Evaluation of Specialty Phosphorus Fertilizer Sources for Potato

Carl Rosen, Matt McNearney, and Peter Bierman
Department of Soil, Water, & Climate
University of Minnesota
crosen@umn.edu

Summary: Field experiments were conducted at the Sand Plain Research Farm in Becker, Minn. to evaluate the effects of specialty P fertilizer formulations manufactured by Mosaic Co. on yield, quality, and P nutrition of Russet Burbank potato. Treatments included a zero P control; MAP, MES10, and MESZ fertilizers applied at 60 and 120 lb P_2O_5/A; and ACT142, 143, 144, and 145 fertilizers applied at 120 lb P_2O_5/A. Some of the treatments were also adjusted to permit comparisons of treatments with and without S, Mg, and Zn. One or more of these nutrients are contained in each of the specialty P fertilizers. All of the P sources significantly increased total tuber yield compared with the zero P control. At the 120 lb P_2O_5/A rate, MAP+S resulted in the greatest total yield in the study, but this treatment also had the highest proportion of undersized tubers (<4 oz). The zero P control also had the lowest marketable yield, but treatment effects on marketable yield were not significant due to higher tuber set with P fertilizer. The zero P control had the lowest amounts of small tubers and the highest percentages of large tubers, which was consistent with reduced tuber set when no P was applied. Sulfur, Mg, and Zn had no significant effects on total or marketable yield, but application of Mg and the high rate of Zn did result in lower amounts of small tubers and higher percentages of large tubers. MAP+S had greater tuber set at the high P rate than the low P rate, but increasing the P rate did not increase tuber set with MES10 and MESZ. Application of P increased petiole P concentrations at tuber set and late tuber bulking, but not at early and mid tuber bulking. Application of S, Mg, and Zn had no effects on their concentrations in petioles. The zero P control had significantly lower dry matter production, tuber P concentration, and total P uptake than the treatments receiving P fertilizer. There were no significant differences among the P sources in dry matter, tuber P, and P uptake. Application of Mg significantly increased tuber Mg concentrations.

Background: One of the challenges associated with improving P use efficiency in plants is maintaining an available form of P following application of P fertilizer. Acid and high pH soil will tend to adsorb or precipitate soluble P. Use of elemental sulfur in the formulation has an acidifying effect and may help keep P in solution for a longer period of time, particularly on neutral to alkaline soils. Specialty P fertilizers have recently been developed by The Mosaic Company (US patent #6544313) that blend sulfur into a monoammonium phosphate (MAP)-based product. Formulations containing Zn and Mg have also been developed. This is the third year of a study with the overall objective of determining potato response to specialty P products manufactured by The Mosaic Company. Results in 2007 showed yield increases with specialty P fertilizers compared with conventional sources, but no differences were found in 2008. The reason for this may have been higher soil test P levels in 2008. The objective of this 2009 study was to follow up on previous research and determine the effects of the specialty P fertilizers MES10, MESZ, ACT142, ACT143, ACT144, and ACT145 on growth and yield of irrigated potato.

Materials and Methods

This study was conducted at the Sand Plain Research Farm in Becker, Minnesota on a Hubbard loamy sand soil. The previous crop was rye and selected soil chemical properties before planting were as follows (0-6“): water pH, 5.0; buffer pH, 6.4; organic matter, 2.3%; Bray P1, 18 ppm; ammonium acetate extractable K, Ca, and Mg, 63, 324, and 40 ppm, respectively; hot water extractable B, 0.3 ppm; Ca-phosphate extractable SO_4-S, 1.0 ppm; and DTPA extractable Zn, Cu, Fe, and Mn, 1.1, 0.4, 90.2, and 29.6 ppm, respectively. Extractable nitrate-N and ammonium-N in the top 2 ft prior to planting were 10.9 and 14.1 lb/A, respectively. Extractable SO_4-S in the top 2 ft prior to planting was 20.0 lb/A.

On April 13, 150 lb K_2O/A as 0-0-60 (potassium chloride) was broadcast on all plots and later incorporated by plowing. Because of the low pH and calcium levels, 1000 lbs/A pel-lime was applied and incorporated with a field cultivator on April 20. Four, 20-ft rows were planted for each plot with the middle two rows used for sampling and harvest. Whole "B" Russet Burbank potato seed was hand planted in furrows on April 21, 2009. Row spacing was 12 inches within each row and 36 inches between rows. Each treatment was replicated 4 times in a randomized complete block design. Admire Pro was applied in-furrow for beetle control, along with the fungicides Quadris and Ultra Flourish. Weeds, diseases, and other insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling. Rainfall and irrigation amounts were recorded and are shown in Fig. 1.

Twelve fertilizer treatments were tested and are listed below. MESZ was tested in 2007 and 2008. This was the first year of testing for MES10, ACT142, ACT143, ACT144, and ACT145.

