Phosphorus Fertilization of Sugarbeet In Subtropical India

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ABSTRACT

Field experiments were conducted in northwest India to study the response of sugarbeet (*Beta vulgaris* L.) to phosphorus (P) fertilizer on ten sites of varied P availability (3.1 to 11.2 mg kg^{-1} sodium bicarbonate-extractable P). Responses to P application were unlikely above a critical soil P level of 5.1 mg kg^{-1}. On soils with initial P levels of 0 to 3.5 or 3.6 to 5.1 mg kg^{-1}, root and sugar yield increases were obtained with P fertilizer additions of up to 26 and 13 kg ha^{-1}, respectively. At a responsive site (3.1 mg kg^{-1} P), yields of root and top, relative to no-added-P controls, were 242 and 182% at 60 days of growth, but only 37 and 1%, respectively, at 203 days (harvest). Percent sucrose was greater at 150 and 180 days of growth, but not at final harvest. P absorption decreased with age; tops contained 81% of total P at 60 days, and 45% at harvest. The apparent recovery of applied P varied from 25.4 to 14.2% at harvest with P rates of 13 to 52 kg P ha^{-1}. These P application rates increased post- harvest available P soil levels by 0.4 to 3.8 mg kg^{-1} above the no-P control.

Additional Key Words: *Beta vulgaris* L., soil phosphorus, phosphorus cycling

Recent research in India has shown that sugarbeet (*Beta vulgaris* L.) can be grown successfully as a winter crop in subtropical northwest India. As a result, its commercial cultivation has begun in Sri Ganganagar, and it is being tested for other parts of this zone. Because phosphorus (P) constitutes the second most important fertilizer nutrient needed for crop growth, studies on its response are essential. Large variations in P requirement

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are expected due to differences in its availability in native soils. Where P is sufficient in the soil, additional P fertilization may not be useful, and may even produce detrimental effects (Draycott et al., 1971; James, 1972). Increasing fertilizer costs also make it essential to define precisely the fertilizer requirement for different soils. The only reliable method to accomplish this is soil testing; sodium bicarbonate extractable P (Olsen et al., 1954) has been the most widely used test for this purpose.

Various soil P levels above which P response is unlikely have been reported for various agro-climatic conditions. Westerman et al. (1977) reported 10 mg kg^{-1} as the critical soil P level for Idaho, and 12.5 mg kg^{-1} was suggested for Idaho (Haddock, 1959). For English conditions, Draycott and Durrant (1976) reported that P fertilization did not increase sugarbeet root or sugar yield significantly when soil P exceeds 15 mg kg^{-1}. Because such information was lacking for the agro-climatic conditions of India, we conducted experiments with these objectives: (1) to evaluate the fertilizer P requirements of sugarbeet at different soil test P levels, and (2) to study the response of sugarbeet to P fertilizer levels at various stages of growth.

MATERIALS AND METHODS

Ten field experiments were conducted on different soils in Punjab state of northwest India from 1983-84 to 1987-88. Selected soil characteristics of the experimental sites are summarized in Table 1. In all cases, the experimental design was a randomized block with four replications. The experimental plot consisted of twelve 10 m rows at sites 2 and 6, and eight 6 m rows at other sites; in all cases, rows were spaced 50 cm apart. Each experiment included five treatments (0, 13, 26, 39, and 52 kg P ha^{-1}), except that the highest level (52 kg ha^{-1}) was omitted in experiments 5 and 7. Fertilizer P as superphosphate was drilled below the seed before sowing. Two basal dressings of 60 kg N ha^{-1} in the form of urea were applied to each experiment, one at sowing and second after thinning. A Russian sugarbeet, variety 'Ramonskaya-06,' well-adapted to Indian soils, was planted at each site during the second half of October each year, and thinned by hand to within-row plant spacing of 20 cm. Each experiment was manually hoed twice, at 30-40 and at 60-70 days of growth, to control weeds. No chemical applications were required, because no insect or disease problems occurred. All the beets in each plot of every experiment were harvested in the first fortnight of May, in the year following planting. At harvest, total root yield was determined, and representative samples of roots were analyzed for sucrose by the method of Carruthers and Oldfield (1962).

