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Nitrogen Fertilizer Requirements of Potatoes Using Carefully Scheduled Sprinkler Irrigation

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Abstract. **Nitrogen fertilizer rates and timings were reexamined for potatoes (*Solanum tuberosum* L.) under sprinkler irrigation with scheduling by soil water potential. Four potato cultivars were grown on a silt loam soil in eastern Oregon in 1992, 1993, and 1994. Potatoes were submitted to six treatments: four N fertilizer rates (0, 135, 200, and 270 kg·ha^{-1}) and two split application treatments (67 kg·ha^{-1} applied three times, and 40 kg·ha^{-1} applied five times). The crop was irrigated when the soil water potential at 0.2-m depth reached –60 J·kg^{-1}. No more than the accumulated evapotranspiration was replaced at each irrigation. Over 3 years, the cultivars had similar responses to N rates and N timing. In 1992, following alfalfa, tuber yield was not responsive to N fertilization. In 1993 and 1994, following wheat, tuber yield was maximized by N at 211 and 175 kg·ha^{-1}. Split applications of the N fertilizer did not increase tuber yield in any year. In 1993 and 1994, the highest tuber specific gravity was obtained with no N fertilization. Nitrogen rates above the optimum resulted in darker frying tubers in 1992 and 1993. The N rates maximizing tuber yield in this study were lower than the rates recommended in the university fertilizer guides.**

Malheur County in eastern Oregon was declared a Groundwater Management Area (Oregon Dept. of Environmental Quality, 1991) due to the presence of groundwater nitrate above the U.S. Environmental Protection Agency drinking water standard for NO_3-N of 10 mg·L^{-1}. Groundwater contamination with nitrates can be caused by N fertilizer applications exceeding crop needs and excessive irrigation (Saffigna et al., 1977; Stark et al., 1993). The adoption of irrigation scheduling and N fertilizer management techniques for potato production could reduce water and fertilizer inputs and reduce nitrate leaching.

Sprinkler irrigation allows more precise control of water than furrow irrigation, permitting more accurate management of crop root-zone soil moisture. Irrigation scheduling with a target soil water potential could facilitate managing sprinkler irrigations. Optimum potato yield and quality can be achieved by maintaining the soil water potential in the top 0.3 m of silt loam soils wetter than –60 J·kg^{-1} (Eldredge et al., 1992, 1996; Holder and Cary, 1984; Shock et al., 1992; van Loon, 1981). With carefully scheduled irrigation, rates of N fertilizer applied to potatoes in Malheur County could be reduced without yield losses.

Careful N fertilizer application practices can increase plant N uptake efficiency and reduce nitrate leaching. Banding of N fertilizer close to planting time has been used as a method to improve uptake efficiency and reduce leaching or volatile losses in comparison with broadcast applications.

Split N fertilizer applications, as opposed to a single preplant application, are recommended as a method to improve tuber yield, quality, and N uptake efficiency (Ojala et al., 1990; Westermann et al., 1988). However, where irrigation and N fertilizer management techniques lower nitrate leaching potential, split N applications may not be beneficial.

Four potato cultivars ('Russet Burbank', 'Shepody', 'Frontier Russet', and 'Ranger Russet') were tested for their response to six fertilizer N treatments under sprinkler irrigation with scheduling by soil water potential in Malheur County, Ore.

Materials and Methods

Trials were conducted in three successive years on nearly adjacent fields of Owyhee silt loam (coarse-silty, mixed, mesic, Xerollic Camborthid) at the Malheur Experiment Station, Oregon State Univ., Ontario, Ore. Potatoes followed alfalfa in 1992 and spring wheat in 1993 and 1994. Fields were disked, plowed, and bedded into 0.9-m hills in the fall each year. Tuber seed pieces (60 g) of the four varieties were planted in late April at 0.23-m spacing. The experimental design had six N treatments as main plots, replicated five times, and the cultivars as split plots within the main plots. Main plots were 12 rows wide and 12 m long.

Nitrogen fertilizer treatments consisted of four N rates (0, 135, 200, and 270 kg·ha^{-1}) banded preemergence, and two split application treatments. The latter consisted of N applied at 200 kg·ha^{-1} in either five applications of 40 kg·ha^{-1} from preemergence to mid-July, or in three applications of 67 kg·ha^{-1} from preemergence to mid-June. The preemergence applications were made within 1 week after planting by banding urea into both sides of the potato hill at seed piece depth but offset 0.23 m from the hill center. For the postemergence split applications, urea was broadcast immediately before irrigations.