Fertilizer treatments tested in the specialty phosphorus fertilizers study.

Treatment number	P rate	P source*	Description	S rate	Zn rate	Mg rate
	lb P_2O_5/A			------------- lb/A ---------------		
1	0	Control	46-0-0 + 0-0-50-18S	30	0	0
2	60	MAP + S	11-52-0 + 0-0-50-18S	30	0	0
3	60	MES10	12-40-0-10S	15	0	0
4	60	MESZ	12-40-0-10S-1Zn	15	1.5	0
5	120	MAP	11-52-0	0	0	0
6	120	MAP + S	11-52-0 + 0-0-50-18S	30	0	0
7	120	MES10	12-40-0-10S	30	0	0
8	120	MESZ	12-40-0-10S-1Zn	30	3.0	0
9	120	ACT142	10-49-0-2S-1Zn	4.9	2.5	0
10	120	ACT143 + Mg	10-46-0-3S-1Zn-2Mg + $MgCl_2$	7.8	2.6	35
11	120	ACT144	11-48-0-3S-1Zn	7.5	2.5	0
12	120	ACT145	10-44-0-3S-1Zn	8.2	2.7	0

*MAP = monoammonium phosphate; MES10, MESZ, ACT 142, ACT 143, ACT 144, ACT 145 = specialty P fertilizers from The Mosaic Co.

Phosphorus fertilizer treatments were applied at planting in a band 3 inches to the side and 2 inches below the seed piece using a belt type applicator. Potassium was applied to all plots in the band at planting at a rate of 150 lbs K_2O/A. The K source was 0-0-60 or a combination of 0-0-60 and 0-0-50 (potassium sulfate) for treatments 1, 2, and 6 to equalize the amount of S applied with the high rates of MES10 and MESZ. Treatment 10 received 5 lbs Mg/A at planting from ACT143. For all the other treatments except treatment 11, an additional 30 lb Mg/A was sidedressed on May 14 and incorporated in the hilling operation. The additional Mg was supplied as magnesium chloride deicing salt. Total N applied was 236 lb N/A for all treatments. The rate of N applied at planting was adjusted with urea to be equivalent to the amount applied with the high rates of MES10 and MESZ (36 lb N/A). Sidedress N applications were made with urea at the rate of 100 lb N/A at emergence on May 19 and three post-hilling applications as urea-ammonium nitrate on June 11 (50 lb N/A), June 22 (25 lb N/A), and July 1 (25 lb N/A). Plots were irrigated immediately after post-hilling N application to minimize volatilization.

Plant stands were measured on June 3 and the number of stems per plant was counted on June 9. Petiole samples were collected from the 4th leaf from the terminal on June 18, June 30, July 14, and Aug 5. Petioles were analyzed for nitrate-N, P, S, Mg, and Zn on a dry weight basis. Vines were harvested on Sept 16 from two, 10-ft sections of row, followed by mechanically beating the vines over the entire plot area. Tuber numbers in treatments 1-4 and 6-8 were measured by hand-digging five plants before machine harvest on September 25 and separating them into size categories before counting. Total tuber yield, graded yield, tuber specific gravity, and internal disorders were recorded at final harvest. Subsamples of vines and tubers were collected for moisture determination. Dried tissues were weighed and then ground to pass through a 1 mm screen. Phosphorus, N, S, Mg, and Zn concentrations in plant tissue were determined by AgVise laboratories. Phosphorus uptake was calculated by multiplying vine and tuber P concentrations by the amounts of tuber and vine dry matter. Phosphorus uptake results were not available at the time of this report.

The experiment was statistically analyzed using ANOVA procedures on SAS and means were separated using a Waller-Duncan LSD test at P = 0.10. Orthogonal contrasts were also performed to compare P vs. no P, S vs. no S, Mg vs. no Mg, and Zn vs. no Zn and to evaluate linear response to P fertilizer rate.

Results

Tuber yield: Total tuber yield for the zero P control was significantly lower than any of the treatments receiving P fertilizer, indicating that there was a response to P at the Bray P1 soil test level of 18 ppm and the low soil pH of 5.0 (Table 1). For MAP+S there was a strong trend for total yield to increase as the P rate increased up to 120 lb P_2O_5/A, but for MES10 and MESZ yields were similar for 60 and 120 lb P_2O_5/A. MAP+S at 120 lb P_2O_5/A had the highest total yield and at the 10% probability level it was significantly higher than MESZ, ACT142, and ACT145 at 120 lb P_2O_5/A. MAP+S was numerically higher than MAP alone, but the difference was not significant, indicating that there was no response to S on this soil. Comparable total yields for ACT143 and ACT144 indicate there was no response to Mg and similar yields for MESZ and MES10 at both P rates indicate no response to Zn.

