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BORON REQUIREMENTS of Crops in Alabama

AGRICULTURAL EXPERIMENT STATION
of the ALABAMA POLYTECHNIC INSTITUTE
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BOREON REQUIREMENTS

of

Crops in Alabama[1]

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A SMALL continuous supply of boron is required by plants from germination to maturity. This continuous supply is necessary because boron is used and fixed in the plant and does not move to new growth areas as does nitrogen or magnesium. Since boron does not move to new growth areas, deficiency symptoms appear in the youngest growing parts. Thus, the older leaves remain green, whereas the younger growing tip may not develop or may die.

Boron deficiency also affects connecting tissue or conducting tubes that allow the food products produced in the leaves to move into the storage organs. A deficiency of boron may cause older leaves to be thick, brittle, and generally darker green. Boron-deficient storage organs, as in beets and turnips, will be dark and contain dead tissue. Seed development may be drastically reduced by a deficiency of boron.

Boron is closely associated with calcium absorption and utilization. When the calcium supply in the soil is low, boron will increase its absorption and utilization. A high level of lime in the soil reduces boron absorption and may cause boron deficiency if the supply is at a critical level.

The soil can supply the amount of boron required by most plants. Other plants, especially legumes, may require larger amounts than the soil can provide. Therefore, boron must be added to the soil for adequate growth.

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[1] Information in this bulletin represents results of investigations by the Agronomy and Soils and Horticulture Departments, Experiment Fields, and Substations of the Agricultural Experiment Station of the Alabama Polytechnic Institute.

Boron Deficiency Symptoms of Plants

A plant deficient in boron may not show any visible symptoms. Crimson clover seed production may be seriously limited by a deficiency of boron without any visible deficiency symptoms. Plant storage organs may be damaged without external symptoms as in the case of turnips and cauliflower. Most crops, however, will show an external symptom that is characteristic of the deficiency.

Alfalfa

Boron deficiency in alfalfa appears as a uniform yellowing of terminal leaves or bronzing of interveinal areas, poor development of internodes, and death of growing points, Figure 1. Care should be taken not to confuse boron deficiency with leaf hopper damage. Yellowing or reddening of leaves due to boron deficiency is generally confined to terminal leaves including lateral branches, whereas leaf hopper injury causes leaf discoloration at different levels on the shoot and the internode is not shortened. The girdle by the leaf hopper can be noted at the base of the alfalfa stem.

Apples

Apples can show boron deficiency symptoms in many ways. The fruit becomes corky and the skin may die; lesions or small greenish round spots occur on the fruit. The skin lesions become dark and corky. More severe deficiency results in rosetting of leaves and die-back of limbs.

Beets

Dark spots appear on the surface of the beet and extend into the flesh. Canker or internal dead areas are prominent between the rings of the beet. The growing tip of the plant may die or the plant may have dark green or thickened leaves.

Cabbage and Broccoli

In boron-deficient cabbage or broccoli, young leaves curl before the head is formed; heads may have a discolored or watery core.

Carrots

Yellow to pinkish leaves is a characteristic of boron deficiency. The edible portion of the carrot may split.

FIGURE 1. Top: Uniform yellowing of terminal leaves or bronzing of interveinal areas, poor development of internodes, and death of growing points are symptoms of boron deficiency in alfalfa. Bottom: Dark center with dead tissue is most characteristic symptom of boron deficiency of cauliflower.

Cauliflower

The most characteristic symptom shown by cauliflower is the dark center with dead tissue. Dark areas may appear on head, and leaves may be brittle and thick, Figure 1.

Clovers

Seed reduction occurs before vegetative parts of clover are affected. Severe deficiency reduces vegetative growth and causes red coloration on leaves, first affecting the margin on the tip half, which is most striking on younger leaves.

Corn

Ears show a dark brown narrow band extending around the outer edge of cobs at the base of the kernels. Corn plants may appear dark green and have curled leaves.

Lettuce

Boron deficiency of lettuce appears as a spotting and burning of the tips of more rapidly growing leaves.

Tomatoes

Tomato plants are stunted by insufficient boron. The upper leaves turn orange-yellow with purplish browning of the leaf margins.

Turnips

In boron-deficient turnips, root tubers have brown heart or watery core. In more deficient plants the leaves may appear purplish yellow and may die from the margins.

