RESEARCH

Effect of Phosphorus Placement Methods and Rates on Sugarbeet Production under Strip Tillage in Southern Idaho

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Abstract

The use of strip tillage in the sugarbeet production systems of the Pacific Northwest is increasing, and data is needed about options for P placement and application rates for those options. The effects of P application methods (surface and subsurface band) and application rates (0–205 lb/acre P_2O_5) were evaluated in 2009 and 2010 on sugarbeet grown under strip tillage at the USDA-ARS Northwest Irrigation and Soils Research Laboratory, in Kimberly, ID. The soil at the study sites was a Portneuf silt loam (coarse-silty mixed superactive, mesic Durixerollic Xeric Haplocalcids) that had low bicarbonate-extractable P concentrations of 3.7 ppm in 2009 and 6.0 ppm in 2010. In general, yields did not differ between the application methods for P fertilizer application; however, yields increased as the P rate increased and were not maximum even at the highest application rate in this study (>205 lb/acre P_2O_5). Across all treatments and years, the harvested roots removed an average equivalent of 14.3% of the applied fertilizer P, and the entire plant extracted an average equivalent of 22.8% of the applied fertilizer P. Regardless of the application methods used in this study, the results do not provide evidence that the current P fertilizer recommendations from the University of Idaho and the Amalgamated Sugar Company (TASCO) should be changed for strip tillage.

The use of strip tillage in sugarbeet production is growing in the Pacific Northwest because of its potential to reduce tillage costs and conserve soil and soil water through residue management. Strip tillage in the Idaho sugarbeet production area has increased from about 500 acres in 2008 to over 11,000 acres in 2014 (Cane, 2014). Strip tillage creates a residue-free tilled zone that is approximately 6–15 inches wide and 6–8 inches deep. The remaining area between the 22-inch sugarbeet row spacing receives no tillage, and the residue from the previous crop remains on the soil surface. Research in Idaho has demonstrated that sugarbeet root and sucrose yields are comparable between strip tillage and conventional tillage practices under uniform nutrient management (Tarkalson et al., 2012).

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Abbreviations: APP, ammonium polyphosphate; ERS, estimated recoverable sugar; ICP-OES, inductively coupled plasma optical emission spectroscopy; TASCO, the Amalgamated Sugar Company; TDM, top dry mass; TSP, triple super phosphate; UAN, urea ammonium nitrate.

Conversions: For unit conversions relevant to this article, see Table A.

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
0.405	acre	hectare, ha
0.454	pound, lb	kilogram, kg
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha
1.12×10^{-1}	pound per acre, lb/acre	megagram per hectare, Mg/ha
2.54	inch	centimeter, cm (10–2 m)

Because the use of strip tillage is relatively new in sugarbeet production, there is a need to evaluate different fertilizer management practices within the strip tillage system. Historically, under conventional tillage, P fertilizers have been broadcast evenly over the soil surface then uniformly incorporated into the 6- to 15-inch-wide soil surface during tillage. Under strip tillage, applying fertilizers in bands below the plant is possible. As part of this system, before planting a shank is often pulled through the center of each planting row at varying depths (6–8 inches is common), depending on the equipment configuration. A liquid-fertilizer injection tube is often mounted on the back of each shank to allow for band application of the fertilizer below the location where the seeds will be planted. Placement of P fertilizers in a band directly below sugarbeet plants is considered an ideal location since sugarbeet have a taproot system, which can readily access the bands (Anderson and Peterson, 1978).

Providing sufficient amounts of P to sugarbeet is critical to optimizing yield (Westfall et al., 1979). Because soils often do not contain sufficient amounts of native P to meet sugarbeet demands, fertilizers must be used to supplement P requirements. In the Pacific Northwest sugarbeet production area, there has been very little work to evaluate the production effects of banding P fertilizers in strip tillage systems.

The objectives of this research were to: (i) evaluate the effects of two fertilizer P placement methods under strip tillage on sugarbeet yield, P uptake, and P removal; (i) compare multiple P application rates for each placement method on sugarbeet yield, P uptake, and P removal; and (iii) compare the results to published recommendations.

