Research Bulletin XB1004E

Potato Use of Phosphorus And Potassium in Sandy Soils

Agricultural Research Center
College of Agricultural, Human, and Natural Resource Sciences
Washington State University, Pullman, Washington

Contents

About the Authors and Project

Steve Roberts is a soil scientist at the Washington State University Prosser Irrigated Agriculture Research Center, Prosser, Washington 99350. James D. Beaton was formerly the Northwest Director of the Potash and Phosphate Institute of Canada. He is now Vice President and Western Canada Director of that institute.

Research was conducted under project number 0580, College of Agricultural, Human, and Natural Resource Sciences Center, Washington State University, Pullman, Washington 99164. Partial financial support was provided by the Potash and Phosphate Institute and provision of land, water and assistance with potato production by the U and I Group, Kennewick, Washington.

Potato Use of Phosphorus and Potassium in Sandy Soils

Steve Roberts and James D. Beaton

ABSTRACT

The purpose of this study was to determine the most efficient rates of P and K fertilizer to produce maximum yields of potatoes in sandy soil. The specific research objectives were 1) to evaluate the response (yield and nutrient uptake) of potatoes to residual and applied P and K at different fertility levels, and 2) to observe the effect of fertilizer application and crop removal on residual soil test P and K.

The maximum plot yields obtained were 79 mg ha^{-1} for first-crop potatoes in Hezel loamy sand in 1980, and 77 mg ha^{-1} for first-crop potatoes in Quincy sand in 1981. It was concluded that high N rates from 400 to 600 kg N ha^{-1} did not greatly influence the response of potatoes to P and K, and there was no NPK interaction.

The Hezel site with 9 ppm soil test P produced a significant yield response to P, but not to K with pretreatment soil test K at 240 ppm; the Quincy site with 21 ppm P and 214 ppm K showed no yield response to P or K.

Potato petioles at the P responsive Hezel site had 0.35% P at early tuber growth, which dropped to 0.19% in July. High rates of P generally kept petiole P levels above 0.4% at the June sampling. The suggested critical range is from 0.35% to 0.45% at this stage of early tuber growth. The K treatment increased petiole K over the control in July and August, but not in June. In June, both first-crop and second-crop potatoes had petiole K concentrations for control treatments in the suggested critical range of 9.5% to 11% at both the Hezel and Quincy sites. These high K concentrations in plant tissue explain the lack of a K response.

At the termination of the experiment, crop removal resulted in lowering soil test P and K values for control plots below the initial pretreatment soil test levels, and there was little soil test buildup following fertilizer additions. It was concluded that existing soil test critical levels of 20 ppm P and 240 ppm K are valid for potatoes in Hezel and Quincy sandy soils.

INTRODUCTION

Preseason soil testing and plant tissue analysis during the season are potentially valuable guides for diagnosing nutrient deficiencies and predicting crop fertilizer requirements. These diagnostic tests are most useful when they are properly calibrated to establish the relationship between test results and crop response to fertilizer. On some of the sandy soils of Washington, where calibrations for P and K soil tests are lacking for potatoes (*Solanum tuberosum* L.), there is no sound basis for P and K fertilization.

Potatoes are grown extensively on coarse textured soils in central Washington under center pivot irrigation. In this area, P fertilization of land newly tilled for irrigation usually increases potato yields by 15 to 20 percent, while there is usually less response to K fertilizer (Kunkel and Thorton 1986). The fertilizer guide currently in use states critical levels of 20 ppm P and 240 ppm K for potatoes, and is based primarily on fertilizer trials on silt loam soils (Dow et al. 1974; Dow and Kunkel 1963). This critical level may be different for coarser soils important in potato production.

In previous research, yield responses to P and K occurred on Quincy sand with pretreatment soil tests of 9 ppm P and 200 ppm K extractable with $NaHCO_3$ (Middleton et al. 1975). Results of two other potato experiments on Quincy and

Winchester sandy soils that had 7 to 9 ppm soil test P and 200 to 260 ppm K extractable with $NaHCO_3$ produced a significant yield response to P, but only a slight yield increase of 6 to 10 percent from K application (Roberts, Dow and Cline 1984). Additional results of soil test K calibration experiments were summarized in a review article on K nutrition of potatoes (Roberts and McDole 1985).

Critical nutrient ranges for P and K in plant tissue have been established. Tissue analysis should provide a basis for predicting potential limiting nutrient supply and enable corrective action before serious nutrient deficiencies develop. The fourth petiole from the top of the potato plant is most often used in tissue analysis. Dow (1980) tabulated critical nutrient ranges for P and K in potato petioles that can be used as standards of comparison for tissue samples from commercial potato fields.

The concentration of nutrients in tubers may also reflect the nutritional status of the crop. McCollum (1978) reported that tubers with less that 0.3% P probably reflect marginal P nutrition. Maier et al. (1986) reported increased susceptibility of tubers to bruise damage with less than 1.8% K in tubers and less than 8% K in petioles.

Tubers serve as the main repository for nutrients during much of the growing season. Rapid translocation of nutrients to the tubers may decrease nutrient levels in petioles and signify an impending deficiency.

