Response of Sugarbeets Grown Under Dryland Conditions to Phophorus Fertilizer*

J. D. Etchevers and J. T. Moraghan

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INTRODUCTION

Little recent information is available concerning the phosphorus (P) nutrition of sugarbeets in the Red River Valley of Minnesota and North Dakota, where sugarbeets are mainly grown under dryland conditions. In this region the relatively immobile fertilizer P is frequently located in soil zones low in available water for extended portions of the growing season.

Responses of sugarbeets to P fertilizer in the Red River Valley were reported several decades ago by Rost et al. (15) and Odgen et al. (12), but little emphasis was placed on soil testing in these investigations. However, later experiments failed to produce responses to this fertilizer (1). Banding of P fertilizer was found to be an efficient means of increasing plant P in sugarbeets growing on soils low in extractable soil P in the Red River Valley (11).

The $NaHCO_3$-extractable P test (13) is widely used for predicting the need for P fertilizer, but correlation studies under dryland conditions with sugarbeets are sparse. Irrigated sugarbeets in Idaho (21) and Washington State (9) did not benefit appreciably from application of P fertilizer when $NaHCO_3$-extractable P levels in the surface soil were greater than 10 ppm. The critical value for irrigated sugarbeets in Utah was given as 12.5 ppm $NaHCO_3$-extractable P (7). Draycott and Durant (4) found sugarbeets growing on soils with greater than 15mg/l of

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*Published with the approval of the Director, North Dakota Agr. Exp. Sta. as Journal Series No. 1265. The authors are Professor, Centro de Edafologia, Colegio de Postgraduados, Chapingo 56230, Mexico and Professor, Department of Soil Science, North Dakota State University, Farog, ND 58105.

$NaHCO_3$-P showed little benefit from application of P fertilizer under English conditions. Low soil temperatures increase the likelihood of P deficiency in sugarbeets (18) and this may be an important factor in the Red River Valley. Abbott and Nelson (1) in Arizona concluded that soil-test values of 5 to 10 ppm $NaHCO_3$-extractable P would be adequate for sugarbeet-seedling growth in warm soils but inadequate during cool periods.

The primary objectives of this study were: (a) to relate the likelihood of responses by sugarbeets to P fertilizer to levels of $NaHCO_3$-extractable P; and (b) to determine the nature of the response by this crop to P fertilizer at a responsive site.

MATERIALS AND METHODS

Nine field experiments to study the relationship between responsiveness of dryland sugarbeets to P fertilizer and soil levels of 0.5M $NaHCO_3$-P (13) were conducted in the Red River Valley between 1974 and 1976. Levels of soil-extractable P at the sites ranged between 4 and 12 ppm (Table 1). The experimental design in all cases was a randomized block with six replications, and while the range of treatments differed, application rates of 0, 11, 22 and 45 kg P/ha, as 0-48-0, were included at all sites. In each experiment, except Experiment 6, the fertilizer was broadcast and subsequently incorporated to a depth of up to 12 cm before planting; the P fertilizer was banded

Table 1. Selected characteristics of nine experimental sites used to study the response of sugarbeets to P fertilizer in the Red River Valley.

Site	Year	Location	Soil	pH	0.5M $NaHCO_3$-P
					ppm
1	1974	Abercrombie	Gardena-Glyndon	8.0	4.5
2	1974	Hillsboro	Glyndon	8.1	6
3	1974	Hillsboro	Fargo	7.9	11
4	1974	Cummings	Gardena-Glyndon	7.8	7
5	1975	Cummings	Gardena-Glyndon	7.8	12
6	1975	Kelso	Fargo	7.5	6
7	1976	Great Bend	Glyndon	8.1	4
8	1976	Mooreton	Overly	8.2	10
9	1976	Hillsboro	Fargo	7.4	10

at planting 5 cm to the side at a soil depth of 5 cm in experiment 6. Basal dressings of N and, where required, K fertilizers were applied at recommended rates based on soil-test values. The experimental plot normally consisted of six 9.2-m rows spaced 0.56 m (22 inches) apart. Portions of the center rows were harvested for final root yields.