Assessing the Effects of P Fertilizer Placement Methods and Rates

This study was conducted on two adjacent fields in 2009 and 2010 at the USDA-ARS Northwest Irrigation and Soils Research Laboratory, in Kimberly, ID, on a Portneuf silt loam (coarse-silty mixed superactive, mesic Durixerollic Xeric Haplocalcids). Treatments included P fertilizer rates and P fertilizer placement methods under a strip tillage system. A Strip Cat tillage implement (Twin Diamond Industries, Minden, NE) was used for tillage. In 2009, eight P rates were applied: 0, 50, 75, 92, 117, 135, 175, and 205 lb/acre P_2O_5, and in 2010, five P rates were applied: 0, 50, 97, 143, and 190 lb/acre P_2O_5. Fewer P rate treatments were used in 2010 because the available study area was smaller. In both years, there were two P fertilizer placement methods: subsurface banding and surface banding. Application was in the spring, a few days before sugarbeet planting. The subsurface bands were located six inches below the seed, and the surface bands were on the soil surface between rows. Liquid ammonium polyphosphate (APP; 10% N, 34% P_2O_5) was the P fertilizer used for the subsurface band treatment, because it is a common P fertilizer used in the area. Because of the different rates of N applied in the APP with the various P rates, supplemental liquid urea ammonium nitrate (UAN; 32% N) was applied variably to balance out the N between all treatments. The fertilizer application details for 2009 and 2010 are presented in Tables 1 and 2. During both years, the amount of N banded either in the subsurface or on the soil surface was matched for all plots to eliminate N as a factor contributing to variation in treatment response. The only N application difference between 2009 and 2010 was that in 2009 all N was subsurface banded, whereas in 2010, a portion of the N was surface banded. The surface-band P source in 2009 was triple super phosphate (TSP; 45% P_20_5) and in 2010, it was APP. In 2010, after the subsurface APP treatments were applied, the pump on the liquid applicator broke, resulting in the use of TSP as the surface-band P source. In terms of P availability and reactions in the soil, TSP and AAP react similarly (Tisdale et al., 1993); therefore, there should be no difference in the plant response to P based on fertilizer type. The different ways in how the N is applied should not result in variations in plant growth and yield since adequate N was provided in the root zone of all treatments for optimum plant growth and because NO_3 N is very mobile, dispersing throughout the root zone. The treatments were arranged in a randomized block design. Treatment combinations were replicated four times in 2009 and three times in 2010. In 2009, plots were 7.3 ft wide (four 22-inch rows) and 34 ft long. In 2009, plots were 7.3 ft wide (four 22-inch rows) and 50 ft long.

Approximately 1 week before planting, both the APP and UAN fertilizers were applied through tubes mounted at the base of each Strip Cat row shank and with two Capstan Ag SharpShooter injection systems (Capstan Ag Systems, Topeka, KS): one system for the APP and

Table 1. Phosphorus and N application rates for P-rate and P-placement treatments, 2009.

P application method	P rate	APP† injection		TSP‡ surface	UAN§ injection	Total injection
	P_2O_5	P_2O_5	N	P_2O_5	N	N
	lb/acre					
Control	0	0	0	0	150	150
Subsurface	50	50	14	0	136	150
	75	75	22	0	143	150
	92	92	27	0	123	150
	117	117	35	0	115	150
	135	135	39	0	111	150
	175	175	52	0	98	150
	205	205	61	0	89	150
Surface	50	0	0	50	150	150
	75	0	0	75	150	150
	92	0	0	92	150	150
	117	0	0	117	150	150
	135	0	0	135	150	150
	175	0	0	175	150	150
	205	0	0	205	150	150

† Ammonium polyphosphate (liquid, 10% N and 34% P_2O_5).

‡ Triple super phosphate (solid, 0% N and 48% P_2O_5).

§ Urea ammonium nitrate (liquid, 32% N and 0% P_2O_5).

Table 2. Phosphorus and N application rates for P-rate and P-placement treatments, 2010.

P application method	P rate	Injection				Surface				Total injected and surface
		APP†		UAN‡	Total	APP		UAN	Total	
	P_2O_5	P_2O_5	N	N	N	P_2O_5	N	N	N	N
	lb/acre									
Control	0	0	0	56	56	0	0	83	83	139
Subsurface	50	50	14	42	56	0	0	83	83	139
	97	97	29	28	56	0	0	83	83	139
	143	143	42	14	56	0	0	83	83	139
	190	190	56	0	56	0	0	83	83	139
Surface	50	0	0	56	56	50	14	69	83	139
	97	0	0	56	56	97	29	54	83	139
	143	0	0	56	56	143	42	41	83	139
	190	0	0	56	56	190	56	27	83	139

† Ammonium polyphosphate (liquid, 10% N and 34% P_2O_5).