There were no significant differences among any of the treatments in marketable yield. The zero P control had lower marketable yield than any of the treatments receiving P fertilizer, but the contrast between P and no P was not significant. The control had the lowest amounts of small tubers (0-4 and 4-6 oz) and the highest percentages of large tubers (>6 and >10 oz). Sulfur had no effect on tuber size. ACT144 (no Mg) had significantly higher amounts of small, unmarketable tubers (<4 oz) than ACT143 (with Mg). The percentages of large tubers were numerically higher with Mg added, although the differences were not significant. Zinc had no effect on tuber size at 60 lb P_2O_5/A, but at 120 lb P_2O_5/A there were significantly lower amounts of small tubers (0-4 and 4-6 oz) and significantly greater percentages of large tubers (>6 and >10 oz) for MESZ (with Zn) than MES10 (no Zn). Zinc application was 1.5 lb/A at 60 lb P_2O_5/A and 3.0 lb/A at 120 lb P_2O_5/A.

Plant stand, stems and tubers per plant, and tuber quality: There were no significant differences among any of the treatments in plant stand, the number of stems per plant, specific gravity, and the incidence of hollow heart (Table 2). The zero P control had significantly lower numbers of tubers per plant than MAP+S, MES10, and MESZ at either 60 or 120 lb P_2O_5/A. This is consistent with research in previous years showing increased tuber set with P application. These differences in tuber set are also consistent with the lower amounts of small tubers and higher percentages of large tubers for the control treatment (Table 1). MAP+S also had significantly greater tuber set at the high P rate of 120 lb P_2O_5/A than at 60 lb P_2O_5/A and tended to have greater amounts of 0-4 oz tubers at the high P rate. MES10 and MESZ did not follow the same pattern and MES10 actually had significantly greater tuber set at the low P rate.

Petiole nutrient concentrations: Petiole P concentrations at the time of tuber set were significantly higher for all of the treatments receiving P fertilizer than for the zero P control (Table 3). The zero P control also had significantly lower concentrations of petiole P at late tuber bulking when contrasted with the P fertilized treatments as a group (Table 6). There were no significant effects of P application on petiole P at early or mid tuber bulking (Tables 4 and 5).

There were no significant effects of S, Mg, and Zn application on petiole concentrations of these elements on any sampling date. The zero P control had significantly lower petiole Mg concentration than the P fertilized treatments at early and mid tuber bulking, but significantly higher concentrations of Zn than the P treatments at tuber set and early tuber bulking. The zero P control had significantly lower S concentration than the group of P fertilized treatments at tuber set, but significantly higher S concentration than all of the P treatments at early tuber bulking. The reasons for these differences in petiole Mg, Zn, and S concentrations are not clear, although high soil P can inhibit Zn uptake.

The zero P control had significantly higher petiole nitrate-N concentrations than the group of P fertilized treatments at tuber set and early tuber bulking. This could have been due to reduced growth from inadequate P for the control and subsequent concentration of the N that was taken up. The zero P control also had numerically higher petiole nitrate-N concentrations than most of the other treatments at mid and late tuber bulking. The zero P control had significantly higher petiole K concentrations than all of the P fertilized treatments at early tuber bulking, which could also have been a concentration effect from reduced growth. A similar trend in petiole K also occurred at mid tuber bulking. The MESZ treatment at 120 lb P_2O_5/A had significantly higher petiole K concentrations than a number of other treatments at early and mid tuber bulking, but the reasons for these effects are not clear.

Tuber and vine nutrient concentrations: The zero P control had significantly lower tuber P concentrations than the group of treatments receiving P fertilizer (Table 7). The contrast between ACT143 (with Mg) and ACT144 (no Mg) found that Mg application significantly increased tuber Mg. There were no significant differences among any of the treatments in tuber concentrations of N, S, or Zn. The zero P control had significantly higher vine concentrations of S and Zn than the group of treatments receiving P fertilizer. There were no significant differences in vine concentrations of P, N, or Mg.

Tuber and vine dry matter accumulation and P uptake: The zero P control had significantly lower tuber and total dry matter production and tuber and total P uptake than the group of treatments receiving P fertilizer (Table 8). There were no significant differences among any of the treatments in vine dry matter accumulation at harvest or vine P uptake.

Conclusions: All of the P sources significantly increased total tuber yield compared with the zero P control. MAP+S at 120 lb P_2O_5/A had the greatest total yield, primarily due to an increase in undersized tubers. Phosphorus fertilization increased tuber set and decreased tuber size. This is consistent with the results of previous research, although increasing the P rate from 60 to120 lb P_2O_5/A did not increase tuber set for MES10 and MESZ. Application of S, Mg, and Zn had no effects on yield, but Mg and the high rate of Zn resulted in lower amounts of small tubers and higher percentages of large tubers. Application of P increased petiole P concentrations on some sampling dates, but S, Mg, and Zn applications had no effects on their petiole concentrations. Phosphorus fertilization from all P sources increased dry matter production, tuber P concentration, and total P uptake. Application of Mg significantly increased tuber Mg concentration.

