in the tops decreased with increasing age of the plant. At harvest the Cobbler, Chippewa, and Green Mountain varieties contained 143 lbs. in the tops and tubers, with a total yield of 387 bushels per acre. Hawkins further states that although non-tuber portions lost N, the entire plant continued to gain N until the last harvest date.

Petiole Nitrate-Nitrogen

Nitrate-N represents a reserve of unassimilated N in the plant (Viets, 1965). In potatoes, the nitrate-N levels in petioles have been used to determine the N status of the plant (Lorenz 1954; Terman 1951; Tyler 1961; Tyler, Fullmer and Lorenz 1960). Best results for nitrate-N analysis has been obtained using the fourth petiole from the growing tip of the potato plant (Smith, 1968). Levels of nitrate-N in the petiole vary considerably according to the age of the plant and to nutrient availability (Tyler 1960). Lorenz, Tyler and Fullmer (1964) showed using the fourth petiole from the growing tip that in White Rose, Kennebec, Pontiac and Russet

Burbank potatoes, petiole nitrate-N decreases rapidly with plant age and at maturity was present in relatively low concentrations. They stated that 70 days after planting, petiole nitrate-N content of plants in all N fertilizer treatments dropped to less than one-half that found at the first sampling date or 54 days after planting. The nitrate-N continued to decrease until plants were harvested. Sampling 54 days after planting, there were large differences in the nitrate-N content in the petiole between the N fertilized plants and those not receiving N, although all petioles were relatively high in nitrate-N whether or not N had been applied. They further stated that as long as petiole nitrate-N is maintained at a safe level during early and midseason growth, satisfactory yields are obtained and there is no benefit in maintaining extremely high petiole nitrate-N content throughout the growing season. The safe level they concluded was 12, 000, 9, 000 and 5, 000 p. p. m. at the beginning of tuber set, early tuber set until tubers were half grown and half grown tubers until maturity, respectively.

The timing of N application influences the level of petiole nitrate-N. Griffin (1970) in southern Idaho compared 225 lbs. N/A applied annually, monthly and weekly on Russet Burbank potatoes. He reported that the highest level of petiole nitrate-N (using the fourth petiole from the growing tip) occurred in the annual N treatment. The monthly N treatment showed an increase in petiole nitrate-N following each N application and then the level decreased between N applications. Weekly N applications showed a steady decrease in petiole nitrate-N.

Split Nitrogen Applications

Nitrogen fertilizer must be applied before it is needed by the potato plants. Hawkins (1946) reported on Cobbler, Chippewa, Green Mountain and Smooth Rural potatoes that N should be highly available during the 30-day period after the plants are about six to eight inches high. He further stated the N should be available throughout the growing season since N is absorbed until the death of the plant. Lorenz (1954) showed the best total yields on White Rose potatoes occurred when N fertilizers were applied at planting. Murphy and Goven (1965) obtained the highest yield of Katahdin potatoes when 150 lbs. N/A was applied in bands at planting as compared to 60 lbs. in bands at planting plus additional N as side dress or foliar applications.

In contrast to Lorenz, and Murphy and Goven's work, Griffin (1970) in Idaho reported the highest total yield of Russet Burbank potatoes was obtained on three monthly applications (total 225) of 75 lbs. N/A. The annual application of 225 lbs. N/A produced the highest yield of marketable potatoes. Weekly applications of N totaling 225 lbs./A produced the lowest yield of marketable tubers.

Doll, Christenson and Wolcott (1971) suggested that additional N fertilizer should be applied when the soil nitrate-N values fall below 20 p.p.m. before 10-12 weeks after plant emergence to prevent reduction in yields.

Irrigation and Potato Growth

Irrigation management, both amount of water and frequency, is important in the production of potatoes. It is important to maintain adequate and uniform soil moisture and thus minimize plant-moisture stress. Moisture stress was found to reduce the total yield and yield of U.S. No. 1 Russet Burbank potatoes by Robins and Domingo (1956). They further stated that moisture stress at any time after the tubers begin to develop, can cause the formation of "spindle-shaped" tubers. Chase, Kiddler and Kunge (1969) reported the location and intensity of the growth constriction (retarded tuber growth) corresponded to the time and intensity of the imposed moisture stress. "Bottleneck" tubers developed when the growth of small tubers were retarded and "dumbbells," "twisted" and "pointed-end" tubers develop when the growth of larger tubers were retarded (Nielson and Sparks, 1953). Corey and Myers (1955) stated that the yield of U.S. No. 1 grade was significantly reduced by long irrigation frequencies. This corresponded to an increase in off-shape tubers.

The total irrigation amount can be determined by the consumptive use (C. U.) method reported by Jensen and Middleton (1970). They determined that a near-constant relationship exists in the Columbia Basin area of Washington between the C. U. of water by a crop and the rate of evaporation from a selected evaporimeter. The evaporimeter was a-four foot diameter class A Weather Bureau pan located in a clipped lawn 50x50-foot area within a continuously foliated field. For potatoes they established a 1.0 crop factor. This factor was

C. U. = Crop Factor X Evaporation

used when 100% of the soil surface was covered by the potato foliage.

Soil Temperature and Potato Growth

Potatoes are best adapted to cool temperatures and long days. The mean air temperature for the growing season should not exceed 70°F according to Thorne and Peterson (1954). They further stated that tuber formation is retarded at high temperatures and optimum soil temperature for tuber growth is 64°F. Corey (1955) stated that high soil temperatures resulted in a larger percentage of off-shape tubers. They reported that each day the soil temperature is above 65°F after the initial 30 days (at 12" depth) the number of off-shape tubers increases. They also reported that significant temperature differences occurred between several irrigation rates, with the most frequent rate resulting in cooler soils.

Soil Nitrogen and Potato Growth

Plant roots can absorb N as ammonium or nitrate. In warm, well areated soils ammonium is quickly oxidized so that nitrate is the predominant form of available N in most soils fertilized with ammonium or ammonium containing fertilizers (Viets, 1965). The optimum temperature for oxidation of ammonium to nitrate lies between 27 and 35^{o}C as was shown by Frederick (1956). He further stated that in Genesee silt loam nitrate-N was formed at rates of 45, 60, 90 and 129 p.p.m. per week at 15.5, 21, 27 and 35^{o}C, respectively, until the ammonium-N had been oxidized.

Nitrate is readily leached from the soil profile if leaching conditions exist. Griffin (1971) reported in a leaching condition (over watering), nitrate-N levels were the highest in sandy soil columns where small frequent N applications were applied. The N was leached out of columns fertilized annually by the excess water. In Michigan, Doll, Christenson and Wolcott (1971) reported that soil nitrate-N levels fluctuated less during the growing season than did petiole nitrate-N levels, and are possibly the more precise indicator of the N status of the crop.

MATERIALS AND METHODS

Experimental Area

The experiment was conducted during the 1971 season on a Ephrata loamy sand with a depth of 36 to 60 inches at the Umatilla Experiment Station, Hermiston, Oregon. Alfalfa was grown on the plot area from 1965 to 1969 and followed by wheat in 1970. Eighty-eight lbs. of N/A was present in the soil (0-3 ft. depth) as nitrate-N before the N fertilizer treatments were applied. After primary tillage the soil was treated with 4.0 lbs. a.i./A of Dyfonate (organophosphorus soil insecticide) for wire worm control. A broadcast fertilizer application of N, P, K, S and Zn at 31, 48, 86, 19 and 14 lbs./A, respectively, was applied prior to planting. The N was applied as ammonium phosphate and ammonium sulfate. The soil insecticide and fertilizer were incorporated into the soil to a depth of eight to ten inches. Oregon certified seed of the Russet Burbank variety was planted April 19, 1971. At planting 85 lbs. N (as ammonium sulfate and ammonium phosphate) and 41 lbs. P were applied in a band two inches to the side and two inches below the seed piece. The seed pieces were placed seven to eight inches apart within the row and the rows spaced 34 inches apart.

Plot Design

The experimental layout was a split-plot design with irrigation treatments as whole units and N fertilizer treatments as sub-units. The plot area was divided into three irrigation treatments. Each irrigation treatment area was 210 feet long by 60 feet wide with 30-foot buffer areas between treatments. A solid set type sprinkler system with a 30 by 30-foot sprinkler spacing was used in each irrigation treatment.

Within each irrigation treatment the six N fertilizer treatments were randomized using six replications. Each N fertilizer plot was two rows wide and 30 feet long and was separated from adjoining N plots by one border row. Three N fertilizer plots were located between each pair of irrigation laterals with one or two border rows between the N plots and the lateral.

Treatments

Irrigation Treatments

The irrigation treatments consisted of applying an amount of water equal to the estimated consumptive use (C. U.) for potatoes in three frequencies: every 12 hours, every 48 hours, and every 72 hours (Table 1). Consumptive use was estimated daily by

Table 1. Irrigation treatments. [1/]

Irrigation treatment	Frequency of applications (hours)	Total No. of applications	Total water applied (inches)	Average water applied/ application (inches)
I	12	168	33.3	0.20
II	48	43	34.6	0.80
III	72	30	32.8	1.09

[1/] From 6/19-9/10.

multiplying the crop factor by the daily pan evaporation as described by Jensen (1970).

$$C.U. = \text{Crop Factor X Evaporation}$$

To compensate for the dry placement of the evaporation pan in this experiment a crop factor of 0.9[1/] was used instead of the 1.0 crop factor stated by Jensen (1970). For the 12-hour irrigation frequency the previous day's calculated C. U. was applied in equal amounts at 7 a.m. and 7 p.m. The 48 and 72-hour irrigation frequencies received the previous 48 and 72-hour calculated C. U., respectively, and was applied in a single irrigation at 7 a.m. Water pressure, sprinkler spacing, and nozzle size were used to calculate the length of time for each application of water.

[1/] Personal communication from Dr. Ullery, Assistant Professor, Soil Science, O. S. U., Corvallis, Oregon.

Six inches of irrigation water was applied uniformly to the field during the period from planting (April 19) to June 19. The irrigation treatments were started on June 19 and continued until September 10 just prior to kill down.