Sweetpotatoes

A boron-deficient sweetpotato plant has a shortened internode, curled petiole, and the terminal bud may die. The potato may be corky or have a dark center.

Muscadine Grapes

Boron deficiency of muscadine grapes is evidenced by dark brown watersoaked areas in the apical tendrils, followed by die-back of tendrils and chlorosis and twisting of young leaves. In the later stage, dead areas appear in the old leaves. The internodes may be shortened and brittle.

SOURCE OF BORON FOR FERTILIZER USE

Borax

Borax ($Na_2B_4O_7.10H_2O$) in a pure form is a white crystalline material containing 11.3 per cent boron. The pure form is too expensive to use as a fertilizer material. Boron recommendations are generally expressed in terms of borax. Commercial grades are described below.

Fertilizer Borate

Fertilizer Borate ($Na_2B_4O_7.10H_2O$) is a commercial grade of borax for fertilizer use. This compound contains 10.5 per cent boron and is 93 per cent borax equivalent. It is very soluble in soil moisture. It requires 10.7 pounds of this material to be equivalent to 10 pounds of borax.

Fertilizer Borate, High Grade or Tronabor

Fertilizer Borate, high grade or Tronabor, ($Na_2B_4O_7.5H_2O$) is a borax compound containing 13.6 per cent boron and 121 per cent borax equivalent. It requires only 8.25 pounds of this material to be equivalent to 10 pounds of borax.

Colemanite

Colemanite ($Ca_2B_6O_{11}.5H_2O$) contains 10.1 per cent boron and is equivalent to about 89 per cent borax. This material is less soluble in soil solution than borax and does not leach out of coarse-textured soils as rapidly. This property makes Colemanite a better source of boron for sensitive crops on coarse-textured soils.

Polybor

Polybor-2 and -3 (78% $Na_2B_8O_{13}.4H_2O$ and 20% $Na_2B_4O_7.5H_2O$) contains 20.5 per cent boron and is equivalent to 181 per cent borax. Only 5.5 pounds of this material is equivalent to 10 pounds of borax.

Chicken Manure Containing Boron

Poultrymen often apply polybor to chicken droppings to control flies. The amount of polybor used varies considerably depending on time of year, fly population, and other factors. An average condition may be considered. A farmer with 1,000 hens will use 100 pounds of polybor over a 3-month period during the fly season. He cleans the house at the end of the year obtaining 30 tons of manure. This contains 100 pounds of polybor (equivalent to 181 pounds of borax) or 6 pounds of borax per ton. The boron will not be uniformly mixed and one-fourth may contain 24 pounds per ton and three-fourths may not contain any added boron. Manure containing large amounts of polybor should be used with care around sensitive crops (see list of sensitive crops on page 28).

Synthetic Boron Slags and Frits

These materials are manufactured to give less soluble boron compounds. They are being tested as sources of boron for crops.

Basic Slag

Some basic slags contain small amounts of boron, dependent upon the quality of borax added as a flux (not a reliable source).

Commercial Fertilizers

Many commercial grade fertilizers containing minor elements are available. These mixes generally contain only about 20 pounds of borax per ton, which is insufficient boron for alfalfa, crimson clover for seed, cauliflower and other crops that require large amounts of borax. Boron may be present as impurities in other fertilizer materials. However, this is generally not more than 1 pound of borax per ton of fertilizer.

Boron Materials of Low Solubility and Their Use for Plant Growth

For many years it has been a common practice to add boron to the soil in the form of very soluble boron compounds. The use of a very soluble boron carrier has two definite disadvantages: (1) initial solubility is very high and relatively small amounts can cause toxicity to some plants, (2) soluble boron is leached from sandy soils rapidly so that the greater portion of the added boron is lost.

Three boron carriers, fertilizer borate high grade, Colemanite, and Howlite, containing 13.6, 10.1, and 11.0 per cent boron, respectively, were tested in a greenhouse and field studies *(14)*. These carriers represent a sodium borate of high solubility, a calcium borate of intermediate solubility, and a borosilicate of low solubility. Howlite is not a commercial source of boron, but it is a typical borosilicate of the low solubility class.

The water-soluble boron in fertilizer borate was 5 times greater than in Colemanite and 25 times greater than in Howlite.

