Reprinted from AGRONOMY JOURNAL
Vol. 64, March-April 1972, p. 180-183

Controlling Soil Crusting with Phosphoric Acid to Enhance Seedling Emergence[1]

C. W. Robbins, D. L. Carter, and G. E. Leggett[2]

ABSTRACT

Obtaining adequate and uniform stands of small seeded crops is often a serious problem on soils susceptible to crusting. A study was conducted to determine if spraying dilute phosphoric acid in narrow bands along the seeded rows would increase sugar beet (*Beta vulgaris* L.) seedling emergence by preventing or minimizing soil crusting and provide the needed nutritional P for crop production. Dilute phosphoric acid was sprayed along rows seeded to sugar beets on a Portneuf silt loam. Several acid concentrations and P rates were applied. Stand counts were made before and after thinning, and P concentrations were measured in sugar beet petioles sampled at three dates during the growing season. Laboratory studies were conducted to determine the effects of the phosphoric acid on soil properties.

Applying 69 kg P/ha as dilute phosphoric acid in liquid volumes of 650 to 1,300 liters/ha reduced crusting by increasing aggregate stability in the soil surface, increased sugar beet seedling emergence, and provided the P needed by the sugar beet crop. The acid dissolved $CaCO_3$ and $MgCO_3$ in the soil surface freeing Ca^{++} and Mg^{++}. The cations likely reacted with $PO_4^{\equiv}$ from the acid to form slightly soluble Ca and Mg phosphates that acted as cementing agents in soil aggregates. Using dilute phosphoric acid to reduce crusting may be equally effective for assuring satisfactory stands of other crops on calcareous soils.

Additional key words: **Sugarbeets, Aggregate stability, Phosphorus fertilization.**

[1] Contribution from the Northwest Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA; Idaho Agricultural Experiment Station, cooperating. Received July 1, 1971.

[2] Soil Scientist and Research Soil Scientists, respectively, Snake River Conservation Research Center, Route 1, Box 186, Kimberly, Idaho 83341.

SOIL crusting is a serious problem in obtaining adequate and uniform stands of crops such as sugar beets (*Beta vulgaris* L.), cotton (*Gossypium hirsutum* L.), carrots (*Daucus* sp.), lettuce (*Lactuca* sp.), tomatoes (*Lycopersicon* sp.), broccoli (*Brassica oleracea*), and small grains (4, 5, 6, 8). Soils are susceptible to crusting when the structure in the surface is readily destroyed. Three mechnisms important in soil crust formation include: (i) mechanical destruction of aggregates and simultaneous compaction by raindrop impact; (ii) washing of fine particles into the interaggregate spaces; and (iii) rupture of soil aggregates by air entrapped in the previously dry soil particles (9, 11, 13, 14). The influence of saturating cations on dispersion or flocculation is also important (10).

Increasing the soil moisture content in the soil surface by frequent light irrigations or by covering the soil with plastic or other materials to prevent drying will reduce crust strength (4, 6, 7). But frequent, light irrigations increase labor requirements except with specialized automated systems, and materials to cover the soil surface are expensive. Synthetic soil conditioners can be applied to the soil surface to reduce soil structure breakdown (1, 4), but such materials are too expensive for most crops.

Mechanical methods of obtaining satisfactory crop stands include punch planting (5), planting seeds in groups to increase the force applied by the sedlings at a given point, and shallow cultivations to physically break up the soil crust. Punch planting allows planting through a crust, but it does not protect against fine soil particles washing into the hole before germination or emergence. This process could bury the seed too deeply or limit emergence as a result of subsequent crusting. Shallow cultivation is used to break up soil crusts, but often such practices injure young seedlings.

Johnson and Law (8) sprayed H_2SO_4 at various concentrations and rates in 5-cm bands on the seeded row to prevent crusting. These treatments were effective on calcareous soils, but the practice was not recommended because application hazards to men and equipment were too great.

This paper reports the effectiveness of agricultural grade H_3PO_4 as a combined soil crust preventative and a P source for sugar beets when sprayed in a narrow band on the seeded rows immediately after planting.

MATERIALS AND METHODS

Field Studies

Dilute agricultural H_3PO_4 was sprayed in bands 7.5 cm wide directly on sugar beet rows seeded in calcareous Portneuf silt loam in 1968 and 1970. Ammonium nitrate was broadcast and disked in before seedbed preparation each year at an N rate of 112 kg/ha. The plots were 8 rows wide and 16 m long. The row spacing was 61 cm in 1968 and 56 cm in 1970.