Nitrogen Fertilizer Treatments

To determine plant response to N fertilization, six N fertilizer treatments were used. Three N treatments consisted of single applications of N applied at 116 lbs./A, 196 lbs./A and 276 lbs./A, while the other three N fertilizer treatments consisted of split or multiple applications of N at 196 lbs./A, 276 lbs./A and 356 lbs./A. The N fertilizer treatments are summarized in Table 2. All six N fertilizer treatments received 31 lbs. N/A broadcast prior to planting and 85 lbs. N/A banded at planting. Additional N fertilizer for the single N applications was applied two days after planting as a side dress application of ammonium-nitrate. The split N treatments received varying amounts of additional N as broadcast applications of ammonium nitrate. Table 2 lists the dates and amounts of N applied to the three split N treatments.

Table 2. Nitrogen fertilizer treatments in lbs. /A.

Treatment	Preplant and banding at planting	Broadcast after planting				Total
		6/22	7/3	7/16	7/25	
1	116	--	--	--	--	116
2	196	--	--	--	--	196
3	276	--	--	--	--	276
4	116	80	40	60	60	356
5	116	20	20	20	20	196
6	116	40	40	40	40	276

Sampling

Petiole Sampling

Within each irrigation treatment petioles were removed from the N fertilizer treatments on five sampling dates: July 6, July 21, August 4, August 24, and September 9. The first mature leaf or usually the fourth petiole from the growing tip was cut close to the stem end, the leaves and one inch of the petiole from the tip end was discarded. The petiole samples were removed between 10 a.m. and 1 p.m., placed in pastic bags and immediately stored on ice. Within two hours after sampling, the petioles were dried in a forced air oven at 70°C for 24 hours. In each N treatment 20 petioles from replication one and 20 from replication two were removed and combined to give a composite sample of 40 petioles for two replications. Similarly, petiole samples from replications three and four, and five and six were combined to provide one sample for each replication pair.

Soil Sampling

Soil samples were removed from the experimental area prior to planting the potatoes. Additional samples were removed from the six N treatments on three sampling dates during the growing season (July 14, August 2, and September 15). Samples were taken halfway between hills in the row and halfway down the ridge with a soil probe in one-foot increments to a depth of three feet. The fourth foot was sampled on July 14 and September 15 in only three N treatments (276 lbs./A single and split and 356 lbs./A split). Four subsamples were removed in each N treatment in each replication. The six replications were then combined to give a composite sample for each N fertilizer treatment.

Tuber and Vine Sampling

Tuber and vine samples were collected to determine N utilization by the potato crop. Samples were collected from three N fertilizer treatments (276 lbs. N/A single and split and 356 lbs. N/A split) and in two irrigation frequency treatments (12 and 72 hours). Vine samples were collected in each sampling area just prior to vine killdown by removing three hills in each of the six N fertilizer replications. The three hills from replication one, two and three were combined to give a composite (nine hills) plant vine sample. Similarly, hills from replication four, five and six were combined. The vine samples were then chopped, well mixed, weighed and a smaller sample of approximately one pound was removed. The one pound vine sample was then weighed and dried at 70°C for 24 hours.

The tuber samples were collected when the potatoes were graded. Two or three large (8-10 oz.) and small (2-3 oz.) tubers were collected from each sampling area. Similarly to vine sampling, replications one, two and three, and four, five and six were combined. The tuber samples were then weighed, chopped and dried at 70°C for 72 hours.

Analysis of Samples

Soil samples were analyzed for nitrate-N and ammonium-N using the steam distillation method described by Bremner (1966). Petiole nitrate-N was extracted in .02M formic acid solution and was analyzed using steam distillation (Bremner 1966). Total-N in vines and tubers was analyzed after digestion by the micro-kyeldahl procedure outlined by Bremner (1965).

Potato Grading

Two rows 20 feet long were harvested from each N-fertilizer plot. Total yield weight was obtained in the field. The potatoes were graded according to standards set by the U. S. D. A. effective September 1, 1971, and by the Oregon-California Potato Committee. The U. S. No. 1 grade were potatoes with a two-inch minimum diameter or weighing at least four ounces and fairly well shaped.[2/] The U. S. No. 2 grade were potatoes with a two-inch minimum diameter or weighing at least four ounces and not seriously misshapen.[3/] Those tubers which did not meet the above standards were graded as culls. The U. S. No. 1 grade tubers were divided into three categories: "strippers"--two-inch minimum diameter or four ounces minimum weight to seven ounces; "boxes"--seven ounces to 14 ounces; "bakers"--14 ounces plus.

2/ Fairly well shaped means that the potato is not materially pointed, dumbbell-shaped or otherwise materially deformed.

3/ Not seriously misshapen means that the potato is not seriously pointed, dumbbell-shaped or otherwise not badly deformed.

Air and Soil Temperature Measurements

Maximum air temperature readings were obtained from the official daily recordings made on the Umatilla Experiment Station for the U. S. Weather Bureau.

One soil temperature probe was placed in each of two irrigation treatments (12 and 72 hour). The probes were placed at a depth of four-inches below the top of the hill. Daily maximum and minimum soil temperature readings were recorded.

Statistical Analysis

Results from each individual irrigation frequency were tested for significance at the 5% level using F tests in the analysis of variance and Tukey's ω procedure (Steel and Torrie, 1960). The means of the fertilizer treatments were then combined across irrigation treatments as described by Cochran and Cox (1957) and tested for significance at the 5% level using F tests in the analysis of variance and Tukey's ω procedure.

RESULTS AND DISCUSSIONS

Under the conditions set in this experiment, the interaction of irrigation frequencies and N treatments were nonsignificant at the 5% level of probability, and it is concluded that irrigation frequencies and N treatments act independently of each other. The total yield and grade of tubers provide the basis for comparisons and conclusions reached in this study. Thus the relationships that exist between irrigation frequencies, N treatments, soil temperature, petiole nitrate-N, soil nitrate-N and soil ammonium-N values are important when total yield and grade are considered. After first discussing the growth stages, total yield and grade are considered as they relate with these other parameters.

Date of Cultural Operations and Growth Stages

Some of the important cultural operations and growth stages are given in Table 3. The plot area was planted April 19, 1971, with emergence occurring 22 days later on May 10. The time from planting to tuber initiation was 26 days and the tubers reached one inch in diameter 61 days after planting. The period from planting to kill was 150 days and from tuber initiation to kill 124 days.

Table 3. Dates of cultural operations and growth stages.

Planting	April 19
25-50% emergence	May 10
Tuber initiation	May 14
One-inch tuber stage	June 20
Rows close	June 15 (N treatments 3, 4, 5 and 6; June 30 treatment 2)
Plants lodge	July 1 (treatments 3, 4, 5 and 6)
Killing date	September 15
Harvest	September 27

Number of days:

Planting to 25-50% emergence	22 days
Planting to tuber initiation	26 days
Tuber initiation to kill	124 days
Planting to one-inch tuber stage	61 days
One-inch tuber stage to kill	88 days
Planting to kill	150 days
Planting to harvest	164 days

Irrigation Total Yield and Grade

There was little variation in total amounts of water applied in each of the three irrigation frequency treatments (Table 1). The total difference between the 48 and 72-hour irrigation frequencies was 1.8 inches.

Total yields and grades of potatoes for the three irrigation frequencies are given in Table 4. The highest total yield of 33.0 tons/A [4/] was recorded by the 48-hour irrigation frequency. The

[4/] Unless otherwise stated, reported yield differences are significant at the 5% level of probability.

Table 4. Influence of irrigation frequency on mean yields of Russet Burbank potatoes.[1/]

Irrigation frequency	Yields of tubers - tons/A							
	Total yield	Grade						
		U.S. 1	U.S. 2	U.S. 1 & 2	Culls	Strippers[3/]	Boxers	Bakers
12 hr.	31.5[a][2/]	14.6[a]	9.9[a]	24.5[a]	7.0	9.1	5.2[a]	0.4[a]
48 hr.	33.0[b]	13.3[b]	11.7[b]	25.1[a]	7.9	8.8	4.2[b]	0.3[a]
72 hr.	32.8[a]	14.8[a]	9.4[a]	24.2[a]	8.6	10.1	4.5[ab]	0.2[a]

[1/] Averaged across N treatments.

[2/] Means within a column followed by the same letter are not significantly different at the 5% probability level.

[3/] Strippers--2-inch minimum diameter or 4 oz. minimum weight to 7 oz.; Boxers--7 to 14 oz.; Bakers--14 oz. plus.

highest yields of U. S. No. 1 grade were recorded by the 12 and 72-hour irrigation frequencies with 14.6 and 14.8 tons/A, respectively. Irrigation frequencies of 12 and 72-hours yielded the highest tonnage of "boxers" (7 to 14 oz. tubers) with 5.2 and 4.5 tons/A, respectively.

Yield differences recorded among irrigation frequency treatments tended to be small. The difference between the high and low yields among the irrigation treatments were 1.5, 1.5 and 1.0 tons/A for total, U. S. No. 1 and "boxer" yields, respectively. Total and U. S. No. 1 yields did not decrease as the time interval between irrigations increased. Other workers have reported that total yield decreases when moisture stress is imposed on a growing potato crop (Robins 1956). Decreases also occur in U. S. No. 1 yields, by increasing the number of off-shape tubers, when soil moisture is not adequately uniform (Chase 1969; Robins 1956; and Corey 1955). In this experiment increasing the time interval between irrigations produced only small differences in yield and grade and failed to show increasing amounts of off-shape tubers. Little benefit then, was gained by irrigating at the 12 and 48-hour frequencies over the 72-hour frequency.

Nitrogen Fertilization, Total Yield and Grade

Total yield and grade values in Table 6 show the influence of

Table 5. Influence of irrigation frequency on percent grade of Russet Burbank potatoes.[1/]

Irrigation frequency	Total yield (ton/A)	Percent of total yield			Percent of U.S. No. 1's		
		Grade			Grade		
		U.S. 1	U.S. 2	Culls	Strippers[2/]	Boxers	Bakers
12 hr.	31.5[a]	46	31	22	62	36	3.0
48 hr.	33.0[b]	40	35	24	66	32	2.0
72 hr.	32.8[a]	45	29	26	68	30	1.0

1/ Averaged across N treatments.

2/ Strippers--2-inch minimum diameter or 4 oz. minimum weight to 7 oz.; Boxers--7 oz. to 14 oz; Bakers--14 oz. plus.