Particle size had only a slight effect on the water-soluble boron recovered from fertilizer borate. However, for Colemanite and Howlite, the amount of water-soluble boron recovered was 6 to

TABLE 1. EFFECTS OF DIFFERENT RATES OF THREE BORON CARRIERS ON TURNIPS GROWN IN THE GREENHOUSE

Boron carrier added per acre	Yield, boron content, and degree of toxicity			
	Tops	Roots	Boron in tops	Plant toxicity
	Av. dry wt. per pot	Av. dry wt. per pot		
Pounds	*Grams*	*Grams*	*p.p.m.*	*Degree*
None	10.9	99.6	24	None
Fertilizer borate				
3	8.7	82.1	48	None
6	10.8	75.4	60	None
12	10.2	65.1	91	None
24	10.9	53.8	140	Slight
Colemanite				
15	11.7	85.3	56	None
30	11.3	76.0	100	None
60	12.7	54.0	144	Slight
120	12.0	57.0	337	Severe
Howlite				
75	10.0	63.6	280	None
150	9.9	55.6	------[1]	Slight
300	11.0	45.0	460	Severe
600	8.2	24.7	460	Severe

[1] Sample missing.

TABLE 2. EFFECTS OF DIFFERENT RATES OF THREE BORON CARRIERS ON SOYBEANS GROWN IN THE GREENHOUSE

Boron carrier added per acre	Yield, boron content, and degree of toxicity to plants				
	Before leaching soil			After leaching soil	
	Av. dry wt. per pot	Boron content	Plant toxicity	Av. dry wt. per pot	Plant toxicity
Pounds	*Grams*	*p.p.m.*	*Degree*	*Grams*	*Degree*
None	7.5	49	None	9.7	None
Fertilizer borate					
2	7.3	84	None	10.5	None
4	6.5	107	None	11.6	None
8	5.5	162	Slight	11.2	Slight
16	3.0	250	Moderate	11.0	Slight
Colemanite					
10	7.1	88	Slight	10.5	Slight
20	5.7	150	Moderate	11.2	Moderate
40	5.5	231	Severe	9.6	Moderate
80	0.9	------[1]	Severe	7.6	Severe
Howlite					
50	3.3	49	Slight	8.4	Slight
100	0.3	225	Moderate	6.3	Moderate
200	0.1	------[1]	Severe	1.8	Severe
400	----[2]	------[2]	Severe	0.6	Severe

[1] Insufficient material for analysis.
[2] Died immediately following germination.

8 times greater for finer than 80-mesh material as compared to coarser than 10-mesh material. This indicates importance of particle size in controlling the rate of solubility of more slowly soluble sources of boron.

Water-soluble boron in fertilizer borate, Colemanite, and Howlite was in the ratio of approximately 1:5:25. Nevertheless, boron contents and toxicity symptoms of turnips and soybeans grown in the greenhouse in Norfolk loamy sand indicated a requirement of about twice as much Colemanite as fertilizer borate and 2 to 3 times as much Howlite as Colemanite to produce the same degree of toxicity, Tables 1 and 2.

Results of the field-leaching study on Norfolk loamy sand indicate that high-grade fertilizer borate leached from the topsoil rapidly and collected in the lower zones of 8 to 16, and 16 to 24 inches. Twelve months later most of the water-soluble boron was leached past the 2-foot depth. Howlite leached from the topsoil slowly; the concentrations of water-soluble boron remained fairly constant for the 6- and 12-month periods. Colemanite was intermediate between the highly soluble sodium borate and the less soluble borosilicate from the standpoint of loss by leaching, Figures 2, 3, and 4.