The purpose of this study was to determine the most efficient applications of P and K fertilizer for maximum yield of Russet Burbank potatoes in sandy soil. The specific objectives were 1) to evaluate the response (yield and nutrient uptake) of potatoes to residual and applied P and K at different N fertility levels, and 2) to observe the effect of fertilizer application and crop removal on residual soil test P and K. The nutrient levels of P and K were monitored in the soil and in plant tissue and related to crop response.

PROCEDURES

Experiments involving P and K fertilizer applications on Russet Burbank potatoes (*Solanum tubersum* L.) were conducted at two locations on farms near Paterson, Washington. One experiment was at the McNary Farm on Hezel loamy sand (Hezel site) with first-crop potatoes in 1980, followed by second-crop potatoes in 1982 on the same plots. The second experiment was at the Prior Farm on Quincy sand (Quincy site) with first-crop potatoes in 1981 and second-crop potatoes on the same plots in 1983. Hezel soil has a surface layer of loamy sand with silt loam subsoil, and the Quincy series has deep coarse sand. Both sites were irrigated from the Columbia River below the mouth of the Snake River with solid set (12.2 by 12.2 m) sprinklers. The Columbia River supplies 4kg K ha^{-1} and 10kg S ha^{-1} in an equal irrigation from the Snake River (Roberts and McDole 1985).

Cultural Practices. The plot area was chisel-plowed and rototilled before planting. The Hezel site was rangeland not previously cropped; the Quincy site had not been cropped for several years. Fertilizer was applied and incorporated before planting, except as noted later. Potatoes were planted the third week in April at both sites in 86-cm rows with seed pieces placed 23 cm apart in the rows. Recommended herbicides and insecticides were used. Daily sprinkler irrigation was used throughout the main part of the season with scheduling based on pan evaporation.

Soil analysis. Pretreatment soil samples were taken from the surface and from the soil profile in 30-cm increments to a depth of 120 cm. Soil test results from composite samples by the WSU Soil Testing Laboratory are given in Table 1. Extractable P was determined using $NaHCO_3$ (Olsen et al. 1954) and available K was determined in the same extract by flame emission spectrophotometry.

Fertilizer treatments. Treatments involving different levels of N, P, and K were replicated

in randomized complete block experimental designs at both sites. Individual plots were 6 rows (spaced 86 cm apart) wide and 12 m long. The P and K were supplied as preplant broadcast treatments of triple superphosphate and KCl, respectively.

At the Hezel site there were four replicates of PK treatments in two blocks. One block received 400 kg N ha^{-1} and another 600 kg N ha^{-1}. Tabulated data from the Hezel site are the means of eight replications. The N was applied as urea with one-third broadcast at planting and the remaining applied in equal amounts the first and last week of June. Field corn (*Zea mays*) was grown as a rotation crop in 1981 without added fertilizer between first-crop and second-crop potatoes.

First-crop potatoes at the Quincy site received a blanket application of 440 kg N ha^{-1}, and second-crop potatoes received 600 kg N ha^{-1} in 1983. Each year a control plot with 400 kg N ha^{-1} was replicated five times along with PK treatments. One-third of the N was broadcast as urea at planting and the rest was applied as urea ammonium nitrate at frequent intervals in sprinkler water from June 15 to August 1. The S and Zn were applied only on first-crop potatoes at each location to give 50 kg S ha^{-1} and 11 kg Zn ha^{-1} from gypsum, $ZnSO_4$ and Zn chelate combined. At the Quincy site, oats were grown in the rotation without fertilizer in 1982 between first-crop and second-crop potatoes.

Plant analysis and harvest. Potato leaf petioles were collected for chemical analysis at early tuber growth in mid-June followed by two additional samplings at monthly intervals thereafter. A composite of the fourth or fifth petioles from the tops was collected from each plot, oven-dried immediately at 70˚C and finely ground in a Wileymill. Subsamples were analyzed for NO_3-N using Devarda steam distillation (Bremmer 1965). P was determined with the molybdivanado-phosphoric acid procedure (Kitson and Mellon 1944) in samples wet-ashed in nitric and perchloric acids, and K was determined in the same acid digest with a flame photometer.

The total yield of potatoes was determined at maturity in mid-September by harvesting three rows 4.6 m long from each plot. The samples were processed to determine yield of U.S. No. 1 tubers and the specific gravity. Tuber subsamples were diced, oven-dried at 70˚C, and analyzed for P and K by the same procedures used for petiole analysis. Total crop removal of P and K was calculated based on total dry matter yield of tubers.

RESULTS AND DISCUSSION

Conversion Note: mg ha^{-1} x 0.446 = tons/a

Tuber yield for first-crop and second-crop potatoes in experiments at both the Hezel and Quincy sites are shown in Tables 2 and 3. The first-crop yields averaged over 70 mg ha^{-1}, while the second crop averaged yields of 50 to

Table 1. Pretreatment Soil Test Results at Hezel and Quincy Sites[a]

	pH	N	P	K	O.M.	Electrolytic Conductivity (salts)
		mg kg^{-1}			%	Siemen m^{-1}
Hezel site, 1980	7.0	5	9.0	240	0.9	0.03
Quincy site, 1981	6.8	4	20.8	214	1.1	0.02

[a]mg kg^{-1} = ppm; Siemen m^{-1} x 10 = mmhos cm^{-1}; N is sum of NH_4-N + NO_3-N for each 30-cm increment to a depth of 120 cm.