Table 6. Influence of N fertilizer treatments on mean yields of Russet Burbank potatoes. 1/

Nitrogen treatment (lbs. N/A)	Yield of tubers, tons/A							
	Total yield	Grade						
		U.S. 1	U.S. 2	U.S. 1 & 2	Culls	Strippers 4/	Boxers	Bakers
116	29.6^{b} 3/	13.8^{bc}	7.2	21.0^{b}	8.6	10.2	3.5^{a}	0.1^{a}
196	32.2^{a}	16.9^{d}	7.8	24.7^{a}	7.5	11.1	5.5^{bc}	0.3^{a}
276	33.8^{a}	17.3^{d}	9.6	26.9^{a}	6.9	10.4	6.3^{c}	0.6^{b}
356 2/	33.5^{a}	11.7^{a}	14.2	25.9^{a}	7.6	7.6	3.7^{a}	0.3^{a}
196 2/	32.4^{a}	13.2^{abc}	11.2	24.4^{a}	8.0	8.3	4.6^{ab}	0.2^{a}
276 2/	33.3^{a}	12.8^{ab}	12.1	24.9^{a}	8.4	8.3	4.3^{ab}	0.2^{a}

1/ Averaged across irrigation treatments.

2/ Split N treatments.

3/ Means within a column followed by the same letter are not significantly different at the 5% probability level.

4/ Strippers--2-inch minimum diameter or 4 oz. minimum weight to 7 oz.; Boxers--7 to 14 oz.; Bakers--14 oz. plus.

N fertilization on Russet Burbank potatoes. Eighty-eight lbs. N/A was present in the soil (0-3 ft. depth) as nitrate-N, before the N treatments were applied. Thus total N available for plant growth was the 88 lbs./A of soil N plus the N fertilizer added to the various N treatments.

Total Yield

Increasing the rate of N fertilizer from 116 lbs./A to 196 lbs./A increased the total yield (Table 6) from 29.6 tons/A to 32.2 tons/A. Further N fertilizer increases did not increase total yields. Total N available for this high yielding treatment was 196 lbs./A applied and 88 lbs./A in the soil or a total of 284 lbs./A. This is a similar total N value that Tyler (1961), and Jackson (1971) reported for optimum yields. They stated 240 lbs. N/A and 260 lbs. N/A, respectively, produced the highest total yields. Split N treatments neither increased nor decreased total yield over single N treatments. Comparable results were obtained by Murphy (1965). This contrasts with Griffin's (1970) work, who reported that monthly N fertilizer applications produced the highest total yield.

Combined U.S. No. 1 and U.S. No. 2 Grades

The combined yield of U.S. No. 1 and U.S. No. 2 grade (Table 6) increased from 21.0 tons/A to 24.7 tons/A as N fertilization was increased from 116 lbs. A to 196 lbs. /A. Nitrogen fertilizer applications beyond 196 lbs. /A had no further effect on the combined yield of U. S. No. 1's and U. S. No. 2's. Split N fertilizer applications recorded no yield increases or decreases over single N applications. Culls or potatoes not included in the combined U. S. No. 1 and U. S. No. 2 grades were predominantly small well-formed tubers under two-inches in diameter or under four ounces in weight. The 116 lbs. /A N fertilizer treatment gave the largest tonnage of culls. This can probably be attributed to insufficient N to size of these tubers.

U. S. No. 2 Grade

The U. S. No. 2 grade consisted of off-shape tubers with the beginnings of "pointed-ends" and "dumbbelling." Increasing the rate of N from 116 lbs. /A to 356 lbs. /A increased the yield of U. S. No. 2's from 7.2 tons/A to 14.2 tons/A (Table 6). Split N applications also increased yields of U. S. No. 2's over single N applications: 7.8 tons/A versus 11.2 tons/A at the 196 lbs. N/A single and split rates, respectively. Similar results were recorded in the 276 lbs. N/A treatment when split and single applications are compared. The 356 lbs. N/A application, being both the highest rate of N and also a split N application produced the highest tonnage of U. S. No. 2's at 14.2 tons/A. Apparently the rate of tuber growth after the period of high soil temperatures in July and

August can account for the differences in U. S. No. 2 grade. The low N treatment of 116 lbs. /A produced the smallest amount of tuber growth following the high soil temperatures in August. Thus the 116 lbs. N/A treatment produced the lowest tonnage of off-shape tubers (U. S. No. 2 grade). As the N application increased (increased N delays maturity) more growth occurred after the high soil temperature period producing increasing tonnages of off-shape tubers. Single N fertilizer treatments apparently produced a greater portion of tuber growth before the high soil temperatures. The split N treatments continued their rate of growth longer into the growing season and thereby were influenced by the high soil temperatures.

U. S. No. 1 Grade

The highest yields of U. S. No. 1's, 16. 9 tons/A and 17. 3 tons/A, were obtained at single applications of 196 lbs. N/A and 276 lbs. N/A, respectively. Offsetting the decrease in U. S. No. 1 grade in the split N treatments were increasing tonnages of off-shape tubers or U. S. No. 2 grade.

All single N treatments had similar percentages of about 50% of U. S. No. 1's (Table 7). Splitting the N fertilizer over four applications in the growing season decreased the percentage of U. S. No. 1's to an average of about 40%.

The U. S. No. 1's were divided into three categories:

Table 7. Influence of N fertilizer treatments on percent grade of Russet Burbank potatoes.[1/]

Nitrogen treatment (lbs. N/A)	Total yield (tons/A)	Percent of total yield			Percent of U.S. No. 1's		
			Grade			Grade	
		U.S. 1	U.S. 2	Culls	Strippers[3/]	Boxers	Bakers
116	29.6	47	24	29	74	25	1.0
196	32.2	52	24	24	66	33	2.0
276	33.8	51	28	21	60	36	3.0
356[2/]	33.5	35	42	23	65	32	3.0
196[2/]	32.4	41	35	24	63	35	2.0
276[2/]	33.3	38	36	26	65	34	2.0

1/ Averaged across irrigation treatments.

2/ Split N treatment.

3/ Strippers--2-inch minimum diameter or 4 oz. minimum weight; Boxers--7 to 14 oz.; Bakers--14 oz. plus.

"strippers" - two-inch minimum diamer or four ounces minimum weight; "boxer" - seven to 14 ounces; "bakers" - 14 ounces plus. The single applications of 196 lbs. N/A and 276 lbs. N/A recorded the highest yields of "boxers" of 5.5 tons/A and 6.3 tons/A. "Bakers" recorded the highest yield at the single 276 lbs. N/A application. All N treatments except the lowest N treatment (116 lbs./A) showed relatively uniform percentages (Table 7) of "strippers" (64%) and "boxers" (34%).

Air and Soil Temperature During Season

Maximum daily air temperatures are given in Figure 1. The period from July 15 to August 15 recorded temperatures that were frequently over 100°F and the maximum daily air temperature during this period did not fall below 95°F. These high air temperatures resulted in high soil temperatures at the four-inch depth under the potato crop. During this period maximum soil temperatures were about 75°F and frequently above 80°F. These maximum soil temperatures were totaled for the observation period to give a cumulative total and a daily average temperature (Table 8). For the period from June 15 to July 15 a cumulative total of 2200°F was recorded with a daily average temperature of 71.0°F. From July 16 to August 15 a total of 2445°F and an average daily temperature of 78.9°F was recorded. From planting up to July 15 no

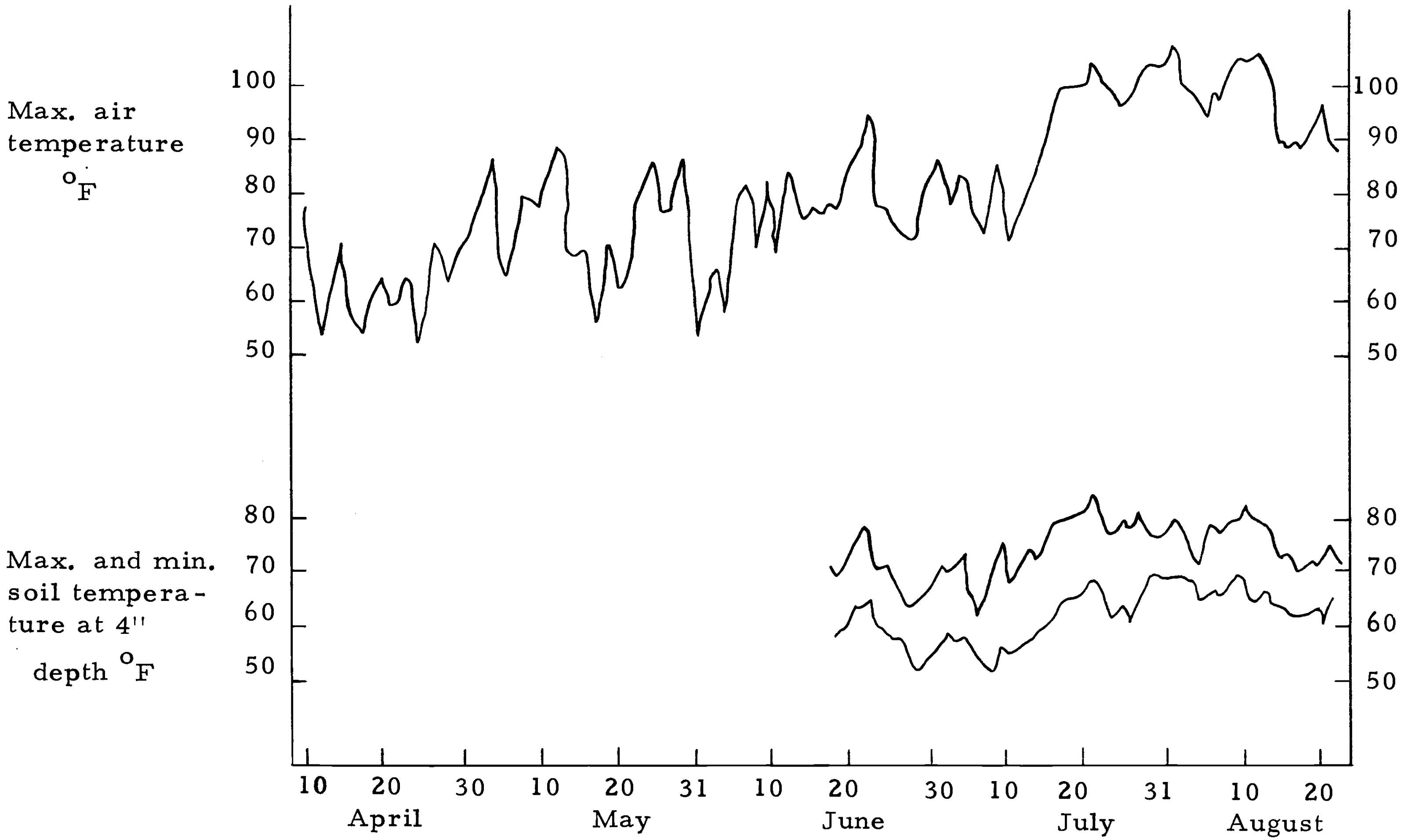

Figure 1. Air and four-inch soil temperature at the Hermiston Experiment Station for 1971.