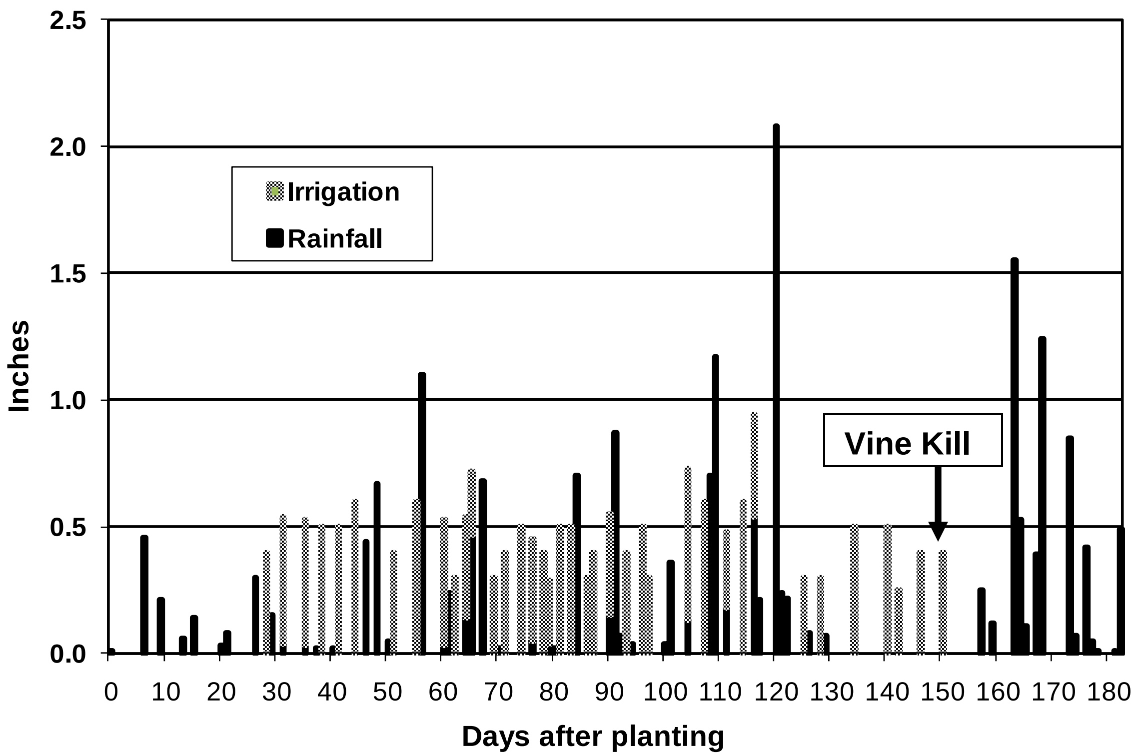

Figure 1. Rainfall and irrigation amounts during the 2009 growing season.

Table 1. Effects of specialty P fertilizers on tuber yield and size distribution of Russet Burbank potatoes.