The crop was irrigated at 3 mm·h^{-1} with a solid-set sprinkler system with nozzles spaced 13 m × 10 m. The sprinkler system laterals were located in border rows between main plots. The coefficient of uniformity of water distribution, calculated according to Christiansen (1942), was 92%. Soil water potential was measured by 15 granular matrix sensors (GMS; Watermark Soil Moisture Sensors model 200SS, Irrometer Co., Riverside, Calif.) at 0.2-m depth and 15 GMS at 0.5-m depth distributed uniformly in the trial. The GMS were offset 0.15 m from the hill center (Stieber and Shock, 1995). Sensors were previously calibrated to soil water potential (Eldredge et al., 1993). The GMS were read at 8:00 AM daily starting a few days before tuber set each year and continuing through tuber bulking. The field was irrigated when the average soil water potential at the 0.2-m depth reached –60 J·kg^{-1}. The accumulated crop evapotranspiration (Et_c), as calculated for 'Russet Burbank', was replaced at each irrigation. Crop Et_c was determined using an AgriMet (U.S. Bureau of Reclamation, Boise, Idaho) weather station at the Malheur Experiment Station and a modified Penman equation (Wright, 1982). Crop Et_c was recorded from crop emergence until the final irrigation. To reduce the risk of water movement below the top 0.3 m of soil, water applications at each irrigation did not exceed 30 mm, regardless of the accumulated Et_c. Irrigations were started no sooner than 1 week before tuber set each year (Cappaert et al., 1994; Shock et al., 1992).

The insecticide phorate {0,0-diethyl S-[(ethylthio) methyl] phosphorodithioate} was applied at 3.4 kg·ha^{-1} together with the preemergence urea treatments in early May. The herbicides pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] and metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1methyl-ethyl) acetamide] were broadcast at 1.12 kg·ha^{-1} and 2.24 kg·ha^{-1}, respectively, in mid-May and incorporated immediately with a Lilliston cultivator.

The soil in each plot was sampled in 0.3-m increments to 1.8 m and analyzed for nitrate and ammonium in late March and again within 1 week after harvest. The nitrate and ammonium were extracted using 2 M KCl and analyzed using the cadmium reduction method

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for the nitrate and the exchangeable ammonium method (Carlson, 1978, 1986).

At harvest, a 20-tuber sample (170- to 283-g size class) of 'Russet Burbank' from each plot was analyzed for total N. Plant tops were assumed to contain 25% as much N as the tubers. The top : tuber N content ratio, used to calculate top N content at harvest, was determined from previous 'Russet Burbank' N content analyses (unpublished data). The use of this ratio could underestimate top N uptake at high N rates, since the proportion of total plant N in tops can increase as N rates increase (Joern and Vitosh, 1995; Lauer, 1985; Saffigna et al., 1977). However, the top : tuber N ratio and the whole plant N uptake values reported in this study are in agreement with the values for N content of potato tissue at the Malheur Experiment Station (Stieber and Shock, 1991). The whole plant N uptake values are also in agreement with the data of Kleinkopf et al. (1981), Joern and Vitosh (1995), Lauer (1985), Tyler et al. (1983), and Westermann et al. (1988), for similar N rates. Nitrogen mineralization was calculated by adding the total crop N uptake at harvest (N recovery) to the available N in the profile after harvest ("accounted N") and subtracting the available N supply (residual soil N, fertilizer N, and N from irrigation water). Nitrogen contribution from the irrigation water was 60 $g \cdot ha^{-1} \cdot mm^{-1}$ of water applied based on analysis.

Nitrogen mineralization was also determined by anaerobic incubation for 7 d at 40 °C using soil samples collected in late March; for the 1992 site, a 1995 soil sample was used from the same field planted to potato with wheat as the previous crop.