A more detailed study of response of dryland sugarbeets to P fertilizer was conducted at Site 1 in 1974. The rates of broadcast and incorporated P fertilizer, as 0-48-0, were 0, 11, 22, 45 and 90 kg P/ha. Each plot replicated six times in a randomized block design, consisted of eight 24.2-m length rows spaced 0.56 m apart. Sections of rows, 9.1-m lengths for intermediate harvests and 18.1-m lengths for the final harvest, were utilized for determination of yield of recoverable sugar and P accumulation in storage roots and in plant tops. Petioles of recently mature leaves, dried at 70°C, were periodically sampled for acetic-acid extractable P (6, 20). "Available" water, expressed as the quantity of water in selected soil-depth increments above the 1.5-MPa (15-bar) value, was monitored by gravimetric and neutron thermalization procedures.

Subsamples of brei from 20 roots were analyzed for sugar, Na, K, and amino-N by tare laboratory procedures of the American Crystal Sugar Company. Sugar losses were determined by the impurity approach of Carruthers and Oldfield (2). The impurity index ratio was defined as:

$$\text{Impurity index} = \frac{3.5\text{xppm Na} + 2.5\text{xppm K} + 9.5\text{xppm amino-N}}{\%\ \text{sugar}}$$

RESULTS AND DISCUSSION

Response to Phosphorus Fertilizer and Soil Phosphorus

Data showing the relationship between yields of roots and recoverable sugar and levels of 0.5M $NaHCO_3$-extractable soil P are given in Table 2. Increased yields of roots and recoverable sugar were only statistically significant at Sites 1 and 7, the sites with the lowest levels, 4.5 and 4 ppm, respectively, of extractable P. Small statistically significant yield increases in roots,

Table 2. Yield of storage roots and recoverable sugar together with magnitude of response to application of 45 kg fertilizer P/ha at nine dryland sites in the Red River Valley.

Experiment	$NaHCO_3$-P	Check yield Roots	Check yield Rec. Sugar	Roots Response	Roots "F" ratio[a]	Rec. sugar Response	Rec. sugar "F" ratio[a]
	ppm	t/ha	kg/ha	T/ha		kg/ha	
1	4.5	30.0	4120	6.2	**	950	**
2	6	24.0	3220	1.6	*	290	NS
3	11	34.7	4860	0.9	NS	55	NS
4	7	33.9	5140	2.7	**	220	NS
5	12	36.5	6600	2.4	NS	380	NS
6	6	27.3	4720	0.1	NS	4	NS
7	4	32.7	5660	4.0	**	750	**
8	9.5	37.9	6310	0.6	NS	20	NS
9	10	28.9	4140	1.1	NS	490	NS

[a] NS indicates not significant; * and ** indicates significance at the 0.05 and 0.01 levels of probability.

but not recoverable sugar, were also found at Sites 2 and 4 with 6 and 7 ppm extractable P, respectively. Phosphorus fertilizer in no case had a significant effect on sugar percentage.

Few soils used for sugarbeet production in the Red River Valley contain less than 5 ppm $NaHCO_3$-extractable P; most contain greater than 10 ppm (5). The critical level of 0.5M $NaHCO_3$-P currently used for fertilizer recommendations is 10 ppm. Continued use of this value appears justified since: (a) early-season growth responses to P fertilizer are sometimes observed in sugarbeets growing on soils with P-test values between 5 and 10 ppm-extractable P and may occasionally result in increased yields of recoverable sugar; (b) fields are heterogeneous with respect to extractable P and portions of some fields averaging 10 ppm, or even higher, extractable P may require added P for maximum production; and (c) added P fertilizer may be beneficial in years when early growing season temperatures are below average.

Harvesting Date and Response to Phosphorus Fertilizer

Yield data. The influence of harvest date and level of P fertilizer on selected yield characteristics at Site 1, with 4.5 ppm extractable P, are given in Table 3. Statistically significant responses of roots and recoverable sugar to added fertilizer occurred at all harvests, but the percentage response data clearly show that the relative responses decreased as the season progressed. This seasonal trend was even more apparent for leaf canopy growth; no response in yield of tops was found at the 123-day harvest, even though a vigorous canopy with a large quantity of dry matter was still present at that time.