In 1985-86, a more detailed study of the response of sugarbeets to P fertilizer was conducted at site 6 (3.1 mg kg^{-1} soil P). At 60, 90, 120, 150, 180, and 203 (harvest) days of crop growth, a portion of each plot was harvested to determine top and root

Table 1. Characteristics of topsoil (0-22.5 cm) at ten study sites.†

Expt Nr	Year	Research Location	Soil Texture	pH (1:2)	EC Soil: Water	Percent Organic Carbon	Bicarbonate-extractable P (mg kg^{-1})	NH_4OAc-extractable K (mg kg^{-1})
1	83-84	Kheri	Loamy sand	8.3	0.36	0.30	3.5	65
2	83-84	Zira	Loamy sand	8.6	0.40	0.42	11.3	60
3	84-85	Jalandhar	Sandy loam	8.1	0.32	0.42	6.0	40
4	84-85	Kheri	Sandy clay loam	8.5	0.35	0.36	5.3	68
5	84-85	Kheri	Sandy clay loam	8.5	0.35	0.38	5.0	60
6	85-86	Jalandhar	Sandy loam	8.2	0.30	0.38	3.1	45
7	85-86	Kheri	Sandy loam	8.4	0.36	0.34	5.1	60
8	85-86	Kheri	Loamy sand	8.4	0.35	0.34	4.9	58
9	86-87	Jalandhar	Sandy clay loam	8.0	0.34	0.44	9.0	60
10	87-88	Jalandhar	Sandy loam	8.1	0.30	0.40	3.6	35

†Means of four replications. EC = Electrical conductivity (μmhos cm^{-1}); P and K were determined in sodium bicarbonate and ammonium acetate extracts, respectively.

yields. At each harvest, 20 petioles of recently-mature leaves were combined and analyzed for total P by the vanadomolybdate method, after wet ashing with triple acid (Jackson, 1967). After dry matter determinations, samples of tops and roots also were analyzed for total P. After the final harvest, soil samples were collected from 0-22.5 and 22.5-45 cm depth, and analyzed for bicarbonate-extractable P (Olsen et al., 1954).

RESULTS AND DISCUSSION

Phosphorus response in relation to soil phosphorus

The response of root and sugar yield to levels of applied P in soils of various soil test P levels is presented in Table 2. Significant root yield responses to P fertilization were observed in experiments 1, 5, 6, 8, and 10, all sites having soil P test levels below 5 mg kg^{-1}. Significant yield increase was obtained with P applications up to 26 kg P ha^{-1} in experiments 1 and 6 in which original soil P levels were below 3.5 mg kg^{-1}, and up to 13 kg P ha^{-1} at sites 5, 8, and 10 at which original soil P levels were 3.6 to 5.0 mg kg^{-1}. Root or sugar yields were not increased significantly in soils with starting P levels above 5.0 mg kg^{-1}. The pattern of sugar yield responses to applied P were similar to those of root yield except in experiment 7 (with soil test P level of 5.1 mg kg^{-1}), where contrary to root yield, the sugar yield response was significant. The increase in sucrose percentage given by the lowest P level applied made the sucrose yield increase significant in this experiment. In no other case, however, did the fertilizer P have a significant effect on percent sucrose (data not shown). There was no detrimental effect of any level of P fertilization on root yield, sucrose concentration, or sugar yield, at any soil P level. Westerman et al. (1977) and Moraghan and Etchevers (1981) also found no detrimental effect of P fertilizer, even in soils containing 106 mg P kg^{-1}.

From a scatter diagram (Cate and Nelson, 1965) drawn by

Table 2. Root and sugar yield as influenced by fertilizer P levels in soils differing in bicarbonate-extractable P (Olsen et al., 1954).