Tubers were harvested from the middle 9 m of one 12-m row for each variety in each main plot in early October each year, and graded by market class (U.S. no. 1 and U.S. no. 2) and size (113 to 170 g, 170 to 283 g, and >283 g). Tubers were graded as U.S. no. 2 if any of the following conditions existed: growth cracks, bottleneck shape, abnormally curved shape, or two or more knobs. A representative 20-tuber subsample from every cultivar in every main plot was stored until early November when tuber specific gravity and fry color were determined. Tuber fry color was determined at the stem end of tuber strips according to the methodology described in Shock et al. (1994). Data were analyzed by analysis of variance as a split-plot design. Mean separation was determined by the protected least significant difference (LSD) test. Tuber yield and grade response to N fertilization were also examined by regression using the quadratic model, and maximum responses were calculated using the first derivative of the formula where the equation was statistically significant.

Results and Discussion

Soil water potential at 0.2-m depth generally remained above (wetter than) the target $-60\ J \cdot kg^{-1}$, except for brief periods in 1993 and in Aug. 1994 (Table 1, Fig. 1). Each year, water applications (including precipitation) were close to or just slightly less than Et_c, so that total water applied was less than Et_c for the season (Table 1). Thirteen, 10, and 17 irrigations were applied in 1992, 1993, and 1994, respectively. Soil water potential at 0.5 m-depth remained below (drier) that at 0.2 m during the season. In 1993 and 1994, soil water potential at 0.5 m became progressively lower (drier) during the season, suggesting net depletion of soil water at this depth.

Tuber yield response to N fertilizer rates. In 1992, total tuber yields averaged over varieties were not responsive to N fertilization (Fig. 2). In 1992, yield on plots receiving no N averaged 45.6 and 67.5 $Mg \cdot ha^{-1}$ of U.S. no. 1 and total tubers, respectively, and N fertilization did not increase yield significantly (data not shown). The previous crop of alfalfa seed resulted in higher soil nitrate and ammonium at planting in 1992 than in 1993 and 1994 , as shown below. These results support evidence that a previous legume crop can provide all the N necessary for a potato crop (Porter and Sisson, 1993; Stark and Westermann, 1993). In 1993 and 1994, U.S. no. 1 and total yields were improved by N at 135 $kg \cdot ha^{-1}$, but higher N levels had no further effect (Tables 2 and 3). Nitrogen at 135 $kg \cdot ha^{-1}$ increased total yield 23% and 19% in 1993 and 1994, respectively. The N rate × variety interaction was significant only in 1993, when 'Frontier Russet' failed to respond.

Examining the quadratic yield and grade responses to applied N, maximum total yield was reached by N rates of 129, 211, and 175

Table 1. Accumulated potato evapotranspiration (Et_c) (from emergence to the last irrigation), total water applied (includes precipitation), and average soil water potential for sprinkler irrigated potatoes.

Year	Et_c (mm)	Total water applied (mm)	Average soil water potential ($J \cdot kg^{-1}$) 0.2-m depth	0.5-m depth
1992	678	567	32.3 ± 20.3	65.5 ± 22.4
1993	522	371	31.6 ± 16.8	63.8 ± 30.7
1994	671	558	55.0 ± 30.4	92.1 ± 34.1