Table 8. Cumulative maximum and average soil temperatures in degrees F at a 4-inch depth under Russet Burbank potatoes.

	6/15 to 9/15	6/15 to 7/15	7/16 to 8/15
Cumulative maximum	6208	2200	2445
Average	65.3	71.0	78.9

signs of "dumbbelling" or "pointed ends" were observed. After August 15 off-shape tubers began to appear. The higher soil temperatures from July 16 to August 15 may have been enough to retard tuber enlargement as was stated by Thorne (1954). The U.S. No. 2 grade consisted mostly of "pointed-ends" and "dumb-belled" tubers which according to Nielson (1953) comes later in the season than other types of off-shape tubers. The differences in the U.S. No. 2 grade among N fertilizer treatments can be apparently accounted for by the amount of tuber development occurring after the period of high soil temperatures July 15 to August 15.

Petiole Nitrate-Nitrogen

The nitrate-N in the potato petiole represents a reserve of unassimilated N in the plant. This reserve of unassimilated N varied considerably according to the age of the plant and to the N availability. The influence of N treatments on petiole nitrate-N levels can be seen in Figures 2, 3, and 4. In the single N treatments petiole nitrate-N levels decreased from the first sampling date, July 6. The split N treatments showed increases in petiole nitrate-N from the first (July 6) to third (August 4) sampling date and then petiole nitrate-N levels began to decrease.

The 116 lbs. N/A treatment gave the lowest level of petiole nitrate-N during the growing season. This treatment averaged 0.13% petiole nitrate-N and showed little variation as the season progressed. As the level of N fertilizer was increased from 116 lbs./A to 356 lbs./A there was an increase in the petiole nitrate-N level. Splitting the N fertilizer gave higher petiole nitrate-N levels than the corresponding single N treatments. Figures 2, 3 and 4 show the dates of N fertilizer application in relation to the date of petiole sampling. The higher petiole nitrate-N levels in the split N treatments were apparently due to the longer period of time over which N fertilizer was supplied.

The difference in petiole nitrate-N among irrigation frequencies (Figures 5 through 10) were not associated with differences in total yield or grade. Petiole nitrate-N levels tended to be higher in the 12 and 48-hour irrigation frequencies than in the 72-hour frequency. Differences in petiole nitrate-N levels between the 12 and 48-hour irrigation frequencies were slight. In the 72-hour irrigation frequency, apparently the depth of water penetration

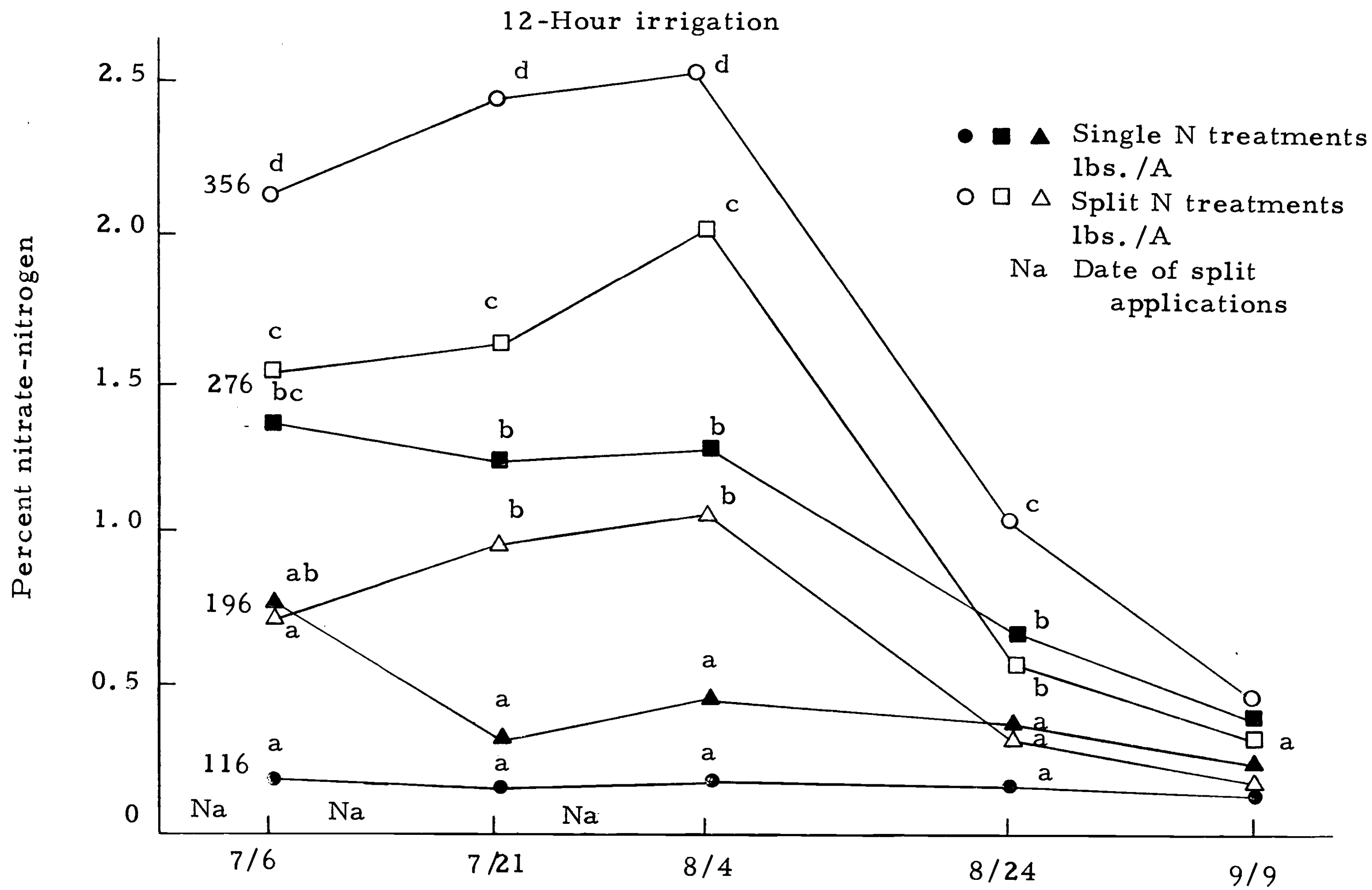

Figure 2. Concentration of petiole nitrate-N on dry weight basis as influenced by N treatments under the 12-hour irrigation. Means on a sampling date followed by the same letter are not significantly different at the five percent probability level.

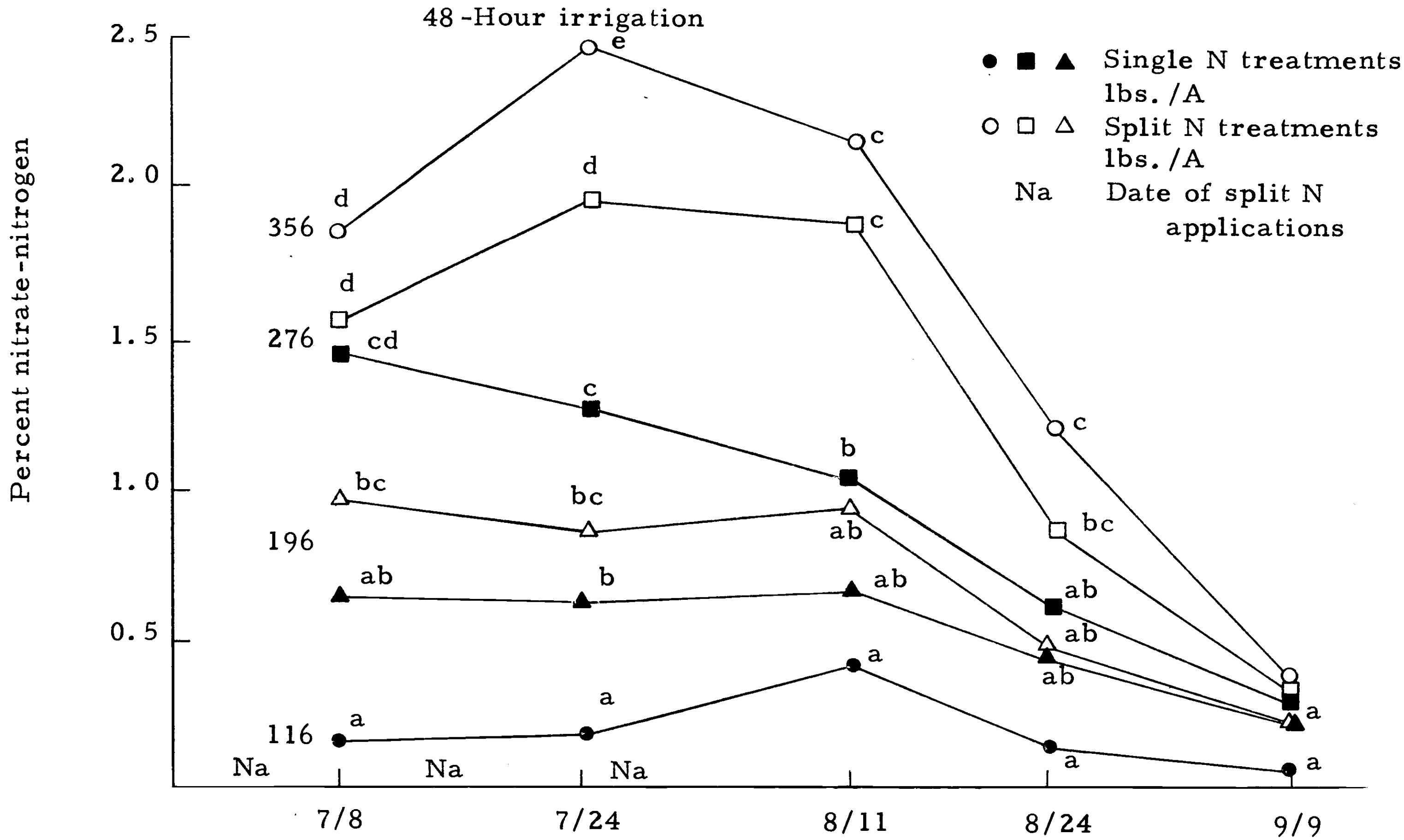

Figure 3. Concentration of petiole nitrate-N on a dry weight basis as influenced by N treatments under the 48-hour irrigation. Means on a sampling date followed by the same letter are not significantly different at the five percent probability level.