60 mg. In each case, first-crop potatoes had twice as many U.S. No. 1 grade tubers as second-crop potatoes.

Nitrogen effect. The average first-crop potato yield from the Hezel experiment increased significantly from 73 mg ha^{-1} with 400 kg N ha^{-1} to 76 mg ha^{-1} with 600 kg N ha^{-1}. Yield results in Table 2 represent averages of these N rate data for each treatment. In contrast, total yield at the Quincy site showed no significant yield response with over 400 kg N ha^{-1} (Table 3). The N rate of 600 kg N ha^{-1} is not always cost effective. A high rate of N at planting time may even delay early tuber growth (Roberts et al. 1981). The average first-crop yield of U.S. No. 1 tubers from the Hezel experiment increased significantly from 54 mg ha^{-1} with 400 kg N ha^{-1} to 60 mg ha^{-1} for 600 kg N ha^{-1}. Yields for U.S. No. 1 tubers in Table 2 represent average results for these two N rates in conjunction with each treatment.

Yield effects of P and K treatments. There was a significant potato yield response to P at the Hezel site, but there was no yield response to K (Table 2). Applications of P or K did not influence potato yield of the Quincy site (Table 4). The effect of fertilizer P is assessed in treatments 1 to 4 and 1S to 4S (Tables 2 and 3); the minor influence of K is evident in first-crop treatments 6 to 9 and in second-crop treatments 6S to 9S. The first-crop potatoes with the highest yields were a better test of fertilizer response than the lower second-crop yields, which had less stress on the nutrient supply in the soil. The second-crop yield of U.S. No. 1 tubers at the Hezel site was below acceptable levels (Table 2). But both first-crop and second-crop potatoes did respond to applied P. The marginal production was

Table 2. Yield of First-Crop and Second-Crop Potatoes with P, K, and Related Treatments at the Hezel Site

First-Crop, 1980				Second-Crop, 1982			
Treatment Number[a]	P-K	Yield	U.S. 1	Treatment Number[a]	P-K	Yield	U.S. 1
	kg ha^{-1}	mg ha^{-1}			kg ha^{-1}	mg ha^{-1}	
			P Rates				
1	0-200	66.8	50.8	1S	0-200	49.7	22.2
2	50-200	75.1	57.6	2S	0-200	56.0	22.8
3	100-200	77.5	62.2	3S	0-200	60.3	23.7
4	200-200	75.6	58.0	4S	0-200	60.9	23.5
5	50-200	70.7	54.2	5S	50-200	63.2	28.9
			K Rates				
6	100-0	79.8	63.2	6S	100-0	64.7	33.8
7	100-100	73.7	58.3	7S	100-0	62.3	28.7
8	100-200	74.8	57.7	8S	100-0	64.7	30.0
9	100-400	73.4	55.8	9S	100-0	66.8	29.1
			Related Treatments				
10	100-100	74.7	57.9	10S	100-100	66.3	24.9
11[b]	50-200	75.0	52.1	11S	50-200	64.7	27.1
12	50-200	73.3	56.1	12S	50-200	66.3	28.2
13	100-100	78.0	60.6	13S	100-100	65.9	23.3
LSD	0.05	5.78	6.09			6.50	5.80

[a]Values are means of four replications at both 400 kg N ha^{-1} and 600 kg N ha^{-1} with the same treatment numbers applied to the same plot each year.
[b]P and K sidedressed at planting.

probably related to moisture stress or fluctuations that produced uneven growth.

The largest response to P occurred on the Hezel soil, which has an available soil P level of only 9 ppm (Table 1). The Quincy soil had lower soil K than the Hezel soil, but there was also no yield response to K at that site. Kunkel and Thornton (1986) observed that potatoes on newly tilled land, like the Hezel site, rarely responded initially to K fertilization. Soils newly tilled for irrigation usually have adequate soil test K.

Comparing treatment 3S with 12S (Table 2) and treatment 3S with 5S (Table 3) shows that second-crop potatoes benefited as much or more from splitting P application between the two crops as from applying all of the P on the first crop. Likewise, second-crop potatoes were not influenced by whether the K rate treatment was all applied on the first crop or split between the two crops in related treatments (8S and 10S, Tables 2 and 3). Little effect of the split K application was anticipated in the absence of a K response. Natural supplies of available S in the Hezel soil appeared adequate since yield from treatment 13, with no added S, was comparable to those where S was added (Table 2). The response to S was not significant, but may indicate a trend toward a response on newly cropped land.