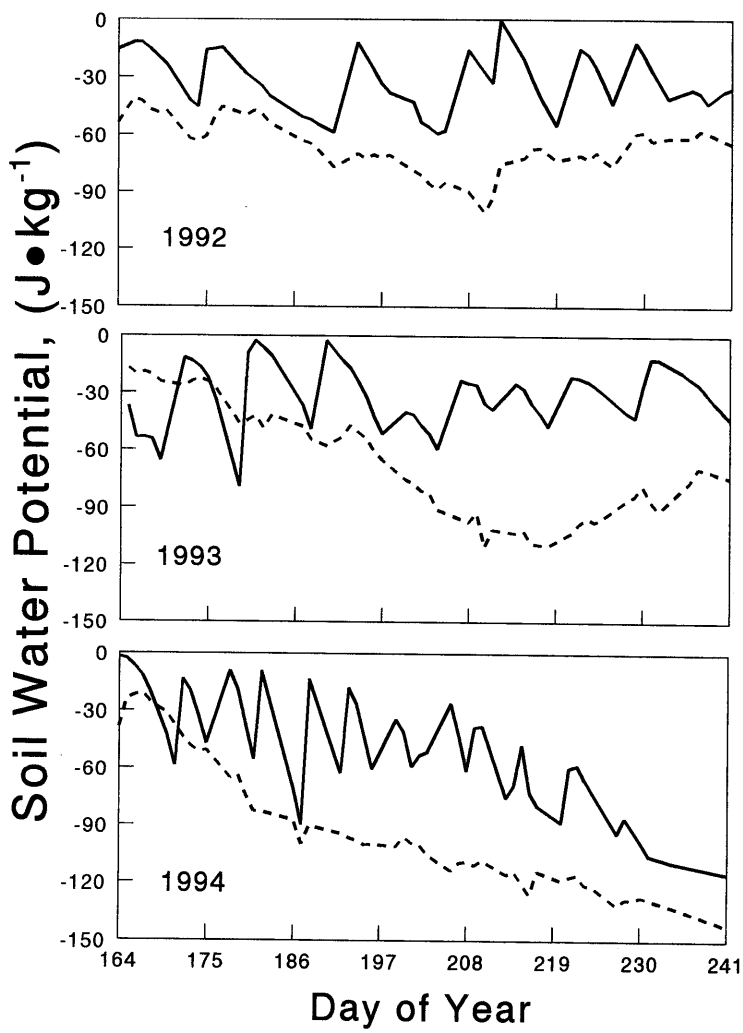

Fig. 1 Soil water potential during the potato tuber bulking at 0.2-m (**continuous line**), and at 0.5-m depth (**dashed line**) for sprinkler irrigated potatoes.

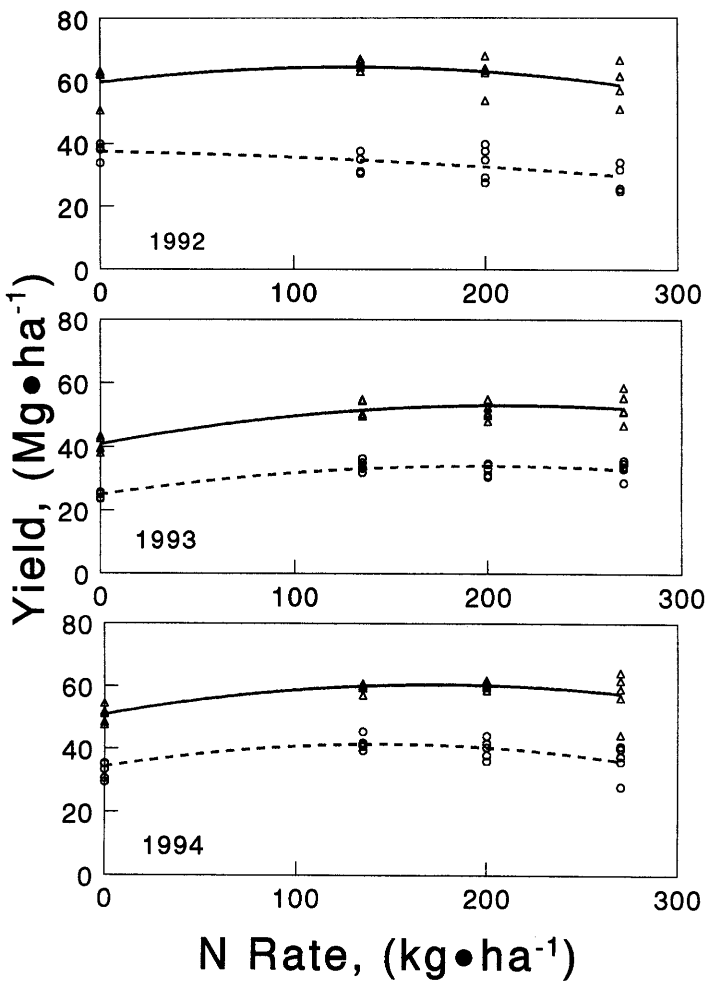

Fig. 2. Total yield (-Δ-) and U.S. no. 1 yield (-O-) response to N rate predicted by the quadratic model. Regression equations for total yield and U.S. no. 1 yield, respectively, are: for 1992, $Y = 59.6 + 0.0748 \cdot X - 0.00029 \cdot X^2$ ($R^2 = 0.20$, NS), and $Y = 37.5 - 0.0119 \cdot X - 0.0000646 \cdot X^2$ ($R^2 = 0.36$, $P = 0.05$); for 1993, $Y = 41 + 0.115 \cdot X - 0.000273 \cdot X^2$ ($R^2 = 0.72$, $P = 0.001$), and $Y = 25 + 0.0923 \cdot X - 0.000233 \cdot X^2$ ($R^2 = 0.79$, $P = 0.001$); for 1994, $Y = 51 + 0.11 \cdot X - 0.000316 \cdot X^2$ ($R^2 = 0.50$, $P = 0.01$), and $Y = 32.8 + 0.114 \cdot X - 0.000374 \cdot X^2$ ($R^2 = 0.55$, $P = 0.01$).