The 1968 studies included H_3PO_4 concentrations applied at three volumes and a third concentration applied at two liquid volumes (Table 1, Results and Discussion). Other treatments included $CaCO_4$ and $Fe_2(CO_4)_3$ spread in 7.5-cm bands on the seeded row at rates of 112, 224, and 448 kg/ha; a check with concentrated superphosphate disked in; and a nonphosphated check. The plots treated with $CaSO_4$ and $Fe_2(SO_4)_3$ also received concentrated superphosphate disked in. All treatments were triplicated in a randomized block design.

After seeding and application of the treatments, the entire plot area was sprinkled to simulate rain. After sprinkling, a soil crust formed, which is common in the area following spring rains.

Stand counts on the inside six rows over a length of 12 m were made following emergence and again after thinning. Thinning crews were instructed to remove plants to obtain a spacing of about 23 cm. Petiole samples collected from plots receiving the H_3PO_4 treatments, the concentrated superphosphate checks, and the nonphosphated checks were dried, ashed in the presence of $Mg(NO_3)_2$, and analyzed for P (15).

Two H_3PO_4 acid spray treatments and a control were applied in 1970 (Table 3, Results and Discussion). These treatments were replicated five times and stand counts were made before and after thinning.

Laboratory Studies

Portneuf silt loam soil from the surface 15 cm was air dried, passed through a 2-mm sieve, and placed in a box in the greenhouse. H_3PO_4 was sprayed on the soil surface using 12% H_3PO_4 at the 1,300 liters/ha rate. The soil was allowed to dry for 24 hours, and distilled water was sprinkled on the surface to wet the soil to approximately field capacity. After the soil was dried for 72 hours, the top 20 mm was removed by 5-mm layers. Below 20 mm the soil was too wet to sample without changing the structure. The remaining soil was allowed to dry for an additional 72 hours and then was removed by 10-mm depth increments to a depth of 70 mm. The soil samples were air dried for analysis.

Samples of each soil layer were sieved, and the aggregates remaining on the 1-mm sieve (> 1 mm) were collected for stability analyses. Aggregate stability was determined by placing 50 g of aggregates on a 0.246-mm (60-mesh) sieve, 20 cm in diameter, and immersing the sieve and the soil in distilled water so that the soil was covered by water but remained inside the sieve walls. After the soil was soaked for 5 min to simulate rapid wetting by rain or irrigation (9, 12), it was shaken through 2.5-cm vertical cycles for 5 min at a rate of 25 cycles/min while immersed in water. The portion of the sample remaining on the sieve was air dried, weighed, and corrected for sand and organic matter larger than 0.246 mm. The aggregates remaining were considered to be water stable.

The $CaCO_3$ equivalent of each soil layer was determined by a manometric method. The pH was measured in a 1:1 soil:water extract, and Ca and Mg were determined on the extract using atomic absorption spectrometry.

RESULTS AND DISCUSSION

Field Studies

Spraying dilute H_3PO_4 in bands on the seeded row increased sugar beet stands before and after thinning where 69 kg P or more was applied per ha in 1968 (Table 1). Prethinning stands were also increased where 35 kg P was applied, but stands after thinning were increased only with the greatest liquid volume. Stand increases were greatest where 138 or 69 kg P/ha was applied in a liquid volume of 1,300 liters/ha. The acid concentrations for these two treatments were 24 and 12%, respectively. These two treatments gave nearly ideal stands after thinning for maximum yields (2), in contrast to low stands where no H_3PO_4 was used. Stands tended to increase as the liquid volume was increased to obtain the same P application. For exam-

Table 1. Effects of phosphoric acid spray treatments on sugar beet stands and P concentrations in sugar beet petioles in 1968.

P applied	Solution volume	Before thinning	After thinning	P concentration in petioles		
				8 July	28 Aug.	15 Oct.
kg/ha	l/ha	beets/ha × 10^{-3} †		%		
			24% H_3PO_4			
138	1,300	139 a‡	52 a	0.220	0.118	0.129
69	650	121 bc	42 cd	.185	.107	.112
35	325	110 cdef	38 de	.120	.091	.103
			12% H_3PO_4			
69	1,300	131 ab	50 ab	.179	.104	.114
35	650	114 bcde	41 cde	.143	.078	.095
17	325	95 fg	39 de	.088	.084	.090
			6% H_3PO_4			
35	1,300	121 bcd	45 bc	.132	.090	.101
17	650	99 efg	40 de	.083	.079	.081
			Controls			
69	prilled	87 g	37 e	.174	.100	.114
0	0	87 g	37 e	.074	.073	.071