Plant analysis and nutrient removal. Plant petiole analysis was used to evaluate the nutrient uptake of P and K applied on first-crop potatoes, and recovery of residual P and K by second-crop potatoes (Tables 4 to 7). Concentrations of P and K in petioles declined consistently from the first through the third sampling. The highest P rate on first-crop potatoes resulted in petiole P concentrations nearly double those of the controls (treatments 1 and 4 in Tables 4 and 6). The early tuber-set

Table 3. Yield of First-Crop and Second-Crop Potatoes with P, K, and Related Treatments at the Quincy Site

First-Crop, 1981				Second-Crop, 1983			
Treatment Number[a]	P-K	Yield	U.S. 1	Treatment Number[a]	P-K	Yield	U.S. 1
	kg ha^{-1}	mg ha^{-1}			kg ha^{-1}	mg ha^{-1}	
			P Rates				
1	0-200	72.1	62.3	1S	0-200	56.7	41.0
2	50-200	71.9	62.7	2S	0-200	60.9	40.8
3	100-200	74.4	65.9	3S	0-200	56.5	41.9
4	200-200	70.8	58.9	4S	0-200	56.6	39.9
5	50-200	72.4	64.2	5S	50-200	55.3	34.9
			K Rates				
6	100-0	71.5	62.7	6S	100-0	54.9	34.7
7	100-100	73.2	63.4	7S	100-0	57.3	36.5
8	100-200	70.8	60.7	8S	100-0	52.4	31.6
9	100-400	72.8	63.2	9S	100-0	55.6	34.5
			Related Treatments				
10	100-100	73.5	64.3	10S	100-100	50.2	29.8
11[b]	50-200	77.3	67.4	11S	100-200	56.6	39.0
12	50-200	75.0	65.4	12S	100-200	52.2	31.8
LSD	0.05	NS	4.2[c]			NS	5.0

[a]Same treatment numbers are assigned to same plots for both crops.
[b]P and K were sidedressed along the row at planting in 1981; treatment consited of 400 kg N ha^{-1} as compared to 440 kg N ha^{-1} for the other treatments in 1981 and 600 kg N ha^{-1} for the other 1983 treatments.
[C]Probability 0.10.

growth stage (Dow 1980), which is nearly the same as the first sampling in June for this study, has an established critical range of 0.35% to 0.45% P that changes through the season (Roberts and Dow 1982; Westermann and Kleinkopf 1985). Petiole P concentrations in this study fall within the accepted range.

Fertilizer K (treatments 7 to 9 or 7S to 9S in Tables 5 and 7) in most cases did not increase petiole K concentrations in the June samples of first-crop or second-crop potatoes at either location. The increased K petiole concentrations in samplings from July and August did not result in higher tuber yields (Tables 2 and 3). Petiole K levels at early tuberization were in the commonly accepted critical concentration range of 9.5% to 11% for Russet Burbank potatoes (Dow 1980). These high concentrations are indicative of satisfactory K availability and help explain the lack of a yield response to fertilizer K.

The concentration of P and K in tubers and values for total nutrient removal in the annual crop are given in Tables 8 to 11. In all cases, P fertilization significantly increased P concentration and total P removal by tubers (Tables 8 and 10). The maximum P concentration of 0.6% in the June sampling of petioles at the Quincy site (Table 6) was associated with values of 0.4% P in the first-crop of tubers and P removal of 56 kg ha^{-1} (Table 10). Total P removal by the two combined crops of tubers exceeded 80 kg ha^{-1} in many of the PK treatments (Tables 8 and 10).

Tubers with less than 0.2% P may be P deficient (McCollum 1978). A yield response to added P occurred when tubers harvested from the control treatments (1 and 1S) had P concentrations of 0.17% to 0.19%. Increasing P fertilization also increased the P concentration in tubers. Because tubers are a dominant sink for plant P, remobilization of P from leaves to tubers can adversely affect crop canopy (Westermann and Kleinkopf 1985).

The residual or applied K, unlike P, had only minimal effect on the concentration of K in tubers, or on K removal in the harvested crop, as shown by K rate treatments 6 to 9 (Tables 9 and 11). In previous studies, P and K removal in tubers was directly correlated with tuber yield (Kunkel et al. 1973). Potato petioles initially contained 10% to 11% K, compared to 1% to 2% K in tubers at harvest. There is little information on established critical levels of K in tubers. A marked increase in susceptibility to bruise damage was found in tubers with less that 1.8% K (Maier et al. 1986). Removal of K by first-crop and second-crop potatoes was 300 kg ha^{-1} or more.

There was a tendency for specific gravity of the tubers to decrease as K fertilization rates increased in first-crop potatoes (treatments 6 to 9, Tables 9 and 11) but not in second-crop potatoes. There is evidence from Idaho (McDole 1978; Roberts and McDole 1985) that excessive K fertilization decreases specific gravity.

Soil analysis. We attempted to determine the effect of fertilizer application and crop removal on soil P and K in sandy soils (Tables 12 and 13). Excluding the cover crop, more P was applied for some treatments than the removal by the first-crop and second-crop potatoes combined. This program of P fertilization with 100 kg P ha^{-1} for each potato crop almost maintained a constant level of soil test P at these two sites. The situation was different for K, where first-crop and second-crop removal combined exceeded all of the K treatment applications. Thus there was a lack of K buildup. Soil K levels were depleted where little or no K was applied (treatments 6 to 9 and 6S to 9S, Tables 12 and 13).