kg·ha^{-1} and maximum yield of U.S. no. 1 tubers at N rates of 0, 199, and 152 kg·ha^{-1} in 1992, 1993 and 1994, respectively (Fig. 2).

Other studies, under a wide range of conditions, indicate that N rates of 135 kg·ha^{-1} or less can maximize potato yields (De la Morena et al., 1994; Evanylo, 1989; Gavlak et al., 1993; Griffin and Hesterman, 1991; Porter and Sisson, 1991,1993). Saffigna et al. (1977) found that with irrigation designed to reduce leaching, N fertilizer could be reduced by 35% from standard recommendations without reductions in yield. Westermann and Kleinkopf (1985), in an irrigated study in southern Idaho, found that early tuber development was highest with preplant N rates between 67 and 134 kg·ha^{-1}. They reported that optimum tuber growth rates were maintained when the soil NO_3-N content during the season was >7.5 mg·kg^{-1} at the depth of 0 to 0.46 m. In our study, the seasonal soil-available N content in the most productive treatments was probably maintained above the minimum established by Westermann and Kleinkopf, because, each year, the preplant and postharvest soil available N contents were >10 mg·kg^{-1} at 0- to 0.6-m depth (Table 4).

Other studies have reported tuber yields to be maximized by N rates >135 kg·ha^{-1}. For the studies done in areas of high summer precipitation (Bundy et al., 1986; Minotti et al., 1994), nitrate leaching is probably difficult to avoid. The studies done in areas of low summer precipitation involved irrigation without recording soil moisture, with irrigation scheduling either fixed or based upon using pan evaporation (Lauer, 1986; Roberts et al., 1982; Rykbost et al., 1993; Williams and Maier, 1990). Irrigation scheduling based upon crop evapotranspiration only, without measurement of soil water, makes it difficult to manage irrigation without nitrate leaching below the crop root zone, as discussed by Hartz (1996), and by Pier and Doerge (1995). In studies by Bundy et al. (1986), Roberts et al. (1982), and Rykbost et al. (1993) yield increases of no more than 5% were obtained with N rates >135 kg·ha^{-1}. The small yield increases obtained by almost doubling of the N rate in the studies above suggests that adding more N would not be economical, consistent with our results.

Tuber quality response to N fertilizer rates. Averaged over all varieties, N fertilization reduced tuber specific gravity in 1993 and 1994 (Table 5), in agreement with previous studies (Lauer, 1986; MacLean, 1984; Ojala et al., 1990; Rykbost et al., 1993; Westermann et al., 1988; Westermann et al., 1994; White and Sanderson, 1983).

Nitrogen rates above the optimum resulted in significantly darker frying tubers in 1992 and 1993, but the differences were small. The fry color at the stem-end of tuber strips was insensitive to N fertilization in 1994. Porter and Sisson (1991) also found a trend for darker frying tubers with increasing N rates in five out of nine site-year combinations. We observed no significant interaction affects between variety and N fertilization on tuber quality. Tuber internal brown center and hollow heart did not occur in potatoes grown in this study.

Tuber response to N fertilizer timing. There was no positive yield or quality response, in any of the 3 years, to split applications of N compared with a single application before tuber set. Nitrogen losses from the single applications before tuber set were probably minimal due to the use of precision irrigation. Several other studies also reported a lack of response of tuber yield to split N applications (Evanylo, 1989; Gavlak et al., 1993; Joern and Vitosh, 1995; MacLean, 1984; Porter and Sisson, 1993; Westermann et al., 1988). Westermann and Kleinkopf (1985) found an increase in total yield in response to split N application in two out of three site-year combinations. In the same trial, split N application never increased the percentage of U.S. no. 1 tubers, but reduced it in one site-year.