‡ Urea ammonium nitrate (liquid, 32% N and 0% P_2O_5).

one system for the UAN. The Capstan Ag SharpShooter injection systems adjusted the liquid fertilizer application rates by varying the on and off cycles of the pressurized system (pulse durations). Each unit had 10 pulse-duration options, including off and full open. Desired application rates were obtained via calibrated settings for the variable pulse-duration settings, a system pressure of 40 lb/sq inch, and a constant tractor speed of 2.5 mi/h. The TSP was surface applied by hand in 2009. Application rates of P and N are listed in Tables 1 and 2. In 2010, a urease inhibitor (Agrotain, Saint Louis, MO) was applied at a rate of 3.4 qt/ton of UAN before application to prevent significant NH_3 losses from the UAN due to microbial urease activity on the soil surface. In 2009, a urease inhibitor was not used because the UAN was injected into the soil.

Before tillage and fertilizer application in the spring, four soil cores (1-inch diameter) were collected in each replication at depths of 0–12 and 12–24 inches. The soil cores were all composited for each replication and depth. The 0–12-inch soil samples were tested for sodium bicarbonate extractable P concentrations (Olson et al., 1954). The 0- to 12-cm and 12- to 24-inch soils samples were extracted with 2M KCl (Mulvaney, 1996) then analyzed for NO_3 N and NH_4^+ N with a flow injection analyzer (Lachat Instruments, Loveland, CO). These data were used to determine the sugarbeet N recommendation. The total N applied each year (Tables 1 and 2) supplied adequate N to meet sugarbeet requirements (TASCO, 2015).

Sugarbeet were planted on 18 June 2009 and 30 Apr. 2010 at a rate of 51,800 seeds/acre. In 2009, sugarbeet were originally planted on 11 May, but because of poor seedling emergence, the study was replanted on 18 June. BTS 27RR10 was the seed variety planted in both years. After planting, 2.8–3.5 inches of water was applied two to three times weekly to promote emergence and good stands. Following emergence, the sites were irrigated uniformly to meet estimated crop evapotranspiration rates. These rates were estimated with the Kimberly-Penman ET model (Wright, 1982) using data from an Agrimet weather station (US Bureau of Reclamation, Boise, ID). To control weeds in the plots, glyphosate was applied as needed in accordance with label guidelines.

Whole plant tops were harvested from 5-ft sections of two rows in each plot on 19 Oct. 2009 and 5 Oct. 2010. The samples were dried at 149°F, weighed to determine top dry-matter mass (TDM), ground to pass through a 0.00787-inch (0.2 mm) sieve, and analyzed for total P using inductively coupled plasma optical emission spectroscopy (ICP-OES) following dry ashing of a 0.00110231-lb (0.5 g) sample at 932°F for 6 h and digestion on a hot plate with 0.33814 oz (10 ml) 1N HNO_3.

Before root harvest, sugarbeet tops were removed from the harvest area (2 rows × 30 ft in 2009 and 2 rows × 30 ft in 2010). Roots were harvested on 23 Oct. 2009 and 12 Oct. 2010. Total root yield was determined from each plot with a load-cell-equipped research harvester. From each plot, three 8-root samples were obtained and bagged (approximately 26 lb/bag). Two of the samples from each plot were sent to the TASCO tare lab for analysis of the percentage of sugar and quality parameters. The percentage of sugar was determined with an Autopol 880 polarimeter (Rudolph Research Analytical, Hackettstown, NJ), a half-normal weight sample dilution, and $Al_2(SO_4)_3$ clarification method [ICUMSA method GS6-3 1994] (Bartens, 2005). Conductivity was measured with a Foxboro conductivity meter model 871EC (Foxboro, Foxboro, MA) and brei nitrate was measured with a Denver Instruments model 250 multimeter (Denver Instruments, Denver, CO) with Orion probes 900200 and 9300 BNWP (Krackler Scientific, Albany, NY). Estimated recoverable sugar (ERS) yield was calculated based on the measured parameters in combination with the measured root yield:

ERS (lb/acre) = [extraction × 0.01 × gross sucrose (lb/acre) / root yield (ton/acre)] × root yield (ton/acre)

where

extraction = 250 + {[(1255.2)(conductivity) – (15000)(percentage sucrose – 6185)] / [(percentage sucrose)(98.66 – [(7.845) (conductivity)])]},

and

gross sucrose = root yield (ton/acre) × percentage sucrose (lb/ton) × 0.01 × 2000.