Treatments				Tuber Yeild										
										#1	# 2	Total		
			P_2O_5 Rate	0-4 oz	4-6 oz	6-10 oz	10-14 oz	>14 oz	Total	> 4 oz	> 4 oz	marketable	> 6oz	> 10 oz
Treatment #	P Source	Description	lb/A	------ cwt/A ------									%	%
1	Control	46-0-0 + 0-0-50	0	38.8	63.9	190.4	151.0	110.5	553.6	431.7	83.1	514.8	81.3	46.5
2	MAP + S	11-52-0 + 0-0-50	60	133.7	176.9	180.3	105.0	66.2	662.0	399.3	129.1	528.4	53.3	26.3
3	MES10	12-40-0-10S	60	131.5	164.2	189.7	112.0	69.9	667.4	383.0	152.9	535.8	55.6	27.2
4	MESZ	12-40-0-10S-1Zn	60	133.4	167.0	198.0	97.7	87.5	683.5	404.1	146.0	550.1	56.0	27.0
5	MAP	11-52-0 +0-0-60	120	137.5	163.6	188.3	114.1	73.8	677.3	375.2	164.6	539.8	55.7	27.9
6	MAP + S	11-52-0 + 0-0-50	120	151.5	168.3	209.6	101.6	87.2	718.2	408.9	157.8	566.7	55.4	26.3
7	MES10	12-40-0-10S	120	126.7	176.7	172.8	109.2	75.3	660.7	436.9	97.1	534.0	54.2	27.9
8	MESZ	12-40-0-10S-1Zn	120	102.2	133.5	184.8	140.1	98.3	658.8	417.0	139.7	556.7	64.5	36.4
9	ACT142	10-49-0-2S-1Zn	120	133.7	162.4	188.4	102.9	68.3	655.6	402.9	119.0	521.9	54.8	26.2
10	ACT143	10-46-0-3S-1Zn-2Mg	120	121.6	166.6	221.5	106.3	63.4	679.4	468.0	89.8	557.8	57.2	24.8
11	ACT144	11-48-0-3S-1Zn (0 Mg)	120	147.1	176.5	214.9	81.4	51.9	671.8	428.3	96.3	524.7	51.7	19.8
12	ACT145	10-44-0-3S-1Zn	120	122.1	144.8	217.7	111.8	60.5	656.9	429.8	105.0	534.8	59.4	26.2
			Significance[1]	**	**	NS	**	NS	**	NS	**	NS	**	**
			LSD (0.1)	20.0	33.1	--	27.9	--	57.7	--	36.2	--	5.7	6.6
			Contrasts											
			P vs No P (trmts 1 vs rest)	**	**	NS	**	*	**	NS	**	NS	**	**
			linear P MAP + S (trmts 1,2,6)	**	**	NS	**	NS	**	NS	**	NS	**	**
			linear P MES10 (trmts 1,3,6)	**	**	NS	**	++	**	NS	NS	NS	**	**
			linear MESZ (trmts 1,4,8)	**	**	NS	NS	NS	**	NS	**	NS	**	*
			Mg vs No Mg (trmts 10 vs 11)	*	NS	NS	++	NS	NS	NS	NS	NS	NS	NS
			MES10 vs MESZ (trmts 3,7 vs 4,8)	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
			MAP vs MAP + S (trmts 5 vs 6)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively

Table 2. Effects of specialty P fertilizers on plant stand, number of stems and tubers per plant, and tuber quality.

Treatment #	P Source	Description	P_2O_5 Rate lb/A	Stand %	Number of Stems per Plant	Tubers per Plant	Specific Gravity	% Hollow Heart
1	Control	46-0-0 + 0-0-50	0	100.0	3.0	8.4	1.0877	12.0
2	MAP + S	11-52-0 + 0-0-50	60	100.0	3.0	16.4	1.0867	7.0
3	MES10	12-40-0-10S	60	100.0	3.0	18.5	1.0853	3.0
4	MESZ	12-40-0-10S-1Zn	60	100.0	3.1	18.3	1.0909	10.3
5	MAP	11-52-0 +0-0-60	120	98.5	3.1	ND	1.0900	4.0
6	MAP + S	11-52-0 + 0-0-50	120	100.0	3.2	20.1	1.0854	8.8
7	MES10	12-40-0-10S	120	100.0	3.0	16.0	1.0849	5.0
8	MESZ	12-40-0-10S-1Zn	120	100.0	3.0	16.8	1.0852	8.0
9	ACT142	10-49-0-2S-1Zn	120	100.0	3.4	ND	1.0884	10.0
10	ACT143	10-46-0-3S-1Zn-2Mg	120	100.0	2.9	ND	1.0906	7.0
11	ACT144	11-48-0-3S-1Zn (0 Mg)	120	100.0	2.8	ND	1.0892	6.0
12	ACT145	10-44-0-3S-1Zn	120	100.0	3.1	ND	1.0856	8.0
			Significance[1]	NS	NS	**	NS	NS
			LSD (0.1)	--	--	2.2	--	--
			Contrasts					
			P vs No P (trmts 1 vs rest)	NS	NS	ND	NS	++
			linear P MAP + S (trmts 1,2,6)	NS	NS	**	NS	NS
			linear P MES10 (trmts 1,3,6)	NS	NS	**	NS	*
			linear MESZ (trmts 1,4,8)	NS	NS	ND	NS	NS
			Mg vs No Mg (trmts 10 vs 11)	NS	NS	ND	NS	NS
			MES10 vs MESZ (trmts 3,7 vs 4,8)	NS	NS	ND	NS	*
			MAP vs MAP + S (trmts 5 vs 6)	*	NS	ND	NS	NS

[1]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively

ND = not determined

Table 3. Effects of specialty P fertilizers on petiole nutrient concentrations at tuber set (June 18).