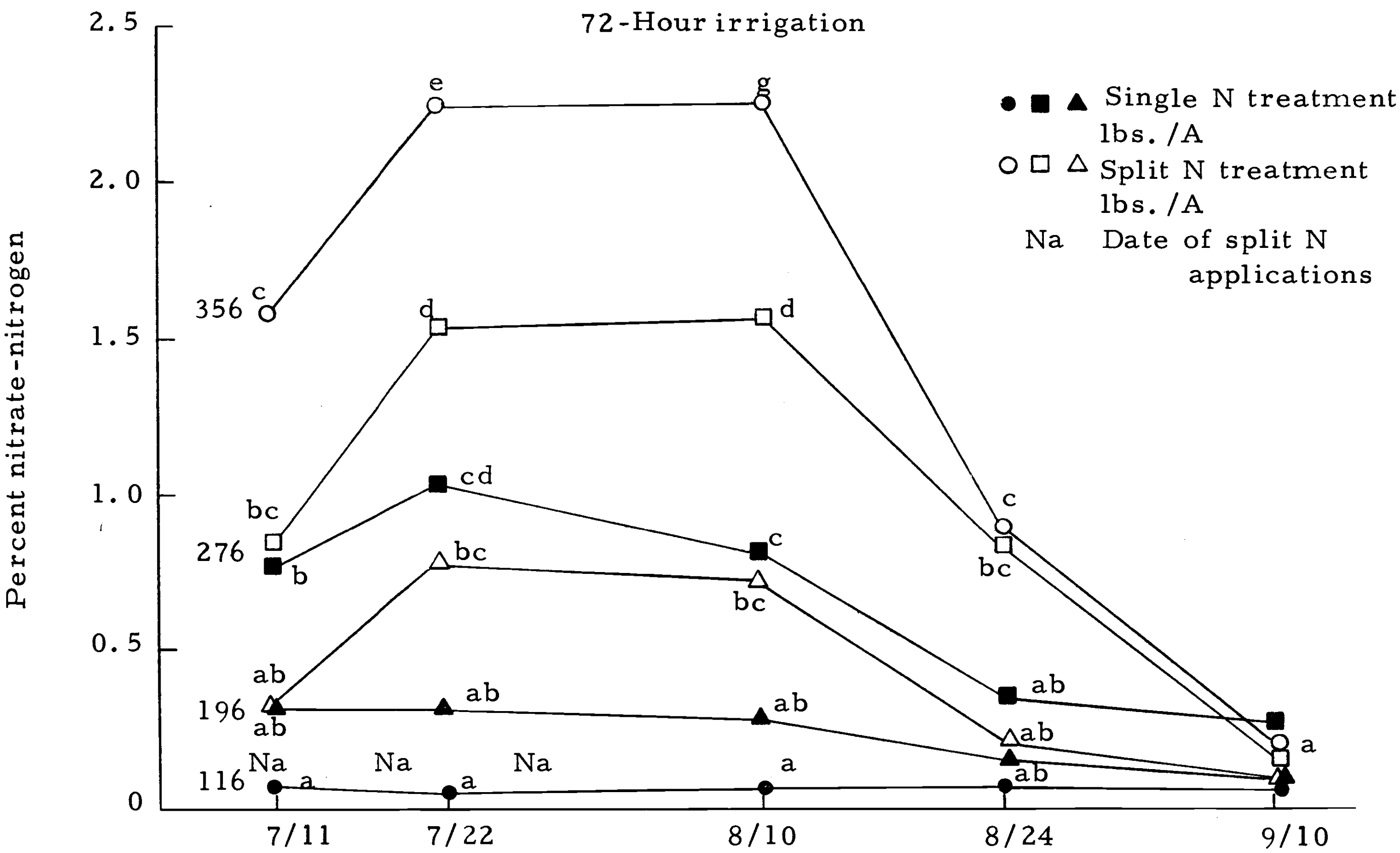

Figure 4. Concentration of petiole nitrate-N on a dry weight basis as influenced by N treatments under the 72-hour irrigation. Means on a sampling date followed by the same letter are not significantly different at the five percent probability level.

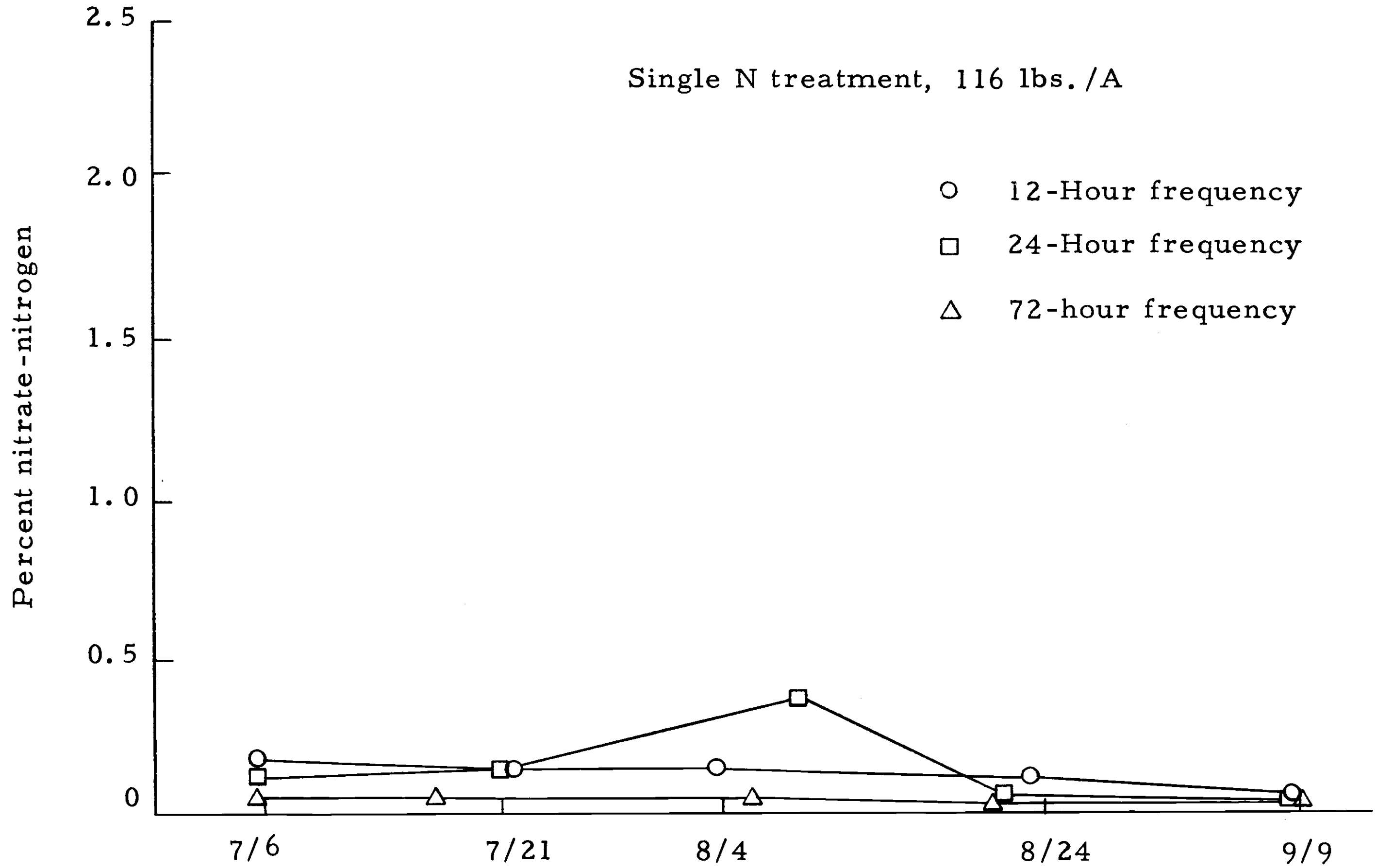

Figure 5. Concentration of petiole nitrate-N on a dryweight basis for the single 116 lbs. N/A treatment as influenced by the 12, 48 and 72-hour irrigation frequencies.