The third root sample was ground, dried at 199°F, and analyzed for total P with ICP-OES following dry ashing of a 0.00110231-lb sample at 932°F for 6 h and digestion on a hot plate with 0.33814 oz 1N HNO_3. The amount of P removed in the harvested root relative to the amount of P applied as fertilizer (P removal efficiency, PRE) and the amount of P taken up by the entire plant relative to the amount of P applied as fertilizer (P use efficiency, PUE) were calculated as follows:

PRE (%) = [(root P mass_{+P} – root P mass_{-P}) / P rate] × 100

where root P mass_{+P} is the root P mass (lb/acre P) from a given P application rate, root P mass_{-P} is the root P mass (lb/acre P) from the 0 lb/acre P rate, and P rate is the lb/acre of P applied.

PUE (%) = [(plant P mass_{+P} – plant P mass_{-P}) / P rate] × 100

where plant P mass_{+P} is the entire root P mass from a given P application rate; plant P mass_{-P} is the entire plant P mass from the 0 lb/acre P rate; and P rate is pounds of P applied per acre.

Statistical analysis was conducted separately for each year due to differences in N supply and management practices. Analysis of variance was conducted for P application rate (P rate) and placement (P application method) as main effects and the interaction for selected production factors (root yield, ERS yield, root sucrose concentration, TDM yield, top P mass, root P mass, plant P mass, PRE, and PUE) using a factorial design model in Statistix 8.2 (Analytical Software, Tallahassee, FL). For each factor, polynomial contrasts were conducted for N-rate main effects to determine the significance of linear and quadratic relationships with P application rate. For a given factor, if both the linear and quadratic models were significant, data from models were presented and discussed.

Initial Soil Analyses

Before P applications, soil in the plots contained a bicarbonate-extractable P concentration of 3.7 ppm in 2008 and 6.0 ppm in 2009. These concentrations are considered low for sugarbeet production in Idaho. The University of Idaho and TASCO recommend P fertilizer applications on soils with a bicarbonate-extractable P concentration of up to 20 ppm (Moore et al., 2009; TASCO, 2015). Based on the bicarbonate-extractable P concentrations at the sites, yield responses were expected.

Plant Population

During both years of the study, the P application methods and P application rates did not affect the plant populations. The average plant populations in the study were 36,600 plants/acre in 2009 and 35,900 plants/acre in 2010. The populations were at the upper end of the acceptable plant population range for optimum production (19,000–35,700 plants/acre; TASCO, 2015). Although the populations were slightly higher than the optimum, there was no evidence that the populations had a great effect on reducing the yield in this study. For example, in 2010 the TASCO growing area had an average root yield of 32.5 ton/acre and the highest annual average root yield in this study was 33.4 ton/acre. In 2009, the root yield from our study was reduced compared with that of the growing-area average yield (19.8 versus 35.3 ton/acre), but this effect is thought to be the result of a shortened growing season during the study because the sugarbeet was replanted in the middle of June. Current ongoing research at the Northwest Soils and Irrigation Research Laboratory supports equivalent yields for sugarbeet at populations slightly above the recommended range compared with the growing-area average (unpublished data, 2015).