Early season responses to P fertilizers, which may result in no or small increases in final sugar yields, have been previously reported (17). One or more of the following factors may contribute to this effect: (a) internal cycling of plant P may decrease the importance of external supplies of P for older plants; (b) availability of P fertilizer may decrease relatively more than soil P as the growing season progresses, especially if available water in the application zone becomes limited; (c) native soil P may be relatively more available later in the growing season due to higher soil temperatures or to increasingly larger volumes of soil being penetrated by the fibrous root system; and (d) P absorption by sugarbeets may decrease with age (16). Banded P fertilizer, per unit of applied P, was more efficient than broadcast and incorporated fertilizr under certain conditions in the Red River Valley (11). Acetic-acid extractable P data from petioles of recently mature leaves suggested that such effects for sugarbeets growing on responsive soils

Table 3. Influence of time of sampling and phosphorus fertilizer on yield of tops, roots and sugar at a P-responsive site (Site 1).

Days after planting	P fertilizer, kg P/ha					LSD (0.05)	Percentage response to 90 kg P/ha
	0	11	22	45	90		
			Roots, kg/ha				
54	1.9	2.7	3.1	3.4	3.4	0.6	79
80	13.1	16.6	17.0	18.5	19.6	2.0	50
100	26.7	29.3	31.4	31.6	32.5	2.6	22
123	30.0	32.7	33.8	36.2	36.1	2.7	20
			Tops, T/ha				
54	0.9	1.3	1.5	1.5	1.5	0.2	67
80	3.3	4.0	4.2	4.6	4.5	0.6	36
100	5.4	6.4	6.4	6.1	6 9	1.0	28
123	6.2	6.3	6.4	6.7	6.3	NS	2
			Sugar, %				
54	8.0	8.0	8.0	8.2	8.3	NS	
80	9.6	9.8	10.1	9.9	10.1	NS	
100	11.3	11.7	11.5	11.6	11.7	NS	
123	15.7	16.1	15.5	15.8	15.5	NS	
			Recoverable sugar, kg/ha				
54	110	150	180	200	200	40	82
80	1020	1300	1410	1460	1680	210	65
100	2260	2870	3030	3090	3180	390	41
123	4120	4570	4570	5070	4960	480	20

[a] Percentage response = $\frac{\text{Yield (90 kg P/ha) - Yield check)}}{\text{Yield (check)}} \times \frac{100}{1}$

are associated with early season responses.

Application of P fertilizer had no significant effect on percentage sugar, even early in the season when large yield responses in tops, roots and recoverable sugar were apparent. This lack of an effect on root quality is commonly found (3). However, in some situations P deficiency reduced absorption of soil nitrate and the accumulation of petiole nitrate (8). Phosphorus fertilization in such cases could conceivably influence root quality. Schmehl and James (17) concluded that applicaiton of P fertilizer may increase the sugar percentage at intermediate levels of soil N.

Table 4. Influence of time of sampling and phosphorus fertilizer on accumulation of P in tops and storage roots of sugarbeet plants grown at a P-responsive site (Site 1).

Days after planting	Plant part	P fertilizer, kg P/ha					LSD (0.05)
		0	11	22	45	90	
		Plant P, kg/ha					
54	Roots	0.4	0.7	0.8	1.0	1.0	0.2
	Tops	2.1	3.2	3.8	4.3	4.4	0.7
	Σ	2.5	3.9	4.6	5.3	5.4	
80	Roots	1.9	2.7	2.6	3.9	4.8	0.5
	Tops	5.5	7.5	8.1	11.1	9.0	2.7
	Σ	7.4	10.2	10.7	15.0	13.8	
100	Roots	3.9	5.1	6.9	8.2	10.2	1.4
	Tops	8.4	10.2	11.4	12.8	16.8	2.6
	Σ	12.3	15.3	18.3	21.0	27.0	
123	Roots	5.2	6.7	8.0	10.8	12.3	1.7
	Tops	7.6	9.1	9.1	11.6	12.5	2.1
	Σ	12.8	15.8	17.1	22.4	24.8	

Phosphorus-uptake data. Accumulation of P in storage roots and tops increased with application of P fertilizer (Table 4). The accumulation in storage roots increased up to the final harvest, but decreased between the 100- and 123-day harvests for tops. This decrease in P in tops was probably mainly due to death of older leaves; however, translocation of the element between tops and roots may also have been a factor. The P in tops in the Red River

Valley is usually returned to the soil and may sometimes benefit subsequent crops.