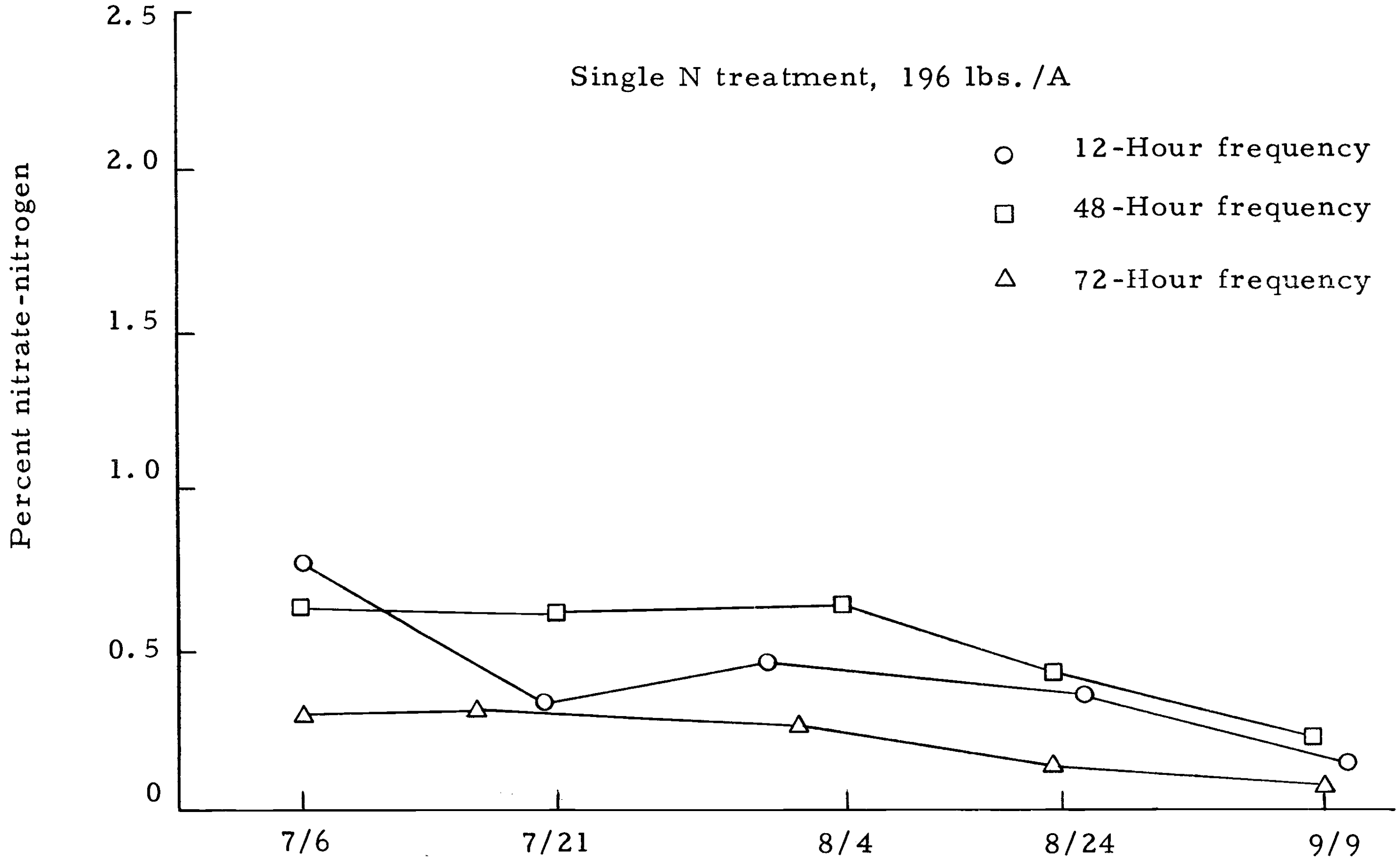

Figure 6. Concentration of petiole nitrate-N on a dry weight basis for the single 196 lbs. N/A treatment as influenced by the 12, 48 and 72-hour irrigation frequencies.

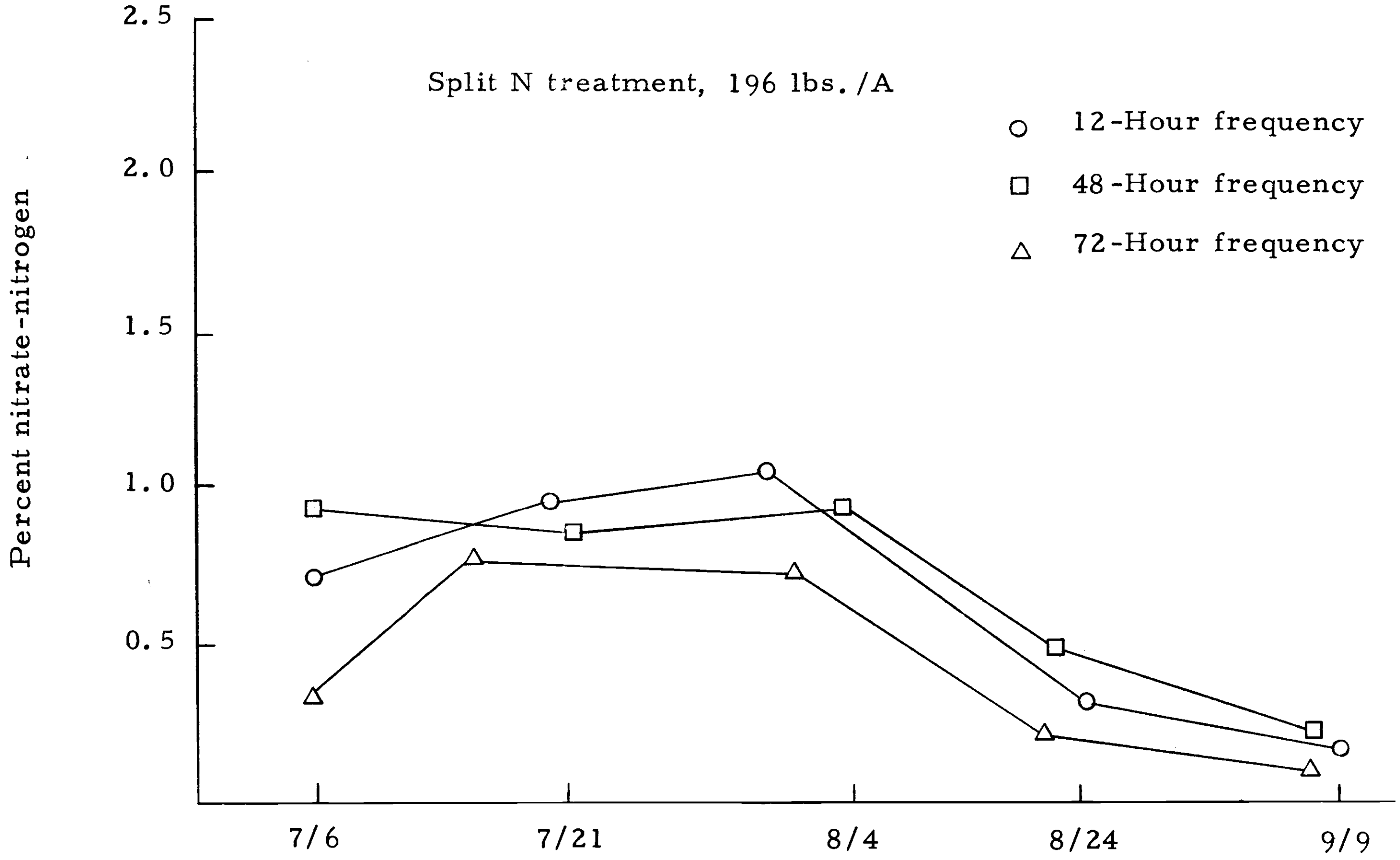

Figure 7. Concentration of petiole nitrate-N on a dry weight basis for the split 196 lbs.N/A treatment as influenced by the 12, 48 and 72-hour irrigation frequencies.

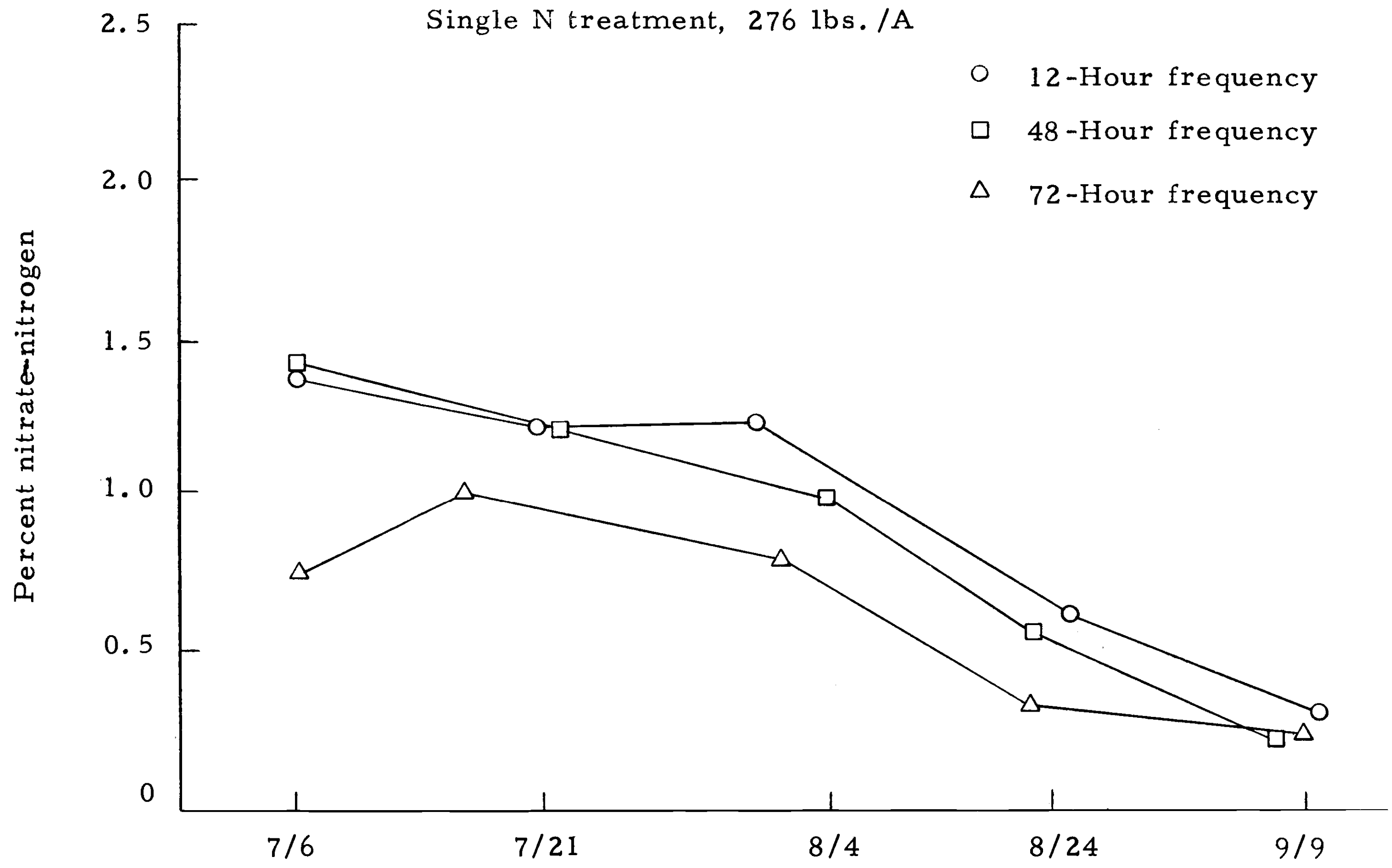

Figure 8. Concentration of petiole nitrate-N on a dry weight basis for the single 276 lbs. N/A treatment as influenced by the 12, 48 and 72-irrigation frequencies.