Root, Sucrose, and Top Biomass Yields

In 2009 and 2010, there were no statistically significant interactions between the P application method and P application rates; therefore, only the main treatment effects are presented and discussed (Tables 3 and 4). For both years of this study, as P application rate increased, root yield, ERS, and TDM increased. During both years, root yield and ERS had significant linear relationships with P application rate, indicating that the P application rates used in this study were not high enough to obtain maximum yields (Tables 3, 4, 5, and 6). In 2009, root yield increased 0.031 ton/(acre·lb P) (0.071 ton/[acre·lb P_2O_5]), and ERS increased 6.5 lb/(acre·lb P) (14.9 lb/[acre·lb P_2O_5]) (Table 5). In 2010, root yield increased 0.076 ton/(acre·lb P) (0.174 ton/[acre·lb P_2O_5]), and ERS increased 28.2 lb/ (acre·lb P) (64.6 lb/[acre·lb P_2O_5]) (Table 5). Other studies have shown that sugarbeet root yield responds to added P, especially when soil-test P concentrations are low (Etchevers and Moraghan, 1983; Sims and Smith, 2001). In 2009 and 2010, TDM had both significant linear and quadratic relationships with the P application rate. The significant quadratic relationships indicates that there is some evidence that maximum TDM was obtained within the range of P application rates used in this study (Table 3). On the basis of the quadratic regression model, TDM yields were maximized in 2009 and 2010 at 65 and 53 lb/acre P (149 and 121 lb/acre P_2O_5) (Table 6).

In general, the application method did not result in differences in yield factors. The only significant effect for application method was in 2009, when subsurface application resulted in a 6% increase in ERS yield compared with surface application. The failure of the application method to have overall effects on yield was surprising because the bicarbonate-extractable soil-test P was low (3.7 ppm in 2009 and 6.0 ppm in 2010) and the surface-applied P was not incorporated into the soil due to the strip tillage system. In addition, past research has shown that subsurface band application of P can increase sugarbeet yield compared with other banding applications. Davis et al. (1962) showed that banding P 3 inches directly below the plant increased sugarbeet root yield by 25% compared with banding P 3 inches below and 1.5 inches to the side of the plant, a result that stresses the importance of placing the P in a location that the sugarbeet taproot can intersect as it grows. Other research has shown that banding P below the plant resulted in yields equivalent to those with broadcast and incorporated P at the same application rates (Romsdal and Schmehl, 1963). Often the deciding factor that relates yield response to different P placement methods is the initial soil-P content available to the plant. Westfall et al. (1979) reported that on average in Montana and Wyoming, when bicarbonate-extractable soil P reached 23 ppm, sugarbeet did not respond to additional P. Both the University of Idaho and TASCO sugarbeet fertilizer recommendations do not recommend P fertilizers at a bicarbonate-extractable soil-P concentration greater than 25 ppm (Moore et al., 2009; TASCO, 2015).

Sucrose concentration was affected by P rate in 2010 but not in 2009. In 2010 there were no differences between application methods for all measured factors (Table 4). Other studies have found no effect of the P application rate on sugarbeet sucrose concentrations (Davis et al., 1962; Etchevers and Moraghan, 1983). More research is needed on modern varieties to determine if sucrose concentration is affected by P supply.

Phosphorus Uptake and Removal Efficiency

In 2009 and 2010, because there were no statistical interactions between P application method and P application rates, only the main treatment effects are presented and discussed (Tables 3 and 4). For both years of the study, top P mass, root P mass, and plant P mass increased as the P application rate increased (Tables 3 and 4). During both years, top P mass, root P mass, and plant P mass had significant linear relationships with the P application rate (Table 5). In 2009, top P mass increased 0.073 lb/(acre·lb P) (0.167 lb/[acre·lb P_2O_5]); root P mass, 0.106 lb/(acre·lb P) (0.242 lb/[acre·lb P_2O_5]); and plant P mass 0.178 lb/(acre·lb P) (0.408 lb/[acre·lb P_2O_5]) (Table 5). In 2010, top P mass increased 0.045 lb/(acre·lb P) (0.103 lb/[acre·lb P_2O_5]); root P mass, 0.124 lb/(acre·lb P) (0.284 lb/[acre·lb P_2O_5]); and plant P mass, 0.168 lb/(acre·lb P) (0.385 lb/[acre·lb P_2O_5]) (Table 6). The significant linear relationships indicate that the

Table 3. Production factors and probability values ($P > F$) from analysis of variance for measured factors, 2009.†