Soil test critical levels for irrigated potatoes in central Washington were established originally at 20 ppm P and 240 ppm K on silt loam soils (Dow et al. 1974). Our study concludes that these same soil test critical levels are valid for fertilizing potatoes in Hezel and Quincy sandy soils. P and K fertilization is probably required in these sands whenever soil test P and K drop below these critical levels, the same as in silt loams.

Table 4. Total P in Petioles of First-Crop and Second-Crop Potatoes With Residual and Applied P, K, and Related Treatments at the Hezel Site

Sampling Dates for Petiole P (%)									
First-Crop, 1980					Second-Crop, 1982				
Treatment Number	P-K	6/11	7/11	8/11	Treatment Number	P-K	6/8	7/9	8/18
	kg ha^{-1}					kg ha^{-1}			
				P Rates					
1	0-200	0.35	0.19	0.14	1S	0-200	0.25	0.16	0.15
2	50-200	0.47	0.24	0.17	2S	0-200	0.32	0.19	0.15
3	100-200	0.48	0.29	0.22	3S	0-200	0.30	0.19	0.15
4	200-200	0.60	0.46	0.34	4S	0-200	0.38	0.21	0.16
5	50-200	0.46	0.25	0.18	5S	50-200	0.39	0.24	0.15
				K Rates					
6	100-0	0.50	0.31	0.20	6S	100-0	0.46	0.29	0.19
7	100-100	0.52	0.30	0.19	7S	100-0	0.45	0.30	0.19
8	100-200	0.51	0.36	0.22	8S	100-0	0.48	0.30	0.19
9	100-400	0.49	0.30	0.25	9S	100-0	0.44	0.31	0.20
				Related Treatments					
10	100-100	0.52	0.33	0.21	10S	100-100	0.46	0.33	0.21
11[b]	50-200	0.29	0.25	0.23	11S	50-200	0.28	0.25	0.18
12	50-200	0.50	0.33	0.23	12S	50-200	0.45	0.33	0.21
13	100-100	0.53	0.34	0.22	13S	100-100	0.48	0.30	0.23
LSD		0.05	0.04	0.03			0.06	0.06	0.04

[a]P and K were sidedressed along the row at planting in 1981; treatment consisted of 400 kg N ha^{-1} as compared to 440 kg N ha^{-1} for the other treatments in 1981 and 600 kg N ha^{-1} for the other 1983 treatments.

Table 5. Total K in Petioles of First-Crop and Second-Crop Potatoes With Residual and Applied P, K, and Related Treatments at the Hezel Site

Sampling Dates for Petiole K (%)									
First-Crop, 1980					Second-Crop, 1982				
Treatment Number	P-K	6/11	7/11	8/11	Treatment Number	P-K	6/8	7/9	8/18
	kg ha^{-1}					kg ha^{-1}			
				P Rates					
1	0-200	11.7	9.6	9.5	1S	0-200	11.1	9.4	8.2
2	50-200	11.2	9.6	9.7	2S	0-200	11.2	9.5	8.2
3	100-200	11.7	9.8	9.7	3S	0-200	11.4	9.7	8.4
4	200-200	11.4	9.7	9.7	4S	0-200	11.4	9.8	8.8
5	50-200	11.5	9.9	10.0	5S	50-200	12.1	10.2	9.0
				K Rates					
6	100-0	11.2	8.7	8.9	6S	100-0	10.6	7.7	6.2
7	100-100	11.2	9.3	9.1	7S	100-0	10.7	8.1	6.4
8	100-200	11.4	10.1	9.7	8S	100-0	10.8	7.9	6.7
9	100-400	11.7	10.1	9.9	9S	100-0	11.4	8.7	7.3
				Related Treatments					
10	100-100	11.3	9.5	9.5	10S	100-100	11.1	9.1	7.5
11	50-200	11.2	9.8	9.9	11S	50-200	10.9	10.1	8.9
12	50-200	11.5	10.1	9.9	12S	50-200	11.5	10.0	8.6
13	100-100	11.3	9.5	9.3	13S	100-100	11.2	8.9	7.1
LSD	0.05	NS	0.52	0.46			0.9	1.0	0.9

[a]P and K were sidedressed along the row at planting in 1981; treatment consisted of 400 kg N ha^{-1} as compared to 440 kg N ha^{-1} for the other treatments in 1981 and 600 kg N ha^{-1} for the other 1983 treatments.

Table 6. Total K in Petioles of First-Crop and Second-Crop Potatoes With Residual and Applied P, K, and Related Treatments at the Quincy Site

Sampling Dates for Petiole P (%)									
First-Crop, 1981					Second-Crop, 1983				
Treatment Number	P-K	6/10	7/13	8/12	Treatment Number	P-K	6/20	7/15	8/16
	kg ha^{-1}					kg ha^{-1}			
				P Rates					
1	0-200	0.32	0.21	0.15	1S	0-200	0.26	0.28	0.20
2	50-200	0.43	0.33	0.17	2S	0-200	0.28	0.32	0.21
3	100-200	0.48	0.40	0.23	3S	0-200	0.33	0.33	0.23
4	200-200	0.60	0.51	0.33	4S	0-200	0.39	0.45	0.33
5	50-200	0.45	0.29	0.18	5S	50-200	0.39	0.44	0.31
				K Rates					
6	100-0	0.48	0.43	0.22	6S	100-0	0.41	0.47	0.43
7	100-100	0.49	0.40	0.25	7S	100-0	0.43	0.48	0.38
8	100-200	0.50	0.42	0.24	8S	100-0	0.41	0.46	0.40
9	100-400	0.46	0.40	0.23	9S	100-0	0.47	0.48	0.44
				Related Treatments					
10	100-100	0.49	0.40	0.24	10S	100-100	0.49	0.53	0.48
11	50-200	0.58	0.39	0.20	11S	100-200	0.44	0.59	0.36
12	50-200	0.49	0.39	0.22	12S	100-200	0.46	0.51	0.43
LSD	0.05	0.04	0.05	0.03			0.03	0.06	0.04