		ROOT YIELD (t ha^{-1})					SUGAR YIELD (t ha^{-1})				
		P level (kg P ha^{-1})					P level (kg P ha^{-1})				
Expt No.	Soil P (mg kg^{-1})	0	13	26	39	52	0	13	26	39	52
1	3.5	50.0c[†]	61.9b	66.4a	65.0ab	65.1ab	8.23c	9.17b	10.22a	10.08a	10.08a
2	11.3	46.0	48.1	47.9	48.2	47.9	6.44	7.12	6.99	6.94	6.99
3	6.0	68.5	70.4	69.8	70.0	70.1	9.79	10.61	10.21	10.15	10.09
4	5.3	56.8	58.2	59.3	60.3	59.3	8.63	9.06	9.26	9.49	9.40
5	5.0	54.0b	60.0a	63.3a	64.0a	–	7.93b	9.42a	10.01a	10.09a	–
6	3.1	50.5c	63.0b	70.2a	70.8a	69.4a	7.58c	9.71b	10.82a	10.84a	10.76a
7	5.1	49.3	53.3	54.3	53.2	–	7.30b	8.08a	8.40a	8.55a	-
8	4.9	50.5b	61.0a	64.2a	62.1a	65.1	7.02b	8.60a	9.08a	8.76a	9.18a
9	9.0	67.0	68.3	68.6	70.1	69.3	9.38	9.48	9.67	9.74	9.88
10	3.6	56.8b	61.4a	61.7a	61.3a	62.5a	7.97b	8.90a	8.97a	8.97a	9.00

[†]For each variable, within a row, means followed by the same letter do not differ significantly (P = 0.05) by Duncan's multiple range test.

plotting bicarbonate-extractable P vs. relative root/sucrose yield, we determined a critical level of about 5.1 mg kg^{-1} below which sugarbeet responded to applied P fertilizers in these soils. Although no information for sugarbeet is available under comparable agro-climatic conditions, our estimated critical level is similar to the 5.0 mg kg^{-1} reported by Dhillon et al. (1988) for green gram, but less than the 7.5 mg kg^{-1} reported for wheat (Vig et al., 1987). In comparison to sugarbeet grown under much different agro-climatic conditions, this critical limit in India is much lower than that reported for the western United States (Westerman et al., 1977; Haddock, 1959), or for England (Draycott and Durrant, 1976).

Most of the soils of northwest India, especially the Punjab, are deficient in available P. Some soils have a medium P level, and only a few have high available P. The levels of available P currently considered to represent low (deficient), medium, and high conditions are <5, 5-9, and >9 mg kg^{-1} of sodium bicarbonate-extractable P, respectively. Based on these groupings, P application to sugarbeet would be recommended only for soils categorized as low in available P. Based on our findings, we recommend that for optimum growth of sugarbeet, 26 kg P ha^{-1} should be applied to soils testing less than 3.5 mg P kg^{-1}, and 13 kg P ha^{-1} should be applied to soils testing 3.6 to 5.1 mg P kg^{-1}.

Phosphorus response at various stages of growth

The influence of P level on selected yield characteristics of crop growth was tested in experiment 6, at a soil test P level of 3.1 mg kg^{-1} (Table 3). The magnitude of relative response for top, root, and sugar yields decreased as the season progressed. Top yield, which in the early growth stages was significantly increased by P fertilization up to 39 kg P ha^{-1}, showed no response

Table 3. Effect of P levels on sugarbeet yield parameters at various periods of growth.

Days after Planting	P fertilizer level (kg ha^{-1})					Response to 52 kg P ha^{-1} (% of control)
	0	13	26	39	52	
			ROOT YIELD (t ha^{-1})			
60	0.7e[†]	1.4d	2.0bc	2.2b	2.4a	242
90	3.2d	6.5c	8.1b	9.0a	9.2a	188
120	9.4d	17.8c	20.5b	23.9a	23.9a	154
150	25.4d	41.7c	48.7b	51.9a	52.3a	106
180	40.5c	60.9b	69.8a	69.4a	69.7a	72
203	50.5c	63.1b	70.3a	70.8a	69.4a	37
			TOP YIELD (t ha^{-1})			
60	7.8d	14.8c	18.0b	20.8a	22.0a	182
90	15.1c	24.3b	28.2a	30.5a	30.0a	99
120	23.3c	33.8b	36.9a	34.4ab	36.9a	58
150	33.6b	45.1a	47.3a	46.1a	45.2a	35
180	41.0b	45.3a	47.5a	47.4a	47.2a	15
203	43.6a	44.0a	44.0a	43.6a	44.0a	1
			SUGAR (% of fresh wt)			
150	10.5b	11.9a	12.3a	12.2a	12.3a	17
180	14.5b	15.3a	15.2a	15.5a	15.5a	7
203	15.0a	15.4a	15.4a	15.3a	15.5a	3
			SUGAR YIELD (t ha^{-1})			
150	2.67c	4.96b	5.96a	6.33a	6.44a	144
180	5.88c	9.31b	10.61a	10.76a	10.80a	84
203	7.58c	9.71b	10.82a	10.84a	10.76a	43