Treatment #	Source	Description	P_2O_5 Rate (lb/A)	NO_3-N ppm	P %	K %	S %	Mg %	Zn ppm
1	Control	46-0-0 + 0-0-50	0	26766	0.19	10.4	0.23	0.30	58
2	MAP + S	11-52-0 + 0-0-50	60	24080	0.37	11.0	0.26	0.31	43
3	MES10	12-40-0-10S	60	22782	0.36	11.1	0.25	0.30	44
4	MESZ	12-40-0-10S-1Zn	60	23173	0.37	11.2	0.25	0.31	48
5	MAP	11-52-0 +0-0-60	120	22982	0.38	10.9	0.25	0.31	42
6	MAP + S	11-52-0 + 0-0-50	120	22340	0.39	11.3	0.26	0.32	47
7	MES10	12-40-0-10S	120	23468	0.38	10.6	0.25	0.29	47
8	MESZ	12-40-0-10S-1Zn	120	23826	0.35	11.4	0.24	0.29	53
9	ACT142	10-49-0-2S-1Zn	120	22198	0.40	10.1	0.25	0.30	45
10	ACT143	10-46-0-3S-1Zn-2Mg	120	23885	0.41	10.5	0.25	0.31	47
11	ACT144	11-48-0-3S-1Zn (0 Mg)	120	23707	0.40	10.2	0.24	0.27	41
12	ACT145	10-44-0-3S-1Zn	120	23209	0.40	11.4	0.25	0.31	53
			Significance[2]	NS	**	NS	NS	NS	++
			LSD (0.1)	--	0.04	--	--	--	12
			Contrasts						
			P vs No P (trmts 1 vs rest)	**	**	++	**	NS	**
			linear P MAP + S (trmts 1,2,6)	**	**	*	**	NS	*
			linear P MES10 (trmts 1,3,6)	*	**	NS	++	NS	*
			linear MESZ (trmts 1,4,8)	*	**	*	NS	NS	NS
			Mg vs No Mg (trmts 10 vs 11)	NS	NS	NS	NS	*	NS
			MES10 vs MESZ (trmts 3,7 vs 4,8)	NS	NS	NS	NS	NS	NS
			MAP vs MAP + S (trmts 5 vs 6)	NS	NS	NS	NS	NS	NS

[2]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively

Table 4. Effects of specialty P fertilizers on petiole nutrient concentrations at early tuber bulking (June 30).

Treatment #	Source	Description	P_2O_5 Rate (lb/A)	NO_3-N ppm	P %	K %	S %	Mg %	Zn ppm
1	Control	46-0-0 + 0-0-50	0	24346	0.24	9.18	0.24	0.40	51
2	MAP + S	11-52-0 + 0-0-50	60	18200	0.28	7.33	0.22	0.46	36
3	MES10	12-40-0-10S	60	20391	0.23	8.13	0.21	0.48	34
4	MESZ	12-40-0-10S-1Zn	60	19984	0.24	7.83	0.21	0.52	36
5	MAP	11-52-0 +0-0-60	120	18127	0.29	7.53	0.20	0.46	33
6	MAP + S	11-52-0 + 0-0-50	120	21066	0.25	7.55	0.21	0.55	30
7	MES10	12-40-0-10S	120	19571	0.24	7.75	0.21	0.50	33
8	MESZ	12-40-0-10S-1Zn	120	19642	0.23	8.43	0.19	0.44	37
9	ACT142	10-49-0-2S-1Zn	120	19684	0.26	7.85	0.22	0.52	33
10	ACT143	10-46-0-3S-1Zn-2Mg	120	19633	0.29	7.85	0.21	0.50	33
11	ACT144	11-48-0-3S-1Zn (0 Mg)	120	20098	0.27	7.50	0.21	0.46	33
12	ACT145	10-44-0-3S-1Zn	120	18926	0.25	8.23	0.21	0.53	34
			Significance[2]	NS	NS	**	*	NS	**
			LSD (0.1)	--	--	0.66	0.02	--	7
			Contrasts						
			P vs No P (trmts 1 vs rest)	**	NS	**	**	*	**
			linear P MAP + S (trmts 1,2,6)	NS	NS	**	**	*	**
			linear P MES10 (trmts 1,3,6)	*	NS	**	**	++	**
			linear MESZ (trmts 1,4,8)	*	NS	*	**	NS	**
			Mg vs No Mg (trmts 10 vs 11)	NS	NS	NS	NS	NS	NS
			MES10 vs MESZ (trmts 3,7 vs 4,8)	NS	NS	NS	NS	NS	NS
			MAP vs MAP + S (trmts 5 vs 6)	NS	NS	NS	NS	NS	NS

[2]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively

Table 5. Effects of specialty P fertilizers on petiole nutrient concentrations at mid tuber bulking (July 14).