[a]P and K were sidedressed along the row at planting in 1981; treatment consisted of 400 kg N ha^{-1} as compared to 440 kg N ha^{-1} for the other treatments in 1981 and 600 kg N ha^{-1} for the other 1983 treatments.

Table 7. Total K in Petioles of First-Crop and Second-Crop Potatoes With Residual and Applied P, K, and Related Treatments at the Quincy Site

Sampling Dates for Petiole K (%)									
First-Crop, 1981					Second-Crop, 1983				
Treatment Number	P-K	6/10	7/13	8/12	Treatment Number	P-K	6/20	7/15	8/16
	kg ha^{-1}					kg ha^{-1}			
				P Rates					
1	0-200	11.6	10.2	10.4	1S	0-200	11.6	9.6	10.9
2	50-200	11.7	10.6	10.6	2S	0-200	11.7	10.5	11.3
3	100-200	11.5	9.8	9.9	3S	0-200	11.7	11.3	11.6
4	200-200	11.6	9.9	9.3	4S	0-200	11.9	10.3	11.3
5	50-200	11.4	9.9	10.4	5S	50-200	12.0	10.5	11.6
				K Rates					
6	100-0	10.8	8.4	7.8	6S	100-0	9.4	7.2	7.9
7	100-100	11.2	8.8	9.2	7S	100-0	9.9	7.6	8.3
8	100-200	11.4	10.1	9.8	8S	100-0	10.5	8.1	9.1
9	100-400	11.5	10.8	10.9	9S	100-0	11.0	9.3	10.0
				Related Treatments					
10	100-100	11.1	9.2	9.4	10S	100-100	11.3	9.3	10.5
11[a]	50-200	11.7	9.6	9.8	11S	100-200	11.5	9.8	10.7
12	50-200	11.7	10.1	10.0	12S	100-200	11.5	10.6	11/2
LSD	0.05	NS	0.85	0.72			0.41	0.84	0.60

[a]P and K were sidedressed along the row at planting in 1981; treatment consisted of 400 kg N ha^{-1} as compared to 440 kg N ha^{-1} for the other treatments in 1981 and 600 kg N ha^{-1} for the other 1983 treatments.

Table 8. Concentration and Total P Uptake in First-Crop and Second-Crop Tubers From Plots With P, K, and Related Treatments at the Hezel Site

First-Crop, 1980				Second-Crop, 1982			
Treatment Number	P-K			Treatment Number	P-K		
	kg ha^{-1}	%	kg ha^{-1}		kg ha^{-1}	%	kg ha^{-1}
			P Rates				
1	0-200	0.17	26	1S	0-200	0.19	20
2	50-200	0.20	25	2S	0-200	0.20	23
3	100-200	0.23	42	3S	0-200	0.21	26
4	200-200	0.29	51	4S	0-200	0.23	28
5	50-200	0.22	36	5S	50-200	0.23	30
			K Rates				
6	100-0	0.25	46	6S	100-0	0.28	37
7	100-100	0.23	40	7S	100-0	0.28	36
8	100-200	0.25	43	8S	100-0	0.29	39
9	100-400	0.22	39	9S	100-0	0.29	40
			Related Treatments				
10	100-100	0.23	39	10S	100-100	0.29	39
11[b]	50-200	0.21	37	11S	50-200	0.25	32
12	50-200	0.24	41	12S	50-200	0.30	41
13	100-100	0.24	44	13S	100-100	—	—
LSD	0.05	0.03	5.3			0.04	4.9

[a]P and K were sidedressed along the row at planting in 1981; treatment consisted of 400 kg N ha^{-1} as compared to 440 kg N ha^{-1} for the other treatments in 1981 and 600 kg N ha^{-1} for the other 1983 treatments.