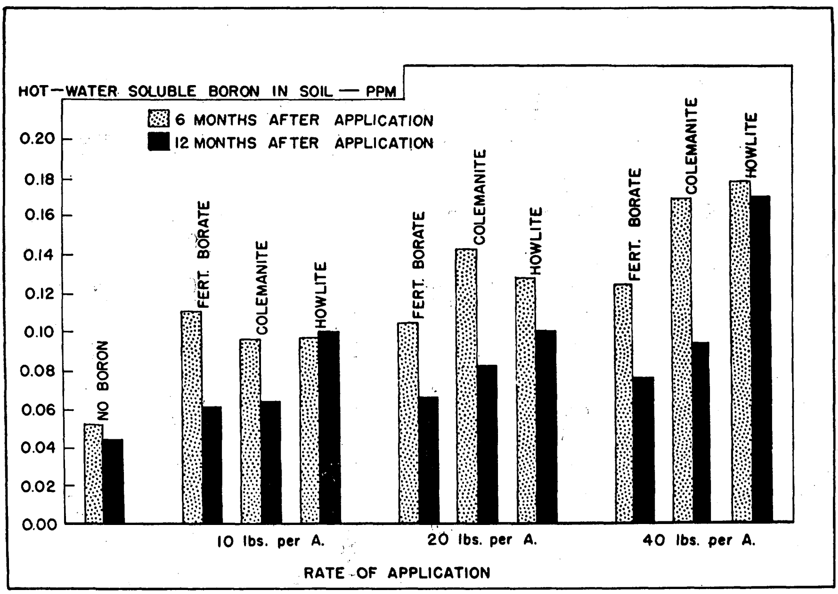

FIGURE 2. Water-soluble boron content of soil at 0- to 8-inch depth.

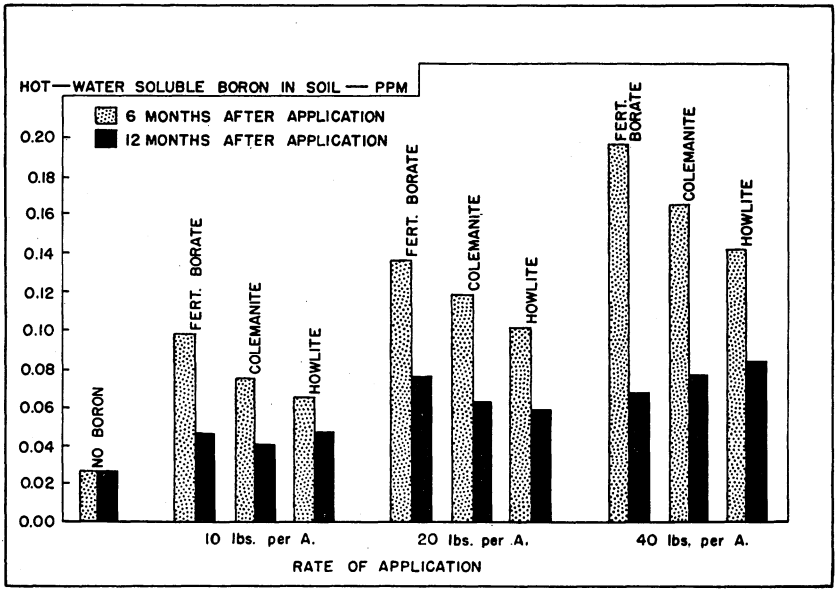

FIGURE 3. Water-soluble boron content of soil at 8- to 16-inch depth.

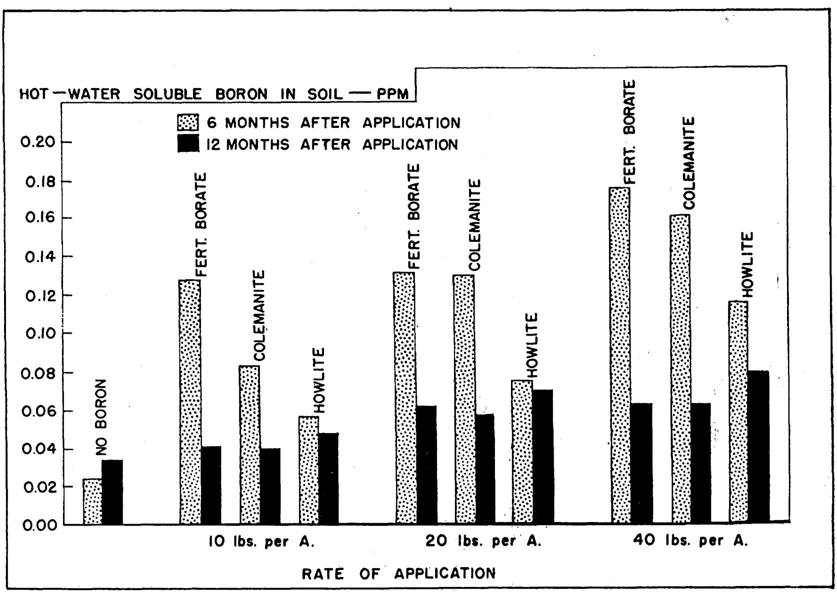

FIGURE 4. Water-soluble boron content of soil at 16- to 24-inch depth.