P application method		Root yield	ERS‡	Root sucrose conc.	TDM§	Top P mass	Root P mass	Plant P mass	PRE¶	PUE#
		ton/acre	lb/acre	%	——— lb/acre ———				—— % ——	
Subsurface		20.2	4572.3	14.4	4588.5	9.4	10.1	19.7	16.0	27.1
Surface		19.3	4312.7	14.3	4436.7	8.7	9.4	17.7	13.6	22.3
P rate (lb/acre P_2O_5)										
0		17.1	4002.4	14.8	3500.0	4.8	3.9	8.2	—††	—
50		20.0	4481.9	14.2	4312.5	7.3	7.2	14.5	17.1	27.7
75		19.8	4380.9	14.2	4778.2	9.0	9.0	18.1	17.6	30.7
92		20.1	4475.8	14.3	4788.4	9.5	9.5	19.0	15.6	27.6
117		20.1	4498.7	14.2	4468.6	9.2	10.0	19.2	13.4	22.2
135		19.4	4223.1	14.0	4599.7	10.2	11.2	21.4	13.8	23.3
175		20.9	4804.0	14.5	4691.3	10.9	13.6	24.5	14.2	22.5
205		20.7	4673.7	14.4	4733.2	10.8	13.4	24.3	11.9	19.0
Source	df									
Application method (AP)	1	0.068	0.027	0.514	0.259	0.057	0.067	0.020	0.027	0.006
P rate (P)	7	0.011	0.036	0.264	0.024	<0.001	<0.001	<0.001	0.056	0.012
AP × P	7	0.694	0.807	0.238	0.163	0.078	0.734	0.260	0.693	0.272
P linear	1	0.001	<0.001		0.020	<0.001	<0.001	<0.001		<0.001
P quadratic	1	0.185	0.130		0.012	0.016	0.496	0.135		0.788

† Bold probability values are significant at the 0.05 level. Elemental P masses were used in calculations.

‡ ERS, estimated recoverable sucrose yield.

§ TDM, top dry matter.

¶ PRE (P removal efficiency) = [(root P mass from given P rate – root P mass from 0 P rate)/P rate] × 100.

PUE (P use efficiency) = [(total plant P mass from given P rate – total plant P mass from 0 P rate)/P rate] × 100.

†† The 0 P rate was used in calculations, thus not reported.

Table 4. Production factors and probability values ($P > F$) from analysis of variance for measured factors, 2010.†

P application method		Root yield	ERS‡	Root sucrose conc.	TDM§	Top P mass	Plant root P mass	Total plant P mass	PRE¶	PUE#
		ton/acre	lb/acre	%	lb/acre				%	
Subsurface		33.4	8736.2	15.7	4411.4	7.1	15.0	22.1	15.1	21.6
Surface		33.4	8714.2	15.6	4853.3	7.6	14.0	21.6	12.6	20.1
P rate (lb/acre P_2O_5)										
0		28.8	7114.4	15.0	3801.2	4.8	8.9	13.7	—††	—
50		33.4	8678.1	15.6	4575.8	6.8	12.4	19.1	15.8	24.9
97		34.2	8877.2	15.6	5042.2	8.3	14.6	22.9	13.5	21.7
143		34.6	9247.2	16.0	5113.6	8.7	17.5	26.2	13.8	20.0
190		36.1	9709.0	16.1	4629.0	8.4	19.1	27.5	12.3	16.6
Source	df									
Application method (AP)	1	0.978	0.942	0.780	0.089	0.300	0.322	0.725	0.389	0.689
P rate (P)	4	0.010	0.001	0.001	0.025	<0.001	<0.001	<0.001	0.838	0.452
AP × P	4	0.966	0.862	0.555	0.065	0.234	0.897	0.749	0.899	0.689
P linear	1	0.001	<0.001	<0.001	0.020	<0.001	<0.001	<0.001		
P quadratic	1	0.185	0.130	0.226	0.012	0.016	0.496	0.135		

† Bold probability values are significant at the 0.05 level. Elemental P masses were used in calculations.

‡ ERS, estimated recoverable sucrose yield.

§ TDM, top dry matter.

¶ PRE (P removal efficiency) = [(root P mass from given P rate – root P mass from 0 P rate)/P rate] × 100.

PUE (P use efficiency) = [(total plant P mass from given P rate – total plant P mass from 0 P rate)/P rate] × 100.

†† The 0 P rate was used in calculations, thus not reported.