Table 9. Concentration of K, Total Removal, and Specific Gravity of Potatoes With Residual and Applied P, K, and Related Treatments at the Hezel Site

Tubers, 1980					Tubers, 1982				
Treatment Number	P-K			Specific Gravity	Treatment Number	P-K			Specific Gravity
	kg ha^{-1}	%	kg ha^{-1}			kg ha^{-1}	%	kg ha^{-1}	
				P Rates					
1	0-200	1.76	274	1.092	1S	0-200	2.17	223	1.072
2	50-200	1.70	297	1.090	2S	0-200	2.07	265	1.072
3	100-200	1.76	318	1.092	3S	0-200	2.17	269	1.073
4	200-200	1.77	312	1.092	4S	0-200	2.16	269	1.073
5	50-200	1.78	293	1.091	5S	50-200	2.14	241	1.074
				K Rates					
6	100-0	1.59	295	1.095	6S	100-0	1.90	253	1.077
7	100-100	1.75	301	1.092	7S	100-0	1.95	250	1.077
8	100-200	1.76	304	1.090	8S	100-0	2.01	267	1.077
9	100-400	1.84	315	1.091	9S	100-0	2.06	281	1.076
				Related Treatments					
10	100-100	1.72	296	1.093	10S	100-100	1.95	262	1.078
11[b]	50-200	1.73	302	1.090	11S	50-200	2.16	283	1.075
12	50-200	1.75	299	1.092	12S	50-200	2.09	284	1.076
13	100-100	1.86	338	1.095	13S	100-100	—	—	1.076
LSD	0.05	NS	NS	0.004			0.20	29	0.004

[a]P and K were sidedressed along the row at planting in 1981; treatment consisted of 400 kg N ha^{-1} as compared to 440 kg N ha^{-1} for the other treatments in 1981 and 600 kg N ha^{-1} for the other 1983 treatments.

Table 10. Concentration and Total P Removal in Tubers With Residual and Applied P, K, and Related Treatments at the Quincy Site

First-Crop, 1981				Second-Crop, 1983			
Treatment Number	P-K			Treatment Number	P-K		
	kg ha^{-1}	%	kg ha^{-1}		kg ha^{-1}	%	kg ha^{-1}
			P Rates				
1	0-200	0.21	30	1S	0-200	0.17	21
2	50-200	0.27	39	2S	0-200	0.19	25
3	100-200	0.32	47	3S	0-200	0.20	24
4	200-200	0.40	56	4S	0-200	0.25	32
5	50-200	0.27	39	5S	50-200	0.26	31
			K Rates				
6	100-0	0.33	47	6S	100-0	0.27	32
7	100-100	0.32	46	7S	100-0	0.27	33
8	100-200	0.34	48	8S	100-0	0.30	34
9	100-400	0.32	46	9S	100-0	0.30	36
			Related Treatments				
10	100-100	0.31	45	10S	100-100	0.30	32
11[b]	50-200	0.32	49	11S	100-200	0.30	36
12	50-200	0.33	49	12S	100-200	0.31	35
LSD	0.05	0.03	5.4			0.03	4.9

Table 11. Concentration , Total K Removal, and Specific Gravity of Tubers With Residual and Applied K at the Quincy Site

First-Crop, 1981					Second-Crop, 1983				
Treatment Number	P-K			Specific Gravity	Treatment Number	P-K			Specific Gravity
	kg ha^{-1}	%	kg ha^{-1}			kg ha^{-1}	%	kg ha^{-1}	
				P Rates					
1	0-200	2.24	321	1.080	1S	0-200	2.62	318	1.080
2	50-200	2.22	315	1.081	2S	0-200	2.76	360	1.080
3	100-200	2.19	324	1.082	3S	0-200	2.62	317	1.081
4	200-200	2.12	298	1.085	4S	0-200	2.65	337	1.083
5	50-200	2.21	318	1.082	5S	50-200	2.62	310	1.084
				K Rates					
6	100-0	1.92	274	1.084	6S	100-0	2.11	250	1.092
7	100-100	2.01	294	1.083	7S	100-0	2.15	265	1.090
8	100-200	2.15	302	1.083	8S	100-0	2.31	259	1.090
9	100-400	2.28	330	1.079	9S	100-0	2.32	274	1.091
				Related Treatments					
10	100-100	2.11	309	1.084	10S	100-100	2.41	258	1.086
11[b]	50-200	2.25	345	1.081	11S	100-200	2.51	298	1.088
12	50-200	2.21	331	1.081	12S	100-200	2.55	284	1.085
LSD	0.05	0.22	33	0.003			0.23	43	0.004

Table 12. Effect of P and K Fertilization and Cropping With Potatoes on Soil Test Results at the Hezel Site

	First-Crop Treatments 1980	Pretreatment Soil Tests 1982[a]			Second-Crop Treatments 1983	Postharvest Soil Tests 1983	
Treatment Number	P-K	P	K	Treatment Number	P-K	P	K
	kg ha^{-1}	mg ha^{-1}			kg ha^{-1}	mg ha^{-1}	
				P Rates			
1[a]	0-200	5.0	217	1S	0-200	4	213
2	50-200	6.1	208	2S	0-200	9	240
3	100-200	7.2	208	3S	0-200	11	236
4	200-200	10.9	212	4S	0-200	13	215
5	50-200	6.5	216	5S	50-200	10	199
				K Rates			
6	100-0	8.2	199	6S	100-0	9	174
7	100-100	7.2	202	7S	100-0	10	237
8	100-200	8.0	218	8S	100-0	10	222
9	100-400	7.5	226	9S	100-0	11	193
				Related Treatments			
10	100-100	7.1	208	10S	100-100	14	219
11[b]	100-200	5.8	215	11S	100-200	9	255
12	100-200	7.6	215	12S	100-200	10	225

[a]Pretreatment soil tests in 1980 averaged 9 ppm P and 240 ppm K.
[b]P and K were sidedressed along the row at planting in 1981; treatment consisted of 400 kg N ha^{-1} as compared to 440 kg N ha^{-1} for the other treatments in 1981 and 600 kg N ha^{-1} for the other 1983 treatments.