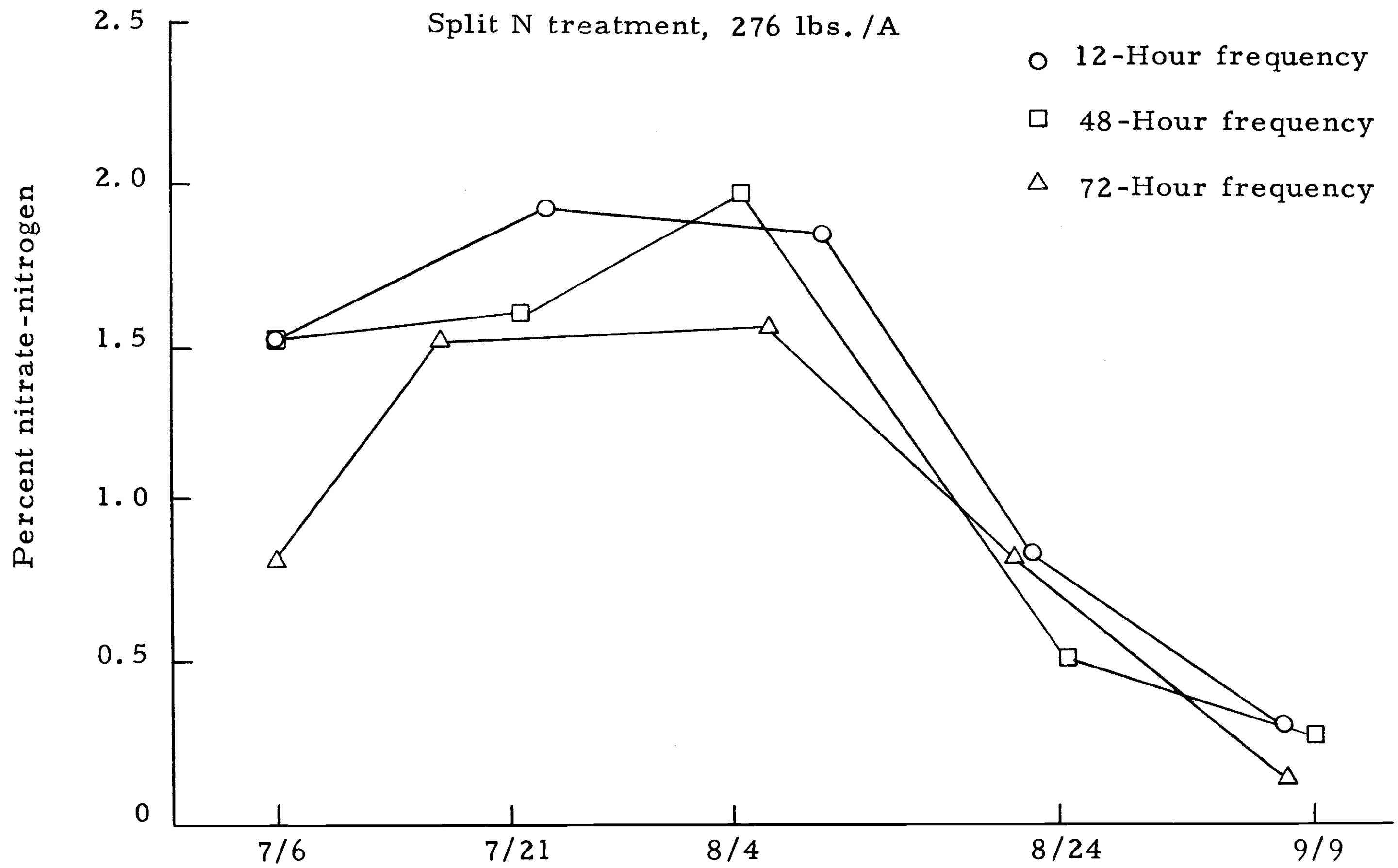

Figure 9. Concentration of petiole nitrate-N on a dry weight basis for the split 276 lbs. N/A treatment as influenced by the 12, 48 and 72-hour irrigation frequencies.

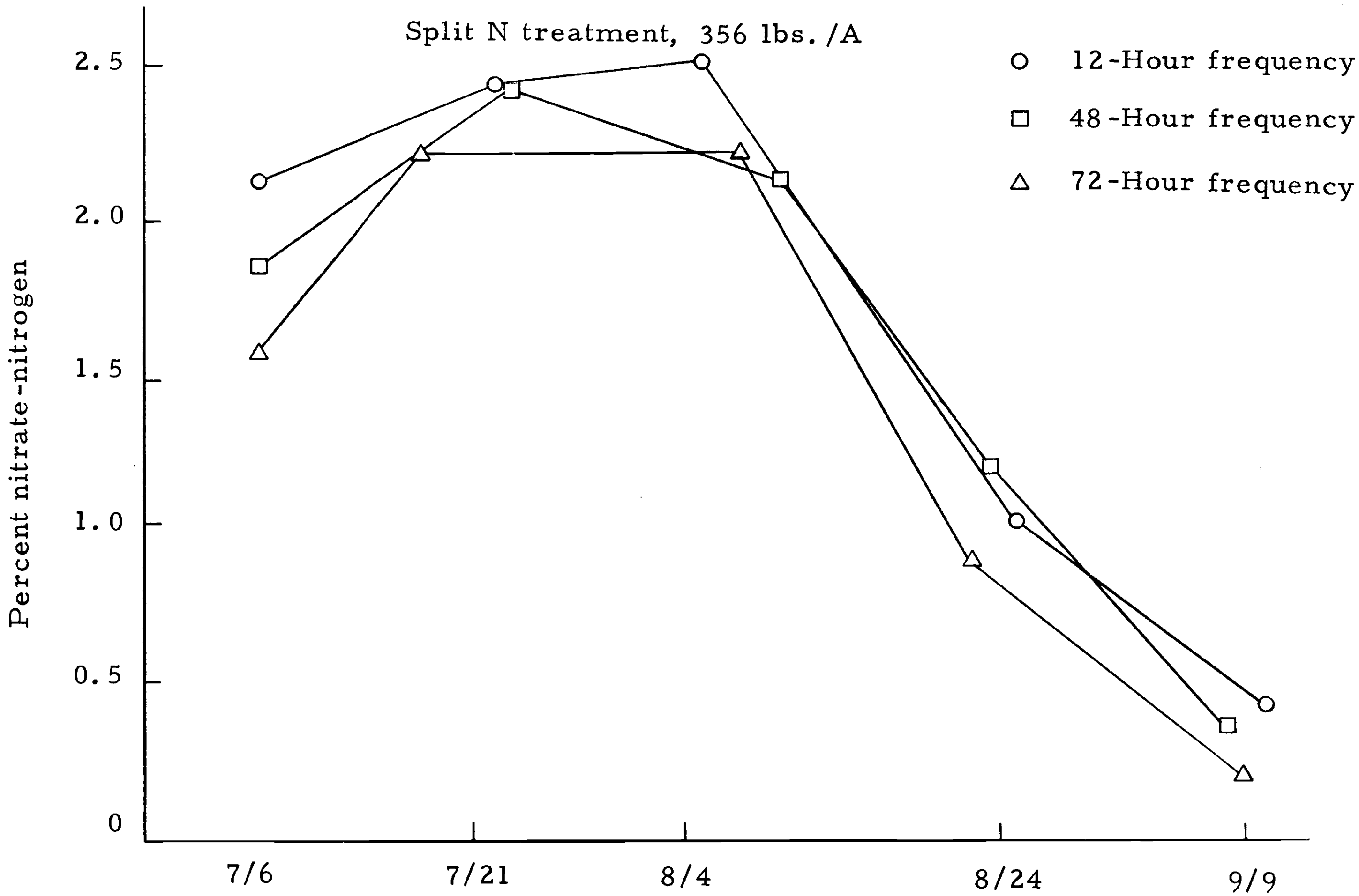

Figure 10. Concentration of petiole nitrate-N on a dry weight basis for the split 356 lbs.N/A treatment as influenced by the 12, 48 and 72-hour irrigation frequencies.

removed slightly more N below the plant roots compared to the 12 and 48 frequencies and therefore lower petiole nitrate-N levels were recorded. The depth of water penetration during irrigations apparently was not appreciably different between the 12 and 48-hour frequencies. The lower petiole nitrate-N levels recorded by the 72-hour irrigation treatment levels were not great enough to give lower tuber yields.

Optimum yields and grades of tubers were recorded for the single N treatment of 196 lbs./A. This fertilizer treatment corresponds to 0.58, 0.42, 0.46, 0.32 and 0.17% petiole nitrate-N on July 6, July 21, August 4, August 24, and September 9 sampling dates, respectively. Higher petiole nitrate-N values on these sampling dates produced no significant total yield or desirable grade increases. Apparently these levels are sufficient for good tuber yields. These levels tend to be considerably lower than those Lorenz (1964) reported for optimum yields.

Soil Nitrogen

Soil Nitrate-Nitrogen

The soil nitrate-N levels showed that differences existed among the three irrigation frequencies (Table 9). These differences in soil nitrate-N, however, were not related to differences in yields

Table 9. Soil nitrate, ammonium and nitrate + ammonium concentrations in lbs. N/A at different sampling dates for the 0-3 foot depth as influenced by N treatments and irrigation treatments.