The apparent recovery data, given in Table 5, show that from 13 to 27% of the fertilizer P, depending upon rate, was utilized. Much of the remaining P fertilizer is undoubtedly available for following crops. Etchevers (5) in a survey of Red River Valley sugarbeet fields found that 40% of the fields studied contained in excess of 20 ppm NaHCO3-P; some fields with long histories of P fertilization had in excess of 45 ppm extractable P. Detrimental effects of high levels of P on sugarbeets were reported from Washington State (9), and high soil P levels were suspected to interfere with micronutrient nutrition of this crop in Nebraska (14). Sugarbeets is not regarded as especially susceptible to Zn deficiency (3). However, severe Zn deficiency can be produced in a susceptible crop, such as flax, by increasing available P levels in soils with marginal levels of available Zn (10).

Table 5. Influence of time of sampling and rate of P fertilizer on apparent recovery of fertilizer P by tops and storage roots of sugarbeets at a responsive site (Site 1).

Days after planting	P fertilizer, kg P/ha			
	11	22	45	90
	Apparent recovery[a], %			
54	13	10	6	3
80	25	15	16	7
100	27	27	19	16
123	27	20	21	13

[a] $\text{Apparent recovery} = \frac{\text{Plant P (added fertilizer)-Plant P (check)}}{\text{kg fertilizer P/ha}} \times \frac{100}{1}$

where "Plant P" is expressed in kg/ha

Petiole-phosphorus data. Acetic acid-extractable P concentrations in petioles of recently mature leaves are given in Table 6. The critical values of extractable P, in agreement with several other recent reports (11, 21), decreased as the growing season progressed; critical values varied from greater than 2000 ppm soon after the establishment of a canopy with a leaf area index in excess of 2, to a value around 600 ppm at the 123-day harvest.

One interesting feature of the extractable-P data was the unusual increase between the 80- and 88-day harvests. As indicated by the data given in Table 7, the "available" water in the 0 to 30-cm depth increment was relatively low during much of the growing season. Ninety four millimeters of the total rainfall of 357 mm recorded during the growing season fell soon after completion of the 80-day sampling. This precipitation should have increased the "available" water in the soil zone where the fertilizer was located, and presumably the availability of fertilizer P in this zone. The magnitude of the increase in the acetic acid plant-extractable P increased with higher levels of fertilizer P.

Table 6. Influence of time of sampling and phosphorus fertilizer on acetic-acid extractable phosphate in petioles from recently mature leaves at a P-responsive site (Site 1).

Days after planting	P fertilizer, kg P/ha					LSD (0.05)
	0	11	22	45	90	
	Plant-extractable P, ppm					
54	1540	1900	2050	2200	2470	330
74	670	1090	1100	1580	1900	220
80	570	720	840	1170	1440	240
88	660	1170	1210	1710	2230	360
100	580	940	1020	1570	2100	270
123	350	530	630	1180	1320	230

Table 7. Available soil water at selected times during the growing season in the 0 the 30 and 0 to 180-cm depth increments of plots treated with 90 kg P fertilizer/ha (Site 1).

Days from planting	Available soil H_2O	
	0-30 cm	0-180 cm
	cm	
31	4.9	36.1
54	0.2	23.4
62	2.4	26.7
80	1.9	18.9
100	0.9	16.1
123	0.1	11.3

SUMMARY

The influence of soil levels of 0.5M $NaHCO_3$-P on field

responses of sugarbeets to P fertilizer was studied at nine sites under dryland conditions in the Red River Valley; levels of extractable soil P ranged between 4 and 12 ppm. Statistically significant responses to 45 kg fertilizer P/ha, resulting in increases of recoverable sugar of 13 and 23%, respectivley, were only obtained at the two sites with the lowest contents, 4 and 4.5 ppm, of extractable P.

The nature of the P-fertilizer response was studied in more detail at the site with 4.5 ppm NaHCO3-P. Percentage increases in yields of tops, roots and recoverable sugar decreased from 67, 79 and 82% at 54 days to 2, 20 and 20%, respectively, at 123 days. Apparent recovery of applied fertilizer P varied from 27 to 13% at 123 days with the 11 and 90 kg P/ha rates of application, respectively. Acetic-acid extractable plant P data suggested that lack of available soil water in the zone of fertilizer application limited uptake of fertilizer P during portion of the growing season.

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