Table 13. Effect of P and K Fertilization and Cropping With Potatoes on Soil Test Results at the Quincy Site

	First-Crop Treatments 1981	Pretreatment Soil Tests 1983[a]			Second-Crop Treatments 1983	Postharvest Soil Tests 1983	
Treatment Number[a]	P-K	P	K	Treatment Number[a]	P-K	P	K
	kg ha^{-1}	mg ha^{-1}			kg ha^{-1}	mg ha^{-1}	
				P Rates			
1[a]	0-200	18c	219ab	1S	0-200	16c	232a
2	50-200	27b	239a	2S	0-200	20bc	235a
3	100-200	23bc	228a	3S	0-200	19bc	224a
4	200-200	36a	241a	4S	0-200	25ab	210ab
5	50-200	24bc	248a	5S	50-200	23ab	231a
				K Rates			
6	100-0	25bc	177b	6S	100-0	23ab	174c
7	100-100	28ab	205ab	7S	100-0	25ab	186bc
8	100-200	26bc	209ab	8S	100-0	27a	203abc
9	100-400	23bc	245a	9S	100-0	27a	207abc
				Related Treatments			
10	100-100	29ab	234a	10S	100-100	28a	201abc
11	50-200	27b	253a	11S	100-200	26a	206abc
12	50-200	28ab	226a	12S	100-200	26a	201abc

[a]Pretreatment soil tests in 1981 showed 21 ppm P and 214 ppm K. Soil tests in a column followed by a different letter or letters are significantly different at 5% probability of multiple range tests.

REFERENCES

Bremner, J.M. 1965. Isotope ratio analysis of nitrogen in nitrogen-15 tracer investigations. In C.A. Black, ed., *Methods of Soil Analysis, Part II. Agronomy* 9:1256-1286. Madison, Wisconsin: American Society of Agronomists.

Dow, A.I. 1980. Critical nutrient ranges in Northwest crops. Regional Ext. Publ. 43. Washington State University, Pullman.

Dow, A.I., A.R. Halvorson, R.E. Thornton and S. Roberts. 1974. Fertilizer guide for irrigated potatoes. Cooperative Extension. FG-7. Washington State University, Pullman.

Dow, A.I., and R. Kunkel. 1963. Fertilizer tests with potatoes. Cooperative Extension. Circ. 335. Washington State University, Pullman.

Kitson, R.E., and M.G. Mellon. 1944. Colorimetric determination of phosphorus as molybdivanado phosphoric acid. *Ind. Eng. Chem. An. Ed.* 16:379-383.

Kunkel, R., N. Holstad, and T.S. Russell. 1973. Mineral element content of potato plants and tubers vs. yield. *Am. Potato J.* 50:275-282.

Kunkel, R. and R.E. Thornton. 1986. Understanding the potato. College of Agric. and Home Ec. Sci. Paper No. 7267. Washington State University, Pullman.

McCollum, R.E. 1978. Analysis of potato growth under differing P regimes. I. Tuber yields and allocation of dry matter and P. *Agron. J.* 70:51-57.

McDole, R.E. 1978. Potassium fertilizer trials with potatoes on coarse-textured soils in southeastern Idaho. *Am. Potato J.* 55:161-170.

Maier, N. A., A. P. Dahlenburg, and A. B. Fresnham. 1986. Potassium nutrition of irrigated potatoes in South Australia. 3. Effect on specific gravity, size and internal bruising of tubers. *Australian J. Exper. Agric.* 26:737-744.

Middleton, J. E., S. Roberts, D. W. James, T. A. Cline, B. L. McNeal and B. L. Carlisle. 1975. Irrigation and fertilization management for efficient crop production on a sandy soil. College of Agric. and Home Ec. Research Ctr., XB0811. Washington State University, Pullman.

Olsen, S. R., C. V. Cole, F. S. Watanabe, and L. A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. 939. Washington, D.C.

Roberts, S., and A.I. Dow. 1982. Critical nutrient ranges for petiole phosphorus levels of sprinkler irrigated Russet Burbank potatoes. *Agron. J.* 74:583-585.

Roberts, S., A. I. Dow, and T. C. Cline. 1984. Slow release nitrogen evaluations and phosphorus and potassium requirements for potatoes on sandy soil. College of Agric. and Home Ec. Research Ctr., XB0943. Washington State University, Pullman.

Roberts, S., and R. E. McDole. 1985. Potassium nutrition of potatoes. Pp. 800-814, in R.D. Munson, ed., *Potassium in Agriculture.* Madison, Wisconsin: American Society of Agronomists.

Roberts, S., W. H. Weaver, and J. P. Phelp. 1981. Effect of rate and time of fertilization on nitrogen and yield of Russet Burbank potatoes under center-pivot irrigation. *Am. Potato J.* 59:77-86.

Westermann, D. T. and G. E. Kleinkopf. 1985. Phosphorus relationships in potato plants. *Agron. J.* 77:490-494.