Table 5. Coefficients for linear functions applied to statistically significant polynomial contrasts of production factors versus P application rates in 2009 and 2010.†

Year		y_0	a	SE	r^2
2009	Root yield	18.3	0.031	1.5	0.25
	ERS	4155.2	6.509	360.5	0.21
	TDM	4072.1	8.944	502.4	0.19
	Top P mass	5.4	0.073	1.6	0.61
	Root P mass	4.7	0.106	1.4	0.81
	Plant P mass	10.0	0.178	2.8	0.76
2010	Root yield	30.2	0.076	2.8	0.42
	ERS	7567.4	28.151	665.6	0.64
	Root sucrose conc.	15.1	0.0117	0.34	0.59
	TDM	4188.9	10.882	699.4	0.19
	Top P mass	5.5	0.045	1.4	0.50
	Root P mass	9.3	0.124	1.8	0.82
	Plant P mass	14.8	0.168	2.5	0.82

† Linear functions: $y = y_0 + ax$; y = measured production factor; y_0 = measured production factor at 0 lb applied P; a = slope (measured production factor increase/unit increase in P rate [lb/acre P]); x = P application rate (lb/acre P). Elemental P used in analysis. Coefficients for data in Tables 3 and 4.

Table 6. Coefficients for quadratic functions applied to sugarbeet top dry matter (TDM) and top P mass in 2009 and 2010.†

Year		y_0	a	b	SE	r^2
2009	TDM	3692.7	32.2	−0.247	472.3	0.31
	Top P mass	3.9	0.173	−0.001	1.39	0.73
2010	TDM	3784.2	50.0	−0.473	619.4	0.42
	Top P mass	4.8	0.12	−0.00089	1.27	0.62

† Quadratic functions: ($y = y_0 + ax + bx^2$); y = measured production factor; y_0 = measured production factor at 0 lb applied P; a = constant; x = P application rate (lb/acre P); b = constant. Elemental P used in analysis.

P application rates used in this study were not high enough to obtain maximum P uptake. In 2009 and 2010, top P mass had both significant linear and quadratic relationships with P application rate (Tables 3 and 4). The quadratic relationships indicate that there is some evidence that the maximum top P mass was obtained within the P application rate range used in this study (Table 3). Based on the quadratic regression models in 2009 and 2010, maximum top P masses of 11.4 lb/acre P (26.1 lb/acre P_2O_5) and 8.7 lb/acre P (19.9 lb/acre P_2O_5) were obtained at application rates of 86 and 67 lb/acre P (197 and 153 lb/acre P_2O_5), respectively (Table 6).

Similar to yield factors, application method, in general, did not result in differences in P uptake. The only significant effect for application method was in 2009, when subsurface application resulted in an 8.5% increase in plant P mass yield compared with surface application.

The effect of P application rate and method on PRE in roots and PUE differed between years. In 2009, PRE was not influenced by P application rate (Table 3), but subsurface P application resulted in a 17.6% increase in PRE compared with surface application. In 2010, P application rate and method did not influence PRE (Table 4). The average PRE across all treatments was 13.9%. The PRE in our study was similar to that found by Etchevers and Moraghan (1983), who reported and average sugarbeet PRE of 11.7% across varying P rates on a soil with a bicarbonate-extractable P concentration of 4.5 mg/kg.

In 2009, PUE increased as P application rate increased (Tables 3). In 2009, PUE had significant linear relationships with P application rate, with PUE decreasing by an average of 0.06% per pound P_2O_5 across P application rates of 50 to 205 lb /acre P_2O_5 (Tables 3). In 2009, subsurface P application resulted in a 21.5% increase in PUE compared with surface application. In 2010, P application rate and method did not influence PUE (Table 4). The average PUE across all treatments was 20.9%. The PUEs in our study were similar to those of Etchevers and Moraghan (1983), who reported an average sugarbeet PUE of 20.4%.

CONCLUSIONS

Increasing use of strip tillage in sugarbeet production in the Pacific Northwest has resulted in much-needed tillage-specific management practices for P fertilizers. In general, applying P fertilizer in a band below the plant or in a band on the soil surface between rows resulted in similar sugarbeet yields. However, the present study has demonstrated the need for high P fertilizer application rates (>205 lb/acre P_2O_5) to maximize yields, especially on soils with low P levels. Research does not provide evidence that the current University of Idaho and TASCO P fertilizer recommendations should be changed for strip tillage regardless of application method. Therefore, at this time we recommend that producers continue to follow the established fertilizer recommendation guidelines.

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