* The conversions to English units are: kg/ha × 0.89 = lb/A; l/ha × 0.108 = gal/A; and beets/ha × 0.405 = beets/A. † Ideal stands after thinning for the 61-cm (24-in) row spacing is considered to be 51,400 beets/ha. ‡ Numbers in the same column followed by the same letter do not differ significantly at the 1% level by Duncan's Multiple Range Test.

ple, the after-thinning stands were greater where 69 kg P/ha was applied by using 1,300 liters of 12% H_3PO_4, as compared with using 650 liters of 24% H_3PO_4. Similar trends were evident where greater volumes of less concentrated acid were applied to reach the 35 kg P/ha application. There were no differences in stand counts on the phosphated and nonphosphated controls.

The low stands after thinning on plots receiving no H_3PO_4 resulted from nonuniform stands before thinning. The crust that formed was about 5 mm thick and cracks developed in a random pattern, leaving uncracked sections ranging from about 100 to 1000 cm^2. Seedlings emerged through cracks formed along the seeded row. In other areas, few seedings emerged, resulting in skips.

Applying $Fe_2(SO_4)_3$ and $CaSO_4$ did not reduce soil crusting or increase sugar beet stands in this study.

The P applied by spraying H_3PO_4 in bands on the seeded rows was as available to the sugar beets as that from the same rate of concentrated superphosphate disked-in (Table 1). The P concentrations in petioles where 69 kg P/ha were applied are generally considered adequate, and there was little variation with application method or acid volume. Comparing the P availability from the two application methods is not strictly a surface vs disked-in comparison. Some soil mixing results from conventional cultivation and thinning practices, and this mixing may increase the availability of the surface-applied P.

The 1968 results showed no justification for applying more P than needed by the crop, and applying part of the P in the spray and part of it by other means required unnecessary expense and operations. Therefore, only two concentrations and two volumes were used in 1970 to apply 69 kg of P/ha. Both treatments increased sugar beet stands before and after thinning, and both treatments gave essentially the same results (Table 2). The stands after thinning were very near ideal for maximum yield (2), thus confirming the 1968 results. Results from these studies showed that spraying phosphoric acid in bands on the seeded rows can increase sugar beet emergence by inhibiting soil crusting and provide the P needed for producing the sugar beet crop.

No particular hazards were encountered in handling and appling the H_3PO_4, in contrast to serious problems noted when using H_2SO_4 (8). The only precautions employed were to avoid contact with eyes and to rinse all equipment with water, with $NaHCO_3$ solution, and again with water after use. The spray equipment was constructed from acid-resistant components available from most commercial spray equipment dealers.

Laboratory Studies

All layers of soil treated in the greenhouse contained from 23 to 25% dry aggregates between 1 and 2 mm in diameter before wet sieving. The H_3PO_4 treatment did not change the percentage of aggregates in this size range. It did markedly increase the water stability of these aggregates in the surface 5 mm from about 15% to nearly 60% (Table 3).

The water-soluble P concentration was high in the surface 5 mm, but decreased rapidly with depth to that of the control soil at a depth of 50 mm (Table 3). The acid application decreased the pH to a depth of about 50 mm. The $CaCO_3$ equivalent was markedly decreased in the surface 5 mm by the acid treatments, but little change was apparent below that depth. The acid treatment apparently dissolved most of the carbonates and possibly other materials in the surface 5 mm of soil, and greatly increased the water-soluble Ca^{++} and Mg^{++} concentrations throughout the 70-mm depth.

The laboratory data indicate that the H_3PO_4 applied to calcareous Portneuf silt loam was neutralized by the $CaCO_3$ and $MgCO_3$, thus solubilizing Ca^{++} and Mg^{++}. These ions, in the presence of $PO_4^{\equiv}$ from the acid, form slightly soluble Ca and Mg phosphates (3, 13). These compounds probably acted as cementing agents to increase the water stability of aggregates in the soil surface, resulting in less structural breakdown and subsequent crust formation.

Table 2. Effects of phosphoric acid spray treatments on sugar beet stands in 1970.

P applied	H_3PO_4 conc.	Solution volume	Before thinning	After thinning
kg/ha	%	l/ha	beets/ha × 10^{-3}*	
69	12	1,300	154 a	53 a†
69	24	650	153 a	51 a
0	0	0	87 b	36 b

* Numbers in the same column followed by the same letter do not differ significantly at the 1% level by Duncan's Multiple Range Test. † Ideal stands after thinning for 56-cm row spacing used is considered to be 53,600 plants/ha.