Residual Effects of Boron Added to Alabama Soils

Boron is generally added to soil as the borate ion. Since this is an anion, unlike calcium and potassium, it is not held by the exchange complex of the soil and is readily leached out of coarse-textured soils. However, borates accumulate to some extent in finer textured soils.

Annual applications of borax at rates of 0, 10, 20, and 30 pounds per acre were made on six Alabama soils *(15)*. Location, soil type, pH, and exchange capacity are given in Table 9. Each year the soil was sampled at two depths, 0 to 6 and 6 to 12 inches, and the amount of water-soluble boron was determined.

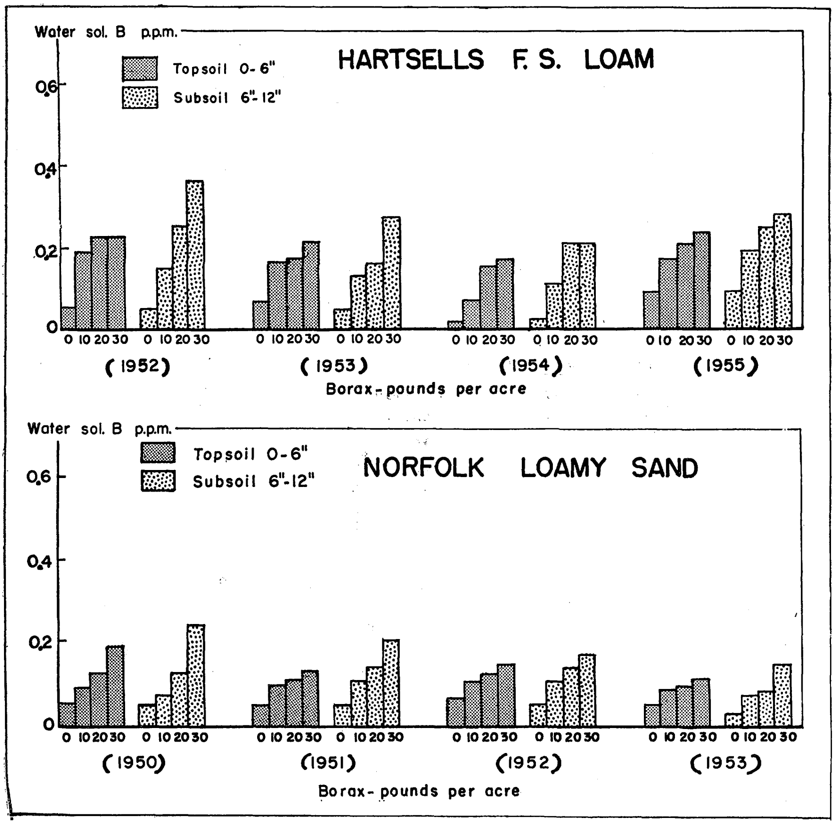

FIGURE 5. Water-soluble boron content of coarse-textured soils during 4 years when annual applications of 0, 10, 20, and 30 pounds of boron per acre were made.

Accumulation of Boron in Soil

Results of this study indicate that the amount of boron that will accumulate in the soil depends to a large degree on soil texture. Increasing rates of borax applied to crimson clover about September 1 on coarse-textured soils resulted in increased amounts of water-soluble boron present in the soil in May. There were, however, no further accumulations of water-soluble boron after the first year in the surface 12 inches of these coarse-textured soils, Figure 5.