Irri-gation	Sampl-ing date	Fertilizer treatments (lbs. N/A																	
		116			196			276			356[1/]			196[1/]			276[1/]		
		NH_4	NO_3	NH_4 NO_3	NH_3	NO_3	NH_4 NO_3	NH_4	NO_3	NH_4 NO_3	NH_4	NO_3	NH_4 NO_3	NH_4	NO_3	NH_4 NO_3	NH_4	NO_3	NH_4 NO_3
12 hrs.	7/14	26	32	58	31	45	76	61	79	140	36	69	105	36	64	100	38	49	87
	8/1	67	21	88	62	34	96	49	48	97	103	69	172	92	24	116	61	41	102
	9/15	42	3	45	54	16	70	51	19	70	47	19	66	44	7	51	43	3	46
	7/15	51	24	75	65	29	94	74	68	142	53	38	91	64	33	97	90	39	129
	8/5	35	10	45	51	18	69	54	24	78	56	31	87	48	27	75	47	24	71
48 hrs.	9/16	46	11	57	49	4	53	43	4	47	54	15	69	54	14	68	33	5	38
	7/15	14	9	23	39	39	78	49	31	80	26	58	84	40	17	57	36	24	60
	8/2	80	9	89	66	13	79	74	25	99	105	63	168	79	25	104	63	31	94
72 hrs.	9/16	62	5	67	45	14	59	44	15	59	42	21	63	53	11	64	43	14	57

1/ Split N treatments.

or grades of tubers. In general the trend was for the short irrigation frequency (12 hour) to have the highest soil nitrate-N levels on the first (July 14) and second (August 5) sampling dates and the long irrigation frequency (72 hour) to have the lowest soil nitrate-N values on these two sampling dates. At the third and last sampling date (September 16) all three irrigation frequencies recorded fairly low soil nitrate-N values. This suggests that nitrate-N losses from the 0-3 foot zone were about the same in all N treatments.

When comparing N fertilizer treatments within irrigations, optimum total yield and grade were obtained at the 196 lbs. N/A treatment. This corresponded to 39, 13 and 14 lbs./A of soil nitrate-N on the July 14, August 2, and September 15 sampling dates, respectively, in the 72-hour frequency. The 356 lbs. N/A treatment tended to record the highest soil test for nitrate-N, particularly on sampling dates subsequent to the first sampling on July 15. For the 356 lbs. N/A treatment 276 lbs./A of N fertilizer had been applied by the first sampling date. Between July 15 and August 5 an additional 80 lbs./A of N fertilizer was applied, which apparently resulted in the similarity in soil nitrate-N values between these two sampling dates.

Soil Ammonium-Nitrogen

Soil test ammonium-N values (Table 9) consistently increased in the 12 and 72-hour irrigation frequencies between the first (July 14) and second (August 5) soil sampling dates. Soil ammonium-N values decreased between these two sampling dates in the 48-hour irrigation treatment. Between July 14 and August 5 additional N fertilizer was added in the split N treatments (Table 2) as ammonium nitrate. This additional N fertilizer could account for the increased ammonium-N values in the split N treatment. But increases of soil ammonium-N occurred also in the single N treatments. The reason for this as well as the differences of soil test ammonium-N among irrigation treatments is not clear. On the sampling date (September 15) prior to harvest the ammonium-N values were generally lower than on August date. The soil ammonium-N values averaged 47 lbs./A on September 15, and were fairly uniform irrespective of N treatment and irrigation treatment. This level was generally higher than initial ammonium-N values before planting. Under conditions of this experiment, warm-moist soils, nitrification should occur at a fast rate. These high soil ammonium-N values indicate a decreased rate of nitrification. One possible explanation could be the Dyfonate (organophosphorus chemical) insecticide used for wire worm control. The Dyfonate could have reduced nitrification through interference with the activity of nitrifying bacteria thus slowing down the oxidation of ammonium to nitrate.

Nitrogen Utilization

To obtain information regarding N utilization, the amount of N removed by the crop was related to the amount of N applied and the amount of soil test N. Total N removal by the potato crop is given in Table 10 for the 276 lbs. N/A single and split fertilizer treatments and 356 lbs. N/A split treatment for the 12 and 72-hour irrigation frequencies. Within these two irrigation frequencies N removal by tops and tubers for the 276 lbs. N/A treatments totaled very close to 280 lbs./A and no difference was recorded between the split and single N treatments. Increasing the N fertilizer rate from 276 lbs./A to 356 lbs./A increased the removal of N by the vines an average of 34 lbs./A. Nitrogen removal by the tubers was similar for the 356 lbs. N/A and 276 lbs. N/A treatments.

Irrigation frequency influenced the removal of N by tubers and vines in the 276 lbs./A N fertilizer treatments. As the time interval increased from 12 to 72-hours an average of 15 less pounds of N/A was removed by the vines and an average of 13 more lbs. N/A was removed by the tubers. When 356 lbs. N/A was applied the amount of N removal by the vines was the same for the 12 and 72-hour irrigations but N removal in the tubers was greater for the 72-hour frequency compared to the 12-hour frequency.

Table 10. Nitrogen removal by Russet Burbank potatoes as influenced by N and irrigation treatments.

Irrigation frequency	Plant portion	Nitrogen treatment (lbs. N/A)		
		276	276 1/	356 1/
	Vines	62 2/	60	87
	Tubers	222	219	218
12 hr.	Total	281	279	305
	Vines	47	46	88
	Tubers	232	236	239
72 hr.	Total	279	281	327

1/ Split N treatment.

2/ Nitrogen removal in lbs. N/A.

At planting 124 lbs. N/A (Table 11) was present in the 0-4 foot soil zone as nitrate and ammonium N. Split N treatments did not result in higher residual soil N at the end of the growing season than did a single N application. Also residual soil N was not appreciably higher for the 356 lbs. N/A treatment than the 276 lbs. N/A treatment. The 12-hour irrigation frequency did not result in appreciably higher residual soil N than did the 72-hour irrigation. This suggests a uniform loss from the 0-4 foot zone.

The N balance can be seen in Table 11. All N balance values are

Table 11. Nitrogen balance as influenced by N and irrigation treatments.

Irrigation treatment		Nitrogen treatment (lbs. N/A		
		276	276[1/]	356[1/]
12 hr.	A. Preplant soil	124	124	124
	B. Fertilizer added	276	276	356
	C. Total N (A+B)	400	400	480
	D. Crop removal	281	279	305
	E. Excess N (C-D)	119	121	175
	F. Soil N at harvest	92	72	81
	G. N balance	-27	-49	-94
72 hr.	A. Preplant soil	124	124	124
	B. Fertilizer added	276	276	356
	C. Total N (A+B)	400	400	480
	D. Crop removal	279	281	327
	E. Excess N (C-D)	121	119	153
	F. Soil at harvest	74	70	77
	G. N balance	-47	-49	-74

[1/] Split N treatments.

negative indicating a loss of N either below the 0-4 foot zone or a loss into the atmosphere by denitrification and volatilization. There is somewhat higher loss of N at the 356 lbs. N/A treatment in both the 12 and 72-hour irrigation. However the differences are less at the 72-hour irrigation primarily due to increased uptake of N in the 356 lbs. N/A treatment.

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine the influence of irrigation frequencies and rates and time of N fertilization on the N status, total yield and grade of Russet Burbank potatoes. The irrigation treatments consisted of applying an amount of water equal to the estimated consumptive use for potatoes in 12, 48 and 72-hours. In each irrigation frequency there were three single N treatments of 116, 196 and 276 lbs. N/A and three split N treatments of 196, 276 and 356 lbs. N/A. There was no interaction of irrigation frequency and N treatment.

Irrigation frequencies recorded only small differences in the yields and grades of tubers and there was essentially no benefit gained by irrigating at the 12 and 48-hour frequency over the 72-hour frequency.

The single 196 lbs./A N fertilizer treatment (with 88 lbs. N/A of nitrate-N in soil) recorded the highest total yield (32.2 tons/A) yield of U.S. No. 1 (16.9 tons/A) and yield of "boxers" (3.5 tons/A). This N treatment corresponded to 0.58, 0.42, 0.46, 0.32 and 0.17% petiole nitrate-N on July 6, July 21, August 4, August 24 and September 9 sampling dates, respectively. Soil nitrate level was 39, 13 and 14 lbs. N/A in the surface three feet of soil on July 14, August 2 and September 15 sampling dates, respectively.

The high soil and air temperatures in July and August apparently contributed to the increased tonnage of off-shape tubers or U.S. No. 2 grade. The higher rates of N fertilization above 196 lbs. N/A and splitting the N application delayed tuber growth and subsequently tubers were influenced more by the period of high temperatures.

Petiole nitrate-N varied considerably according to the age of the plant and to N availability. In the single N treatments petiole nitrate-N levels decreased after the first sampling date (July 6). The split N treatments showed increases, because of increased availability of N fertilizer, in petiole nitrate-N from the first (July 6) to the third (August 4) sampling date and then nitrate-N levels began to decrease. As the level of N fertilizer was increased from 116 lbs. N/A to 356 lbs. N/A there was a corresponding increase in petiole nitrate-N.

Residual soil nitrate-N in all N treatments and all irrigation frequencies approached the same soil levels in the 0-3 foot zone by mid-September. This suggests that losses from this zone were about the same in all treatments.

Soil ammonium values consistently increased in the 12 and 72-hour irrigations between the July 14 and August 2 sampling dates. This indicates an interference in the nitrification process. One possible explanation may have been an interfering influence by the soil insecticide used for wire worm control.

Nitrogen utilization was recorded in the single and split applications of 276 lbs. N/A and the split application of 356 lbs. N/A under the 12 and 72-hour irrigations. The 276 lbs. N/A treatment removed 280 lbs. N/A in the split and single applications and in both the 12 and 72-hour irrigations. In the 356 lbs. N/A treatment 305 lbs. N/A and 327 lbs. N/A was absorbed in the 12 and 72-hour irrigations. Residual N in the 0-4 foot zone showed little difference among N treatments and irrigation treatments. Nitrogen balance at harvest recorded loss of N to the environment either by leaching or volalitization into the atmosphere. Somewhat higher losses occurred at the 356 lbs. N/A treatment where an average of 84 lbs. N/A was lost. Little differences occurred between the 12 and 72-hour irrigations.

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