Treatment #	Source	Description	P_2O_5 Rate (lb/A)	NO_3-N ppm	P %	K %	S %	Mg %	Zn ppm
1	Control	46-0-0 + 0-0-50	0	20118	0.22	8.05	0.24	0.68	40
2	MAP + S	11-52-0 + 0-0-50	60	19116	0.25	7.54	0.27	0.95	36
3	MES10	12-40-0-10S	60	18869	0.23	7.00	0.24	0.98	38
4	MESZ	12-40-0-10S-1Zn	60	15093	0.23	7.02	0.25	0.95	37
5	MAP	11-52-0 +0-0-60	120	18541	0.27	7.56	0.25	0.99	31
6	MAP + S	11-52-0 + 0-0-50	120	16448	0.27	6.89	0.25	0.99	65
7	MES10	12-40-0-10S	120	18450	0.26	6.79	0.25	0.95	35
8	MESZ	12-40-0-10S-1Zn	120	19796	0.29	8.41	0.25	0.83	36
9	ACT142	10-49-0-2S-1Zn	120	21529	0.26	7.59	0.25	0.96	30
10	ACT143	10-46-0-3S-1Zn-2Mg	120	19664	0.26	7.76	0.24	0.93	35
11	ACT144	11-48-0-3S-1Zn (0 Mg)	120	18374	0.22	6.48	0.25	1.01	38
12	ACT145	10-44-0-3S-1Zn	120	17674	0.27	7.92	0.24	0.95	43
			Significance[2]	++	NS	++	NS	++	NS
			LSD (0.1)	3593	--	1.39	--	0.2	--
			Contrasts						
			P vs No P (trmts 1 vs rest)	NS	NS	NS	NS	**	NS
			linear P MAP + S (trmts 1,2,6)	*	NS	++	NS	**	++
			linear P MES10 (trmts 1,3,6)	NS	NS	*	NS	**	NS
			linear MESZ (trmts 1,4,8)	NS	++	NS	NS	NS	NS
			Mg vs No Mg (trmts 10 vs 11)	NS	NS	*	NS	NS	NS
			MES10 vs MESZ (trmts 3,7 vs 4,8)	NS	NS	++	NS	NS	NS
			MAP vs MAP + S (trmts 5 vs 6)	NS	NS	NS	NS	NS	**

[2]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively

Table 6. Effects of specialty P fertilizers on petiole nutrient concentrations at late tuber bulking (August 5).

Treatment #	Source	Description	P_2O_5 Rate (lb/A)	NO_3-N ppm	P %	K %	S %	Mg %	Zn ppm
1	Control	46-0-0 + 0-0-50	0	3971	0.11	4.55	0.16	1.07	37
2	MAP + S	11-52-0 + 0-0-50	60	4138	0.16	5.56	0.16	1.15	37
3	MES10	12-40-0-10S	60	2563	0.14	4.56	0.19	1.25	36
4	MESZ	12-40-0-10S-1Zn	60	1845	0.13	4.92	0.16	1.19	55
5	MAP	11-52-0 +0-0-60	120	3594	0.17	5.42	0.18	1.27	36
6	MAP + S	11-52-0 + 0-0-50	120	3701	0.16	4.92	0.19	1.31	45
7	MES10	12-40-0-10S	120	2966	0.16	4.92	0.19	1.31	32
8	MESZ	12-40-0-10S-1Zn	120	4293	0.16	5.20	0.18	1.08	34
9	ACT142	10-49-0-2S-1Zn	120	2890	0.14	5.36	0.20	1.03	27
10	ACT143	10-46-0-3S-1Zn-2Mg	120	3457	0.14	4.55	0.17	1.15	34
11	ACT144	11-48-0-3S-1Zn (0 Mg)	120	2471	0.13	4.90	0.15	1.21	35
12	ACT145	10-44-0-3S-1Zn	120	2860	0.14	5.93	0.13	1.00	31
			Significance[2]	++	NS	NS	NS	NS	**
			LSD (0.1)	1952	--	--	--	--	10
			Contrasts						
			P vs No P (trmts 1 vs rest)	NS	*	NS	NS	NS	NS
			linear P MAP + S (trmts 1,2,6)	NS	*	NS	NS	*	NS
			linear P MES10 (trmts 1,3,6)	NS	*	NS	NS	*	NS
			linear MESZ (trmts 1,4,8)	NS	**	NS	NS	NS	NS
			Mg vs No Mg (trmts 10 vs 11)	NS	NS	NS	NS	NS	NS
			MES10 vs MESZ (trmts 3,7 vs 4,8)	NS	NS	NS	NS	++	**
			MAP vs MAP + S (trmts 5 vs 6)	NS	NS	NS	NS	NS	++

[2]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively

Table 7. Effects of specialty P fertilizers on tuber and vine nutrient concentrations.