[†]Within a row, means followed by the same letter do not differ significantly ($P = 0.05$) by Duncan's multiple range test.

at harvest. Root yield responded to added P fertilizer at all harvests, although the relative response decreases from 242% of control at first harvest to 37% at final harvest. Sugar yield, which for the highest P fertilization treatment was 144% greater than the control at 150 days, was still 42% above the control yield at 203 days. A decreasing beneficial effect of P application with age of the crop also has been reported for Greece (Papanicolaou et al., 1982) and North Dakota (Etchevers and Moraghan, 1983). Etchevers and Moraghan (1983) suggest some reasons why early-season responses to P fertilizers usually lead to little or no increase in yield at harvest: (1) availability of fertilizer P may decrease relatively more than soil P as the growing season progresses; (2) native soil P may be relatively more available in late season due to a rise in soil temperature; (3) P absorption by sugarbeet may decrease with crop age; and (4) internal cycling of plant P may decrease the importance of external supplies of P for older plants.

The response of percent sucrose was significant at 150 and 180 days of harvest, but became nonsignificant at harvest. Crop maturity could be a factor in this result: perhaps P application enhanced the early growth rate of sugarbeet, leading to early maturity. The comparatively low increase in percent sucrose at 150 or 180 days of crop growth in P treated plots compared to control (no P) plots also may be an indication for P-induced early maturity. These results, however, differ from those of Etchevers and Moraghan (1983), who in the U.S. Red River Valley did not observe increased sucrose with P fertilizer at any sugarbeet growth stage.

Table 4. Phosphorus (P) accumulation in sugarbeet roots and tops at various periods of growth.

Days after Planting	Plant part	P fertilizer level (kg ha^{-1})				
		0	13	26	39	52
		TOTAL P UPTAKE (kg ha^{-1})				
60	Roots	2.1d†	2.4c	2.7b	2.9ab	3.0a
	Tops	8.4d	10.0c	11.4b	12.3ab	12.5a
	Total	10.5d	12.4c	14.1b	15.2a	15.5a
90	Roots	5.6d	6.5c	7.0b	7.5a	7.5a
	Tops	10.9c	13.0b	14.8a	16.0a	16.0a
	Total	16.5d	19.5c	21.8b	23.5a	23.5a
120	Roots	6.4e	9.4d	10.9bc	11.8ab	12.3a
	Tops	13.7c	14.3b	15.8ab	16.9a	17.0a
	Total	20.1d	23.7c	26.7b	28.7a	29.3a
150	Roots	7.6e	10.8d	13.2bc	14.4ab	15.1a
	Tops	14.4c	15.2ab	16.2ab	17.1a	16.8a
	Total	22.0d	26.0c	29.4b	31.5a	31.9a
180	Roots	9.4d	12.7c	14.5b	17.0a	16.4a
	Tops	13.4b	13.7a	15.2a	15.0a	15.6a
	Total	22.8c	26.4b	29.7a	32.0a	32.0a
203	Roots	9.9c	14.5b	16.7a	17.7a	17.6a
	Tops	13.0a	11.7a	12.0a	12.5a	12.7a
	Total	22.9c	26.2b	28.7a	30.2a	30.3a

†Within a row, means followed by the same letter do not differ significantly (P = 0.05) by Duncan's multiple range test.