Table 3. Physical and chemical properties of soil sprayed with 12% H_3PO_4 in the greenhouse in relation to depth as compared to untreated soil.

Depth	Aggregate stability	pH	$CaCO_3$ equivalent	P	Mg^{++}	Ca^{++}
mm	%		%	ppm	me/100 g	
0-5	57	5.51	<0.5	6,250	5.50	11.00
6-10	17	6.55	3.7	1,580	1.93	4.25
11-15	11	6.79	3.8	1,430	1.95	3.50
16-20	10	6.78	3.8	1,430	2.00	3.30
21-30	10	6.84	3.8	300	2.05	3.35
31-40	14	7.28	3.8	104	2.10	4.50
41-50	12	7.80	3.7	18	2.30	6.10
51-60	12	7.88	3.8	10	3.45	9.80
61-70	17	8.01	3.7	15	3.38	9.50
Untreated	13	8.08	3.7	9	0.73	2.35

CONCLUSIONS

These investgiations have shown that spraying dilute agricultural-grade H_3PO_4 on calcareous soil in narrow bands on the seeded row reduces soil crusting and increases sugar beet stand counts to near ideal after thinning. The P from the H_3PO_4 is available to the crop, and the amount needued for the crop is also adequate to control soil crusting, provided 650 to 1,300 liters of 24 to 12% acid, respectively, is applied per hectare. The acid can be applied simultaneously with seeding and with no serious hazard to applicators and equipment. Crust formation is evidently reduced by greatly increased water stability of aggregates in the surface 5 mm of the soil, and the increased aggregate stability probably results from the formation of slightly soluble Ca and Mg phosphates that act as cementing agents in soil aggregates. This method of soil crusting control and combined P fertilization should be equally effective for other crops where crusting inhibits emergence on calcareous soils.

LITERATURE CITED

1. Allison, L. E. 1956. Soil and plant responses to VAMA and HPAN soil conditioners in the presence of high exchangeable sodium. Soil Sci. Soc. Amer. Proc. 20:147-151.

2. Becker, C. F. 1968. The influence of planting rate and thinning method on sugarbeet stand. J. Amer. Sugar Beet Technol. 15:177-185.
3. Bell, L. C., and C. A. Black. 1970. Transformation of dibasic calcium phosphate dihydrate and octacalcium phosphate in slightly acid and alkaline soils. Soil Sci. Soc. Amer. Proc. 34:583-587.
4. Bennett, O. L., D. A. Ashley, and B. D. Doss. 1964. Methods of reducing soil crusting to increase cotton seedling emergence. Agron. J. 56:162-165.
5. Cary, J. W. 1967. Punch planting to establish lettuce and carrots under adverse conditions. Agron. J. 59:406-408.
6. Hanks, R. J., and F. C. Thorp. 1957. Seedling emergence of wheat, grain, sorghum and soybeans as influenced by soil crust strength and moisture content. Soil Sci. Soc. Amer. Proc. 21:357-359.
7. Hudspeth, E. B., and H. M. Taylor. 1961. Factors affecting seedling emergence of Blackwell switchgrass. Agron. J. 55:331-335.
8. Johnson, R. C., and J. B. Law. 1967. Controlling soil crusting in sugarbeet fields by applying concentrated sulfuric acid. J. Amer. Soc. Sugar Beet Technol. 14:615-618.
9. Kemper, W. D., and E. J. Koch. 1966. Aggregate stability of soils from Western United States and Canada. USDA Tech. Bull. 1355.
10. ————, and L. Noonan. 1970. Runoff as affected by salt treatment and soil texture. Soil Sci. Soc. Amer. Proc. 34:126-130.
11. McIntyre, D. S. 1958. Soil splash and the formation of surface crusts by raindrop impact. Soil Sci. 85:261-266.
12. Robinson, D. O., and J. B. Page. 1950. Soil aggregate stability. Soil Sci. Soc. Amer. Proc. 15:25-29.
13. Racz, G. J., and R. J. Soper. 1967. Reaction products of orthophosphates in soils containing varying amounts of calcium and magnesium. Can. J. Soil Sci. 47:223-230.
14. Tackett, J. L., and R. W. Pearson. 1965. Some characteristics of soil crusts formed by simulated rainfall. Soil Sci. 99:407-413.
15. Watanabe, F. S., and S. R. Olsen. 1964. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Amer. Proc. 29:677-678.