Table 2. Potato yield (Mg·ha^{-1}) in response to N rates in 1993.

Nitrogen rate	Cultivar									
	Russet Burbank		Frontier Russet		Ranger Russet		Shepody		Mean	
(kg·ha^{-1})	US no.1	Total	US no.1	Total	US no.1	Total	US no.1	Total	US no.1	Total
0	25.6 a[z]	47.7 a	26.3 a	40.8 a	25.8 a	42.3 a	22.2 a	32.6 a	28.1 a	41.7 a
135	38.8 b	63.9 b	27.2 a	43.1 a	34.2 b	52.5 b	35.1 b	49.4 b	36.3 b	53.1 b
200	34.4 b	61.6 b	27.9 a	44.0 a	38.3 b	57.8 b	31.7 b	45.0 b	36.4 b	54.4 b
270	35.8 b	63.5 b	28.7 a	42.4 a	37.9 b	57.3 b	30.4 b	45.8 b	37.0 b	53.7 b

[z]Mean separation within columns by Fisher's LSD at $P \leq 0.05$.

Table 3. Potato yield (Mg·ha^{-1}) in response to N rates in 1994, averaged across varieties.

Nitrogen rate (kg·ha^{-1})	US no. 1	Total
0	35.3 a[z]	50.4 a
135	43.5 b	59.1 b
200	42.4 b	59.9 b
270	39.0 b	57.7 b

[z]Mean separation within columns by Fisher's LSD at $P \leq 0.05$.

Table 4. Soil N balances and N mineralization for the 0- to 0.6-m depth and university N fertilizer recommendations in 1992–94. All values are in kg·ha^{-1}.

	N supply			Fall N accounting		N mineralization		N recommendations	
Year	Preplant soil NO_3-N + NH_4-N	Optimum N rate[z]	N in irrigation water	Soil NO_3-N + NH_4-N	Plant N uptake	by difference[y]	by anaerobic incubation	Oregon	Idaho
1992	129	0	33	115	261	214	270	179	157
1993	67	135	19	151	270	200	158	246	297
1994	76	135	33	80	279	115	158	246	297

[z]The differences in N balances between N rates were not significant so only the N rate resulting in maximum yield is presented.
[y]Based on the difference between the fall N accounting and the N supply.

Table 5. Effect of N fertilizer rate on tuber specific gravity, averaged across varieties, 1992–94.

Nitrogen rate	Specific gravity (g·cm^{-3})		
(kg·ha^{-1})	1992	1993	1994
0	1.089 a[z]	1.097 a	1.097 a
135	1.084 a	1.087 b	1.090 b
200	1.088 a	1.087 b	1.090 b
270	1.083 a	1.087 b	1.086 c

[z]Mean separation within columns by Fisher's LSD at $P \leq 0.05$.

Recommended N fertilizer rates. Each year, the recommended rate of N fertilizer for these sites, according to either the Idaho or Oregon fertilizer guides (McDole et al., 1987; Oregon State Univ., 1985) was substantially higher than the N rates that maximized yields (Table 4; Fig. 2). Both banding of the N fertilizer after planting and irrigation scheduling based upon soil water potential could have helped reduce the N losses to both leaching and volatilization and improved plant uptake efficiency in this trial. In addition, the fertilizer guides do not take N mineralization into account. Both the available N balances and anaerobic soil incubations show that N mineralization can contribute significant amounts of available N during the season (Table 4). Nitrogen mineralization, measured by anaerobic incubation, was 270 kg·ha^{-1} for the 1992 site and 158 kg·ha^{-1} for the 1993 and 1994 sites. These values are in agreement with those of Carter et al. (1975) who reported N mineralization in the range of 123–236 kg·ha^{-1} per year for soils in southwestern Idaho.

The average amount of N applied to potatoes in Malheur County is 240 kg·ha^{-1}, according to a 1991 survey of N use practices by growers (Jensen and Simko, 1991). The results of our study show that optimization of potato production in southwestern Idaho and Malheur County, Ore., on silt loam soils can be achieved with substantially less N fertilizer than the amounts currently recommended by the university fertilizer guides when potatoes are grown using sprinkler irrigation with scheduling based upon soil water potential.

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