The uptake patterns for P in sugarbeet tops and roots at various stages of crop growth (Table 4) reveal that during the early growth of the crop, P accumulation was much greater in tops than in roots. The proportion of P in tops decreased with crop age: tops contained 81% of the total P uptake at 60 days of growth, but only 45% of the total P at harvest. P accumulation in the storage root increased up to final harvest, but P in the tops decreased after 150 days. The decrease could be due to translocation of P out of the leaves into the roots, or to death of older leaves. However, between 150 and 180 days, the decrease of P in the tops must have been due mainly to translocation, as the death of older leaves was not seen at this time. Total P uptake increased to its maximum at 180 days; about 47, 73, and 90% of this maximum level was accumulated at 60, 90, and 120 days of growth, respectively. These results indicate that the rate of P absorption decreased with age of the crop. This also is evidenced by the total P concentrations in petioles of recently-mature leaves at various growth stages of the crop (Table 5), in which (averaged across P levels) P constituted 0.34% of petiole dry weight at 60 days of growth, decreasing to 0.22% at harvest. The values of P concentration at 26 kg P ha^{-1}, above which no further increase in root or sucrose yield was observed, could be taken as sufficient to indicate maximum yields.

Table 5. Total P in petioles of recently-mature sugarbeet leaves at various times during the growing season.

Days after Planting	P fertilizer level (kg ha^{-1})				
	0	13	26	39	52
	PLANT P (% of dry petiole weight)				
60	0.23c†	0.32b	0.36a	0.39a	0.40a
90	0.19d	0.28c	0.32b	0.34ab	0.37a
120	0.16d	0.26c	0.30c	0.34b	0.38a
150	0.13c	0.24b	0.27a	0.30a	0.31a
180	0.12d	0.23c	0 26b	0.27ab	0.29a
203	0.12c	0.20b	0.24a	0.27a	0.27a

†Within a row, means followed by the same letter do not differ significantly (P = 0.05) by Duncan's multiple range test.

The proportion of applied P recovered in the crop was greatest at 150 days of crop growth (Table 6). As shown by the P uptake data, the decreased recovery at 180 days was due to a slightly greater P uptake in control plots compared to P-treated plots. As discussed previously, the further decrease in recovery at harvest could be due to death of older leaves in P-treated plots. At harvest, only 14.2 to 25.4% of the applied fertilizer P, depending on the application level, was present in the crop. Much of the remaining P undoubtedly is available for subsequent crops. Soil tests after harvest revealed that available P was increased above the control by 0.4 to 3.8 mg kg^{-1}, again depending on the amount of P applied (Table 7). However, all the remaining P was confined to the upper 22.5 cm of the soil profile. Apparently, little leaching of the applied fertilizer P to lower depths occurred, attributable to the low diffusion coefficient of phosphorus (Fox and Kamprath, 1971).

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Table 6. Proportion of applied fertilizer P present in sugarbeet at various times during the growing season.

Days after Planting	P fertilizer level ($kg\ ha^{-1}$)			
	13	26	39	52
	% of P applied†			
60	14.6	13.8	12.1	9.6
90	23.1	20.4	17.9	13.5
120	27.7	25.4	22.1	17.7
150	30.8	28.5	24.4	19.0
180	27.7	26.5	23.6	17.7
203	25.4	22.3	18.7	14.2

$$^{\dagger}\%\ \text{of P applied} = \frac{\text{Plant } P_{fertilized} - \text{Plant } P_{control}}{\text{Fertilizer P}} \times 100$$

(where all values are in $kg\ P\ hg^{-1}$)

Table 7. Soil test values for bicarbonate- extractable P (Olsen, et al., 1954), after harvest of sugarbeet.

Fertilizer P level ($kg\ ha^{-1}$)	EXTRACTABLE P ($mg\ kg^{-1}$)	
	----------Soil depth (cm)----------	
	0-22.5	22.5-45.0
0	2.8	2.6
13	3.2	2.8
26	3.8	2.9
39	5.4	3.1
52	6.6	2.9
LSD (0.05)	0.7	0.4
Original†	3.1	2.9

†Original = Field P level prior to this P-fertilization experiment.

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