Treatment #	Source	Description	P_2O_5 Rate	Elemental concentration									
				% P		% N		% S		% Mg		ppm Zn	
			lb/A	Tubers	Vines	Tubers	Vines	Tubers	Vines	Tubers	Vines	Tubers	Vines
1	Control	46-0-0 + 0-0-50	0	0.14	0.05	1.13	1.45	0.12	0.19	0.07	0.99	19	122
2	MAP + S	11-52-0 + 0-0-50	60	0.15	0.06	1.28	1.33	0.13	0.14	0.08	0.89	18	97
3	MES10	12-40-0-10S	60	0.15	0.06	1.18	1.30	0.12	0.13	0.07	0.79	19	94
4	MESZ	12-40-0-10S-1Zn	60	0.15	0.05	1.10	1.15	0.12	0.13	0.08	0.76	20	102
5	MAP	11-52-0 +0-0-60	120	0.16	0.05	1.23	1.28	0.13	0.12	0.08	0.81	19	93
6	MAP + S	11-52-0 + 0-0-50	120	0.16	0.07	1.13	1.33	0.12	0.15	0.07	0.92	20	91
7	MES10	12-40-0-10S	120	0.16	0.05	1.25	1.28	0.13	0.16	0.07	0.94	19	91
8	MESZ	12-40-0-10S-1Zn	120	0.16	0.06	1.28	1.35	0.12	0.14	0.07	0.83	19	106
9	ACT142	10-49-0-2S-1Zn	120	0.16	0.05	1.23	1.25	0.12	0.13	0.07	0.87	18	100
10	ACT143	10-46-0-3S-1Zn-2Mg	120	0.17	0.05	1.20	1.20	0.13	0.14	0.08	0.93	19	105
11	ACT144	11-48-0-3S-1Zn (0 Mg)	120	0.17	0.05	1.35	1.25	0.13	0.13	0.07	0.84	19	93
12	ACT145	10-44-0-3S-1Zn	120	0.16	0.06	1.20	1.28	0.12	0.12	0.07	0.76	18	91
			Significance[2]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
			LSD (0.1)	-	-	-	-	-	-	-	-	-	-
			Contrasts										
			P vs No P (trmts 1 vs rest)	**	NS	NS	NS	NS	**	NS	*	NS	**
			linear P MAP + S (trmts 1,2,6)	*	NS	NS	NS	NS	NS	NS	NS	NS	**
			linear P MES10 (trmts 1,3,6)	*	NS	NS	NS	NS	NS	NS	NS	NS	**
			linear MESZ (trmts 1,4,8)	++	NS	++	NS	NS	*	NS	++	NS	NS
			Mg vs No Mg (trmts 10 vs 11)	NS	NS	++	NS	NS	NS	*	NS	NS	NS
			MES10 vs MESZ (trmts 3,7 vs 4,8)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
			MAP vs MAP + S (trmts 5 vs 6)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[2]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively

Table 8. Effects of specialty P fertilizers on tuber and vine dry matter accumulation and nutrient uptake.

Treatment #	Source	Description	P_2O_5 Rate lb/A	Dry Matter, lbs/A			P uptake, lbs/A		
				Tubers	Vines	Total	Tubers	Vines	Total
1	Control	46-0-0 + 0-0-50	0	12399	1806	14205	17.1	1.0	18.0
2	MAP + S	11-52-0 + 0-0-50	60	13976	1489	15465	20.5	0.8	21.4
3	MES10	12-40-0-10S	60	14010	2015	16025	20.4	1.2	21.6
4	MESZ	12-40-0-10S-1Zn	60	14882	1727	16608	22.3	0.8	23.1
5	MAP	11-52-0 +0-0-60	120	14358	2270	16629	23.3	1.2	24.5
6	MAP + S	11-52-0 + 0-0-50	120	15317	2506	17823	23.9	1.7	25.6
7	MES10	12-40-0-10S	120	13861	2068	15929	21.8	1.0	22.8
8	MESZ	12-40-0-10S-1Zn	120	14013	2442	16454	21.6	1.5	23.1
9	ACT142	10-49-0-2S-1Zn	120	14421	2076	16496	23.1	1.1	24.2
10	ACT143	10-46-0-3S-1Zn-2Mg	120	14775	1884	16659	24.3	1.0	25.3
11	ACT144	11-48-0-3S-1Zn (0 Mg)	120	14272	2029	16301	23.4	1.0	24.4
12	ACT145	10-44-0-3S-1Zn	120	13909	2248	16157	22.5	1.3	23.8
			Significance[2]	NS	NS	NS	NS	NS	NS
			LSD (0.1)	-	-	-	-	-	-
			Contrasts						
			P vs No P (trmts 1 vs rest)	**	NS	**	**	NS	**
			linear P MAP + S (trmts 1,2,6)	**	*	**	**	*	**
			linear P MES10 (trmts 1,3,6)	++	NS	++	**	NS	**
			linear MESZ (trmts 1,4,8)	++	*	*	**	++	**
			Mg vs No Mg (trmts 10 vs 11)	NS	NS	NS	NS	NS	NS
			MES10 vs MESZ (trmts 3,7 vs 4,8)	NS	NS	NS	NS	NS	NS
			MAP vs MAP + S (trmts 5 vs 6)	NS	NS	NS	NS	NS	NS

[2]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively