Early Growth Response of Sugarbeet to Fertilizer Phosphorus in Phosphorus Deficient Soils of the Red River Valley

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ABSTRACT

Field experiments were conducted over two years in a low phosphorus (P) testing Red River Valley sandy loam soil to determine the response of early season sugarbeet root and shoot growth to fertilizer P. Four rates of fertilizer P (0, 15, 30, and 45 kg P ha^{-1}) were broadcast and incorporated prior to planting. Initial plant and soil samples were taken when sugarbeet seedlings showed purple coloration on the petioles and leaf blade edges (first two true leaves) and continued every two wk for a total of five samplings. Compared to controls (0 kg P ha^{-1}), phosphorus fertilization significantly increased both shoot and root dry matter accumulation. The linear relationship between dry matter accumulation and rate of fertilizer P was significant, but generally 15 kg P ha^{-1} produced most of the total observed response. The general relationship of root dry matter accumulation to P rates was apparent within 30 days after planting and was maintained during the entire sampling period. Final root yields at the end of the growing season were significantly less in the controls compared to treatments where fertilizer P was applied. The data indicate that the reduction in root yields caused by P deficiency is initiated very early and is maintained throughout the growing season. Even though the above ground sugarbeet growth appears to return to near normal as the growing season progresses, root yield potential may have already been reduced.

Additional Key Words: Dry matter accumulation, shoot growth, root growth, early season growth

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Sugarbeet growers in Minnesota and North Dakota have recently observed stunted sugarbeet growth and reduced root yields in certain fields and portions of other fields. Generally, these areas are associated with sandier textured soils which are frequently encountered in many areas of the Red River Valley (RRV). Complaints about these areas have increased in recent years because of: 1) the expansion of sugarbeet production out of the valley proper into sandier textured soils in surrounding areas and 2) an increased awareness of within field variability due to the interest in precision agriculture. Symptoms reported by growers and observed by the authors consist of stunted growth with reddish to purple coloration in the petiole and leaves. These types of symptoms have been associated with phosphorus (P) deficiencies (Draycott, 1993). The P requirement of a sugarbeet crop has been well researched. Sugarbeet response to the application of fertilizer P depends on the availability of soil P, which is determined by soil test (Draycott, 1993). Phosphorus deficiency symptoms mainly occur in seedlings and are rarely observed in older, more mature sugarbeet plants (Draycott, 1993).

Research in the United Kingdom (UK) found little association between the dry matter accumulation in the shoots and the root yields at harvest time (Scott and Jaggard, 1993). This indicates that the appearance of the sugarbeet canopy can be deceptive in terms of evaluating root yield. Scott and Jaggard (1993) also reported that a reduction in sugarbeet root yields was attributable to slow root development in the early part of the growing season combined with a subsequent slower growth rate during the remainder of the growing season.

The tap root of the sugarbeet plant can penetrate deep into the soil profile if restrictions to growth are not present (Brown and Dunham, 1986). However, the majority of the fibrous root system develops in the top 30 cm of soil (Brown and Bisco, 1985). The majority of the required P reaches the root surface by diffusion (Barber, 1980). Coarse textured soils may drain faster than those that are fine textured thus reducing the soil moisture content and increasing diffusion tortuousity, thereby reducing P diffusion rate to the sugarbeet root surface (Barber, 1980). As the fibrous component of the sugarbeet root develops, more of the soil volume is explored exposing the root to more soil P for absorption and utilization by the plant. Draycott (1993) reported that P deficiencies often result in a reduction of taproot growth, but a proliferation of fibrous roots.

Many Minnesota and North Dakota growers have observed what appears to be P deficient sugarbeet plants on sandier textured soils in the early growing season followed by more normal growth for the remainder of the growing season. The later normal growth may be due to the increased fibrous root development thus exposing the plant to more soil P and diminishing the P deficiency. Nevertheless, the root yield potential may have already been reduced, even though shoot growth rate has returned to normal. The literature lacks data on the development of the sugarbeet root when P deficiencies are present early in the growing season, but seem to disappear as the season progresses. The objectives of this experiment were to measure the shoot and root development of the sugarbeet plant during the first 14 to 15 wks after planting in response to fertilizer P applications when grown on soils low in available P.

MATERIALS AND METHODS

Field experiments were conducted over two growing seasons, 1997 and 1998, at the University of Minnesota Northwest Research and Outreach Center near Crookston, Minnesota. The soil at the experimental sites was classified as Wheatville vfsl (coarse-silty over clayey, mixed over smectitic, superactive, frigid Aeric Calciaquoll). The experimental design was a four by two factoral randomized incomplete block with four replicates. Phosphorus treatments consisted of four P rates of 0, 15, 30, and 45 kg P ha^{-1} and two application times only where fertilizer P was applied. Fertilizer P was applied either in the fall prior to the growing season or in the spring prior to planting. Phosphorus in the form of triple superphosphate was broadcast applied and incorporated with a field cultivator immediately after application. Plots were 6.7 m wide and 10.7 m long. Experimental sites were changed each year.

Sugarbeet was planted 2 May, 1997 and 24 April, 1998 in 0.56 m wide rows with a six-row planter. Plots were 12 rows wide. All preplant spring tillage and planting were done so that tractor wheel tracks were confined between rows one and two and rows five and six with each pass of the tractor. Sugarbeet variety Beta 1492 was planted at 2,800,000 seeds ha^{-1} then hand thinned to 70,500 plants ha^{-1} about 4 wk after seedling emergence. Appropriate pesticides were applied throughout the growing season to control weed, insect, and disease pests.

Each plot was subdivided into six row subplots. Final harvest was taken from rows three and four of one subplot. In-season plant samples were taken from rows three through five in the other subplot. Plant samples were taken from 2 m of row starting 42 and 34 days after planting in 1997 and 1998, respectively. Subsequent samplings were taken every 14 d for a total of five in-season samplings. Each sample area was moved within the plot to assure adequate competition from all sides by other sugarbeet plants.

Plants were gently hand pulled from the soil so that the primary tap root was extracted and washed with tap water to remove soil and dust. Roots and shoots were separated just above the crown tissue. Roots were sliced and dried to determine dry weight. Due to the volume of root material, in the fifth sampling in 1997 and the fourth and fifth samplings in 1998, freshly washed roots were weighed and several randomly selected roots were sliced, weighed, and dried for dry weight measurements. Shoots from the first three and first two samplings in 1997 and 1998, respectively, were clipped into smaller pieces and dried. In subsequent samplings shoots were divided into petiole and leaf blade by separation at the point where the leaf blade met the petiole to assist in the drying process. Both shoot parts were blotted with paper towels to remove excess water left from the washing process then weighed. Each shoot part was clipped into small pieces and subsampled. Subsamples were weighed and dried. Drying temperature for all root and shoot samples was 60° C. Shoot dry matter was calculated as the sum of both the leaf and petiole components.

Soil samples were collected from the 0 to 15 cm and 15 to 30 cm depths from each plot when plant samples were collected. Twelve 2 cm diameter soil cores were composited for one sample. The cores were taken from rows two through five within a subplot about 10 cm to the side of the sugarbeet row. Soils were air dried, ground to pass a 1mm screen, and analyzed for P using the $NaHCO_3$ extraction procedure described by Olsen et al. (1954).

Final root yield was measured by machine harvesting the center two rows from a six-row subplot. Five representative roots were randomly selected from each row and combined for each plot. Measurements of tare, sucrose concentration, and loss to molasses were conducted by the American Crystal Sugar Laboratory in East Grand Forks, Minnesota.

Single degree of freedom orthogonal contrasts were used for statistical analysis (Steel and Torrie, 1980) in the Proc GLM component the Statistical Analysis System (SAS, 1996). Shoot and root dry matter values were transformed using $\log_{(10)}$ to accommodate visualization of changes and response to P rates over time. Transformed data analysis was conducted over time using sampling date as a split plot (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Statistical analysis (not shown) showed that early season root and shoot growth was not affected by time of fertilizer P application in either year. Final root yield was significantly affected by time of fertilizer P application only in 1997 when spring applied fertilizer P resulted in 2 Mg ha^{-1} greater root yields compared to fall applied fertilizer P. Allison et al. (1994) reported an inconsistent difference in sucrose concentration due to fall and early and late spring applications of fertilizer, but no difference in root yield. Since the interaction between P rates and time of fertilizer application was not significant in either year, our results and discussion from this point on will be based on the means of the fall and spring applied fertilizer at each rate of applied P.

Data from the second sampling roots and shoots were not available for analysis in 1997 due to a drying oven malfunction. Therefore, 1997 results consist of data from the first, third, fourth, and fifth sampling dates. All five early season samplings were analyzed for the 1998 growing season.

Visible symptoms, which included stunted growth, reddish to purple coloration of petioles and leaf blade edges, as well as cupped, upright leaves, were observed soon after the first two true leaves emerged in each year. These symptoms were most pronounced in the control (0 kg P ha^{-1} rate) treatments, but also appeared to a lesser degree in treatments where fertilizer P had been applied. Differentiation in the sugarbeet canopy growth was apparent throughout the early weeks of the growing season in both years. In 1997, the 0, 15, and 30 kg P ha^{-1} treatments could be visually distinguished. In 1998, the 0, 15, and 30 kg P ha^{-1} treatments could be visually distinguished very early in the growing season, but by the 62 day (second sampling) sampling only the control treatments could be visually distinguished. No distinction could be made between 30 and 45 kg P ha^{-1} treatments at any time during the growing season in 1997 or 1998.

Soil P

Soil test P (0 to 15 cm) was 5 mg P kg^{-1} in the fall prior to the two growing seasons in which the experiment was conducted. The addition of fertilizer P increased the soil test P levels during the early growing season sampling period (Table 1). Soil test P increased linearly with increasing P rates in both years (Table 1). Soil test P in the 15 to 30 cm soil depth ranged from 3 to 4 mg P kg^{-1} in both years and was not affected by either the rate of fertilizer P, time of application, or time of sampling.

Final Sugarbeet Root Harvest

The application of fertilizer P had no effect on root sucrose concentrations or loss to impurities in either year. Sucrose concentrations averaged 161 and 162 g kg^{-1} in 1997 and 1998, respectively. Loss to impurities averaged 13.6 and 18.8 g kg^{-1} in the same respective years. Agarwal and Srivastava (1976) reported that fertilizer P had no effect on sucrose concentration even though root yield was increased.

A highly significant quadratic response of sugarbeet root yields to fertilizer P rates occurred in both years (Table 2). Though the response to P rates was similar in both years, yields were significantly different between years (Table 2). Final sugarbeet root yields were about 30 Mg ha^{-1} greater in 1998 than in 1997 at all P rates (Fig 1). The yield difference between years

Table 1. Soil test P ($NaHCO_3$ extraction) of the surface 15 cm of soil in response to the application of fertilizer P.

	1997 Days after planting				1998 Days after planting				
P rate	42	70	84	98	34	48	62	76	90
— kg P ha^{-1} —	— mg P kg^{-1} —				— mg P kg^{-1} —				
0	4.9	5.0	7.0	5.2	4.4	3.7	5.1	4.6	4.9
15	7.1	6.8	7.8	6.4	6.1	6.4	8.1	8.9	7.6
30	8.9	8.5	8.8	7.3	8.0	11.5	9.2	10.4	8.4
45	13.5	9.5	9.6	10.3	11.8	10.8	14.3	17.5	15.0
Source of Variation	— PR > F† —				— PR > F† —				
P rate linear	***	***	***	***	***	***	***	***	***
P rate quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns

† *, **, ***, and ns represent significance at alpha level of 0.05, 0.01, 0.001, and non-significance, respectively.

Table 2. Sugarbeet root dry matter accumulation early in the growing season and final root yield at harvest in response to the application of fertilizer P (means of four replicates).

	1997 Days after planting					1998 Days after planting					
P rate	42	70	84	98	150†	34	48	62	76	90	157†
— kg P ha^{-1} —	—— kg DM ha^{-1} ——				— Mg ha^{-1} —	—— kg DM ha^{-1} ——					— Mg ha^{-1} —
0	3	37	393	1343	25.6	2	9	126	598	2132	57.3
15	9	129	638	2193	39.8	3	14	264	1114	4047	75.0
30	9	161	778	1964	42.8	3	15	306	1296	4473	73.1
45	10	171	1007	2522	44.9	4	20	354	1420	3885	74.5
Source of Variation	——— PR > F‡ ———					——— PR > F‡ ———					
P rate linear	*	***	**	**	***	*	**	*	***	*	***
P rate quadratic	ns	**	ns	ns	***	ns	ns	ns	ns	*	**
	Analysis of Final Root Harvest Over Both Years										
Year					***						
Year by P rate					ns						

† Root yield at day 150 in 1997 and day 157 in 1998 represents the final sugarbeet root yield and not dry matter.

‡ *, **, ***, and ns represent significance at alpha level of 0.05, 0.01, 0.001, and non-significance, respectively.

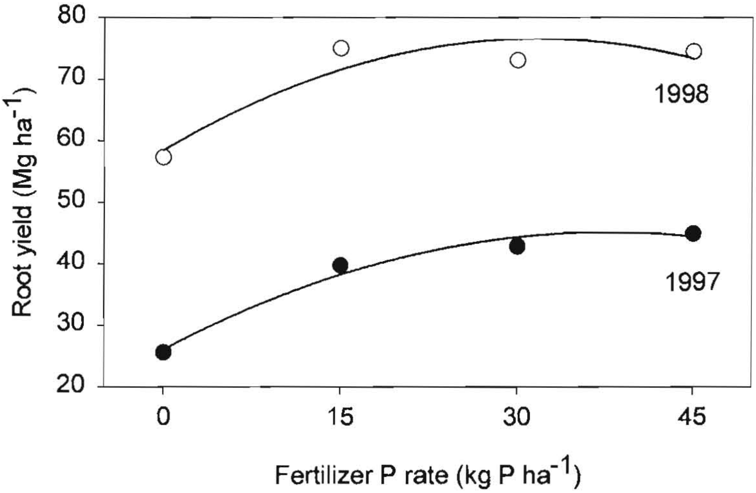

Figure 1. Final sugarbeet root yield response to the application of fertilizer P in 1997 and 1998.

1997: $y = 26.1 + 1.00x - 0.0133x^2$ $R^2 = 0.978$

1998: $y = 58.5 + 1.15x - 0.0181x^2$ $R^2 = 0.879$

is attributed to weather conditions during the growing season. Root yields for the two years were representative of what occurred in RRV commercial fields. Earlier planting in 1998 resulted in seven more growing days compared to 1997. Growing season precipitation was similar in both years, but temperatures averaged 1.1° C month^{-1} greater in 1998, and 1998 had 269 more growing degree days (T-Base = 10° C) compared to 1997.

The quadratic equations that best fit the root yield data means for each year are shown in Fig 1. Maximum root yield was obtained with 39 and 32 kg P ha^{-1} in 1997 and 1998, respectively. Based on the original soil test P value of 5 mg P kg^{-1} and a yield goal of 45 Mg ha^{-1}, the recommended rate of fertilizer P was 39 kg P ha^{-1} (Rehm et al., 1994). Most of the yield increase, however, occurred with the first increment of 15 kg P ha^{-1} (Table 2).

In-Season Sugarbeet Growth

Both sugarbeet root dry matter (Table 2) and shoot dry matter (Table 3) accumulation increased with the application of fertilizer P at all sampling dates in both years. The majority of the increase attributed to fertilizer P occurred with the first increment of 15 kg P ha^{-1} even though, statistically, the response to P rates was significantly linear in most cases (Tables 2 and 3).

Table 3. Sugarbeet shoot dry matter accumulation in response to the application of fertilizer P (means of four replicates).

	1997				1998				
	Days after planting				Days after planting				
P rate	42	70	84	98	34	48	62	76	90
— kg P ha^{-1} —	kg DM ha^{-1}				kg DM ha^{-1}				
0	44	174	806	1760	23	70	400	1141	2811
15	122	475	1204	2337	44	101	703	1950	3633
30	143	514	1323	2283	39	105	813	2056	3806
45	148	580	1461	2581	53	121	902	2289	3616
Source of Variation	PR > F†				PR > F†				
P rate linear	*	***	**	*	*	*	*	***	**
P rate quadratic	ns	***	ns	ns	ns	ns	ns	*	*

† *, **, ***, and ns represent significance at alpha level of 0.05, 0.01, 0.001, and non-significance, respectively.

Agarwal and Srivastava (1976) reported that the application of fertilizer P reduced the shoot:root dry matter ratio indicating that P increased root growth relative to shoot growth. Our experiment indicates little difference in shoot:root dry matter ratio between control treatments and treatments with fertilizer P applied (Fig 2). The shoot:root dry matter ratio did decrease as the early growing season progressed and the plants gained in dry matter accumulation. Root growth was slow during the very early part of the growing season compared to shoot growth. As shoot dry matter accumulation increased root dry matter accumulation increased at a more rapid rate (Fig 2). Milford (1973) and Scott et al. (1974) reported that root growth is slow during the first six weeks of the growing season while leaves are developing. After the 8- to 10-leaf stage the rate of root growth increases with shoot growth increases.

To compare the shoot and root dry matter accumulation response to P rates over the entire sampling period it was necessary to transform the data using $\log_{(10)}$. The response of transformed shoot dry matter accumulation and transformed root dry matter accumulation to P rates and sampling dates were significant in both 1997 and 1998 (Table 4). Dry matter accumulation of both shoot and roots increased for all P rates over the entire sampling period (Fig 3 and Fig 4, respectively). The difference in transformed shoot dry matter accumulation (Fig 3) and root dry matter accumulations (Fig 4) were small where fertilizer P was applied (15, 30, and 45 kg P ha^{-1} rates). The data of all applied P rates were combined to calculate a linear regression line to compare to the linear regression line for the 0 P rate control. The lack of a significant interaction between P rates and sampling dates (Table 4) indicate that linear regression lines for the 0 P rate and all applied P rate are parallel in the transformed shoot dry matter accumulation (Fig 3) and transformed root dry matter accumulation (Fig 4). The exception was in the 1997 transformed shoot dry matter accumulation (Table 4) when the effects of P deficiency seemed to be reduced as the season progressed (Fig 3). These data show that P deficiency suppressed shoot growth, and more importantly, suppressed root growth very early in the growing season prior to when we started sampling. The suppressed root growth due to P deficiency was sustained throughout the entire sampling period even though shoot growth suppression was reduced as the season progressed as it did in 1997.

Sugarbeet growers in the RRV as well as the authors have observed apparent P deficiencies early in the growing season, but within 6 to 8 wks after planting sugarbeet plants appear to recover. Others have reported visible P deficiency symptoms in the early spring on soils with low to medium soil test P levels, but the deficiency symptoms disappeared by mid-season (Sailsbery et al., 1968). Cool soil temperatures that are common in the early spring can enhance P deficiency in sugarbeet (Sipitanos and Ulrich, 1971).

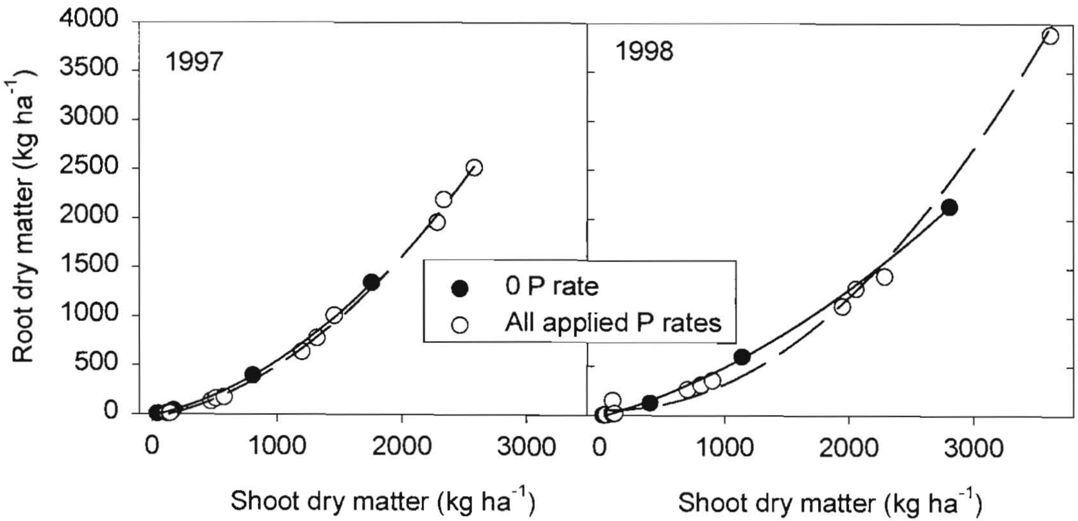

Figure 2. Comparisons of sugarbeet shoot dry matter accumulation to root dry matter accumulation response to fertilizer P during the early periods of two growing seasons.

1997

0 P rate: $y = -14.1 + 0.278x + 2.80X10^{-4}x^2$ $R^2 = .999$

All applied P rates: $y = -37.0 + 0.234x + 2.95X10^{-4}x^2$ $R^2 = 0.998$

1998

0 P rate: $y = -19.2 + 0.370x + 1.41X10^{-4}x^2$ $R^2 = 0.999$

All applied P rates: $y = 57.4 - 5.27X10^{-2}x + 3.13X10^{-4}x^2$ $R^2 = 0.998$

Table 4. Statistical analysis of the of the $\log_{10}$ transformation of the sugarbeet root and shoot dry matter accumulation response to the application of fertilizer P (P rate) and sampling dates (Day).

Source of Variation	Orthogonal Contrasts	1997		1998	
		Log_{10} Root DM	Log_{10} Shoot DM	Log_{10} Root DM	Log_{10} Shoot DM
		PR > F†		PR > F†	
P rate		***	***	**	*
	P rate linear	***	***	**	**
Day		***	***	***	***
	Day linear	***	***	**	***
P rate by Day		ns	*	ns	ns
	P rate linear by Day linear	ns	***	ns	ns

† *, **, ***, and ns represent significance at alpha level of 0.05, 0.01, 0.001, and non-significance, respectively.

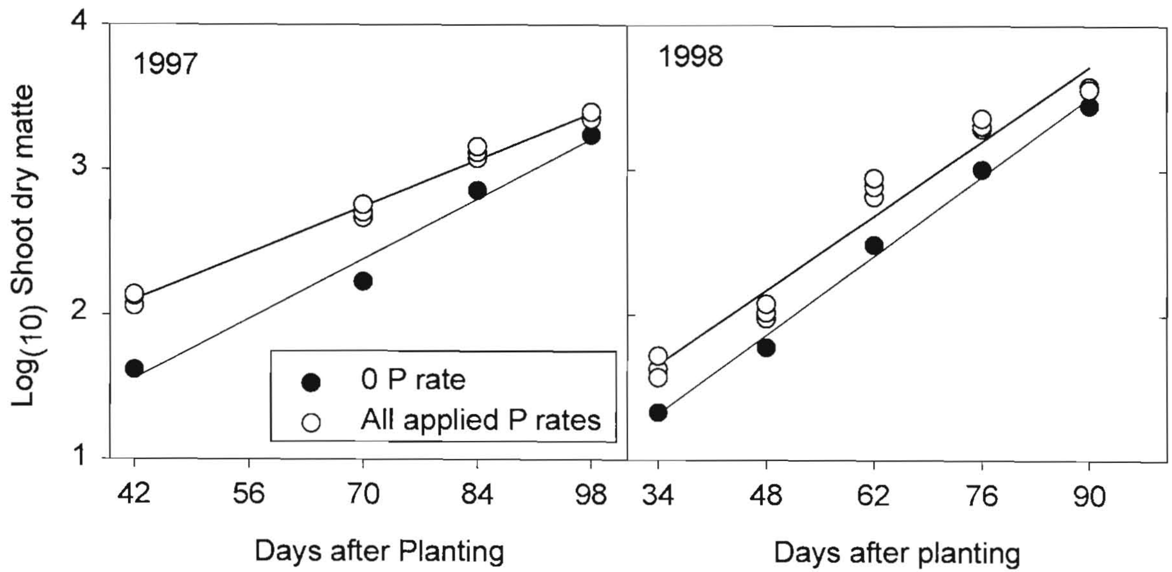

Figure 3. Log_{10} transformation of early season sugarbeet shoot dry matter accumulation response to the application of fertilizer P over sampling dates in 1997 and 1998.

	1997	1998
0 P rate:	$y = 0.320 + 0.029x$ $R^2 = 0.979$	$y = -0.010 + 0.039x$ $R^2 = 0.994$
All applied P rates:	$y = 1.14 + 0.023x$ $R^2 = 0.991$	$y = 0.409 + 0.037x$ $R^2 = 0.961$

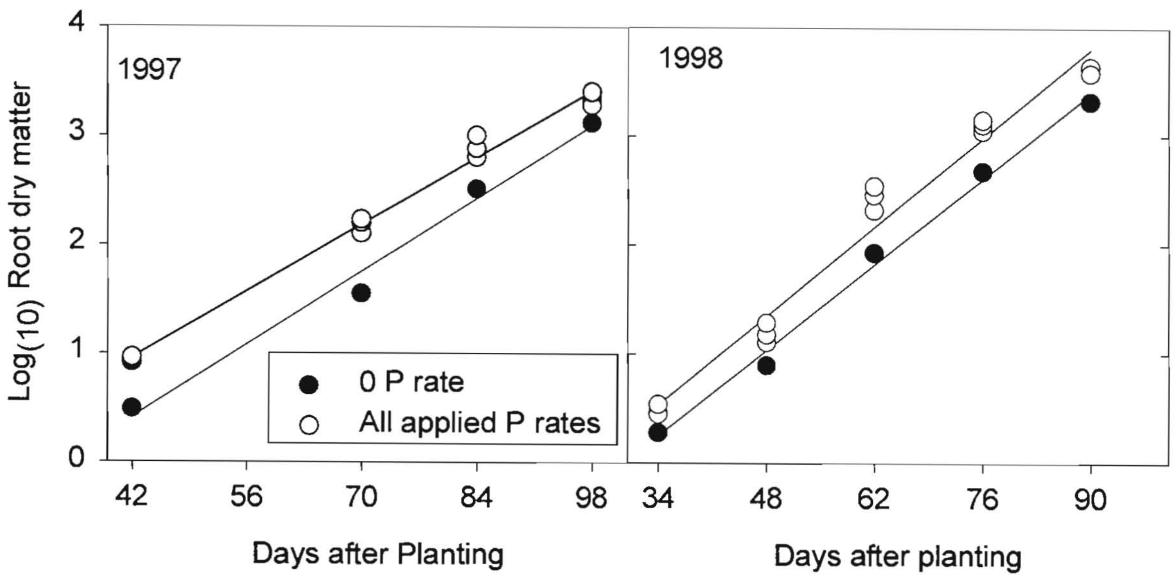

Figure 4. Log_{10} transformation of early season sugarbeet root dry matter accumulation response to the application of fertilizer P over sampling dates in 1997 and 1998.

	1997	1998
0 P rate:	$y = -1.59 + 0.048x$ $R^2 = 0.986$	$y = -1.66 + 0.056x$ $R^2 = 0.993$
All applied P rates:	$y = -0.873 + 0.044x$ $R^2 = 0.992$	$y = -1.45 + 0.058x$ $R^2 = 0.975$

Cool soil temperatures reduce P availability to the sugarbeet plant by slowing the diffusion of P to the root surface (Barber, 1980). Apparent recovery of the sugarbeet plant may be the result of increased soil exploration and thus increased acquisition of soil P. Cold soil temperatures may be causing the P deficiency on sandier textured soils in the RRV, then later, when soil temperatures increase, the root system is more fully developed and the symptoms disappear. However, the authors have observed the described P deficiency symptoms in a sandy textured soil, but not in a finer textured soil when sugarbeet was grown in the greenhouse at 21 to 24° C (data not shown). In this case fertilizer P corrected the deficiency problem. These findings suggest that soil temperature may not be causing the problem, since all the soil was at the same temperature in the greenhouse.

Our data show that even though the sugarbeet plants appear to recover from the P deficiency, the potential root yield was reduced by P deficiency early in the growing season. The yield potential loss occurred during the first month after planting and was maintained throughout the growing season. In areas where the P deficiency symptoms occur, either within portions of a field or for a whole field, the use of a starter fertilizer P at planting may reduce the risk of yield reduction. Anderson and Peterson (1978) found that fertilizer P placed directly below the seed allowed the sugarbeet root to reach the P earlier than if the fertilizer is placed to the side of the seed row. Later in the season the sugarbeet root has the ability to explore more of the soil volume because the root system in more developed.

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