In the case of fine-textured soils, the boron content continued

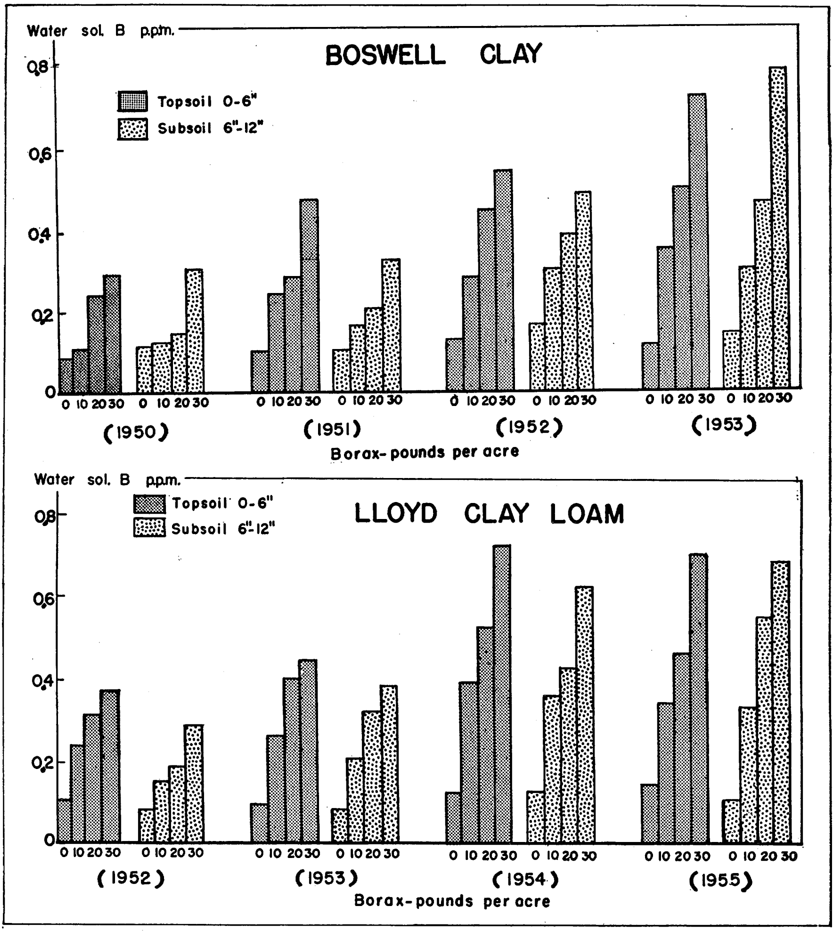

FIGURE 6. Water-soluble boron content of fine-textured soils during 4 years when annual applications of 0, 10, 20, and 30 pounds of boron per acre were made.

to increase with each annual application as well as with increasing rates, Figure 6.

These results were consistent for the 4 coarse- and 2 fine-textured soils. Graphs showing accumulated amounts of water-soluble boron in 2 coarse- and 2 fine-textured soils are presented in Figures 5 and 6.

Effects of Accumulation of Boron on Sensitive Crops

Cotton planted on plots following crimson clover that had received 30 pounds of borax per year for 4 years showed no toxic condition or injury to cotyledons or leaves. Furthermore, there was no decrease in yields on the three soils tested, Boswell clay, Norfolk loamy sand, and Kalmia loamy fine sand.

Soybeans, one of the most sensitive crops to excess boron, was planted on Lloyd clay loam at the Piedmont Substation near Camp Hill following applications of boron at the rate of 30 pounds of borax per acre per year to crimson clover. This crop showed no signs of toxic conditions on the cotyledons or leaves. Water-soluble boron in the Lloyd clay loam increased from 0.10 to 0.72 p.p.m. from the annual 30-pound rate of borax.

Rainfall, organic matter, pH, soil texture, and possibly other factors are effective in determining whether toxicity from residual boron will occur.

Available Boron in Alabama Soils

The amount of boron available to plants is dependent upon several factors. The plant to be grown is important; for example, soybeans can absorb larger amounts of boron from a soil than alfalfa. Consequently, boron deficiency is rarely found in soybeans. Such soil factors as texture, pH, and organic matter affect the amount of available boron.

Table 3. Boron Content of 243 Samples of Alabama Soils by Soil Texture, 1955-56

Soil texture	Number of samples	Average water-soluble boron
	Number	*p.p.m.*
Clay	14	0.171
Clay loams	42	.152
Silt loams	18	.130
Fine sandy loams	126	.091
Sandy loams	25	.068
Loamy sands	12	.062
Sands	6	.032

TABLE 4. BORON CONTENT OF 243 SAMPLES OF ALABAMA SOILS BY AREAS, 1955-56

Soil area	Number of samples	Average water-soluble boron
	Number	*p.p.m.*
Black Belt	10	0.182
Limestone Valley	34	.175
Piedmont Plateau	17	.101
Sand Mountain	22	.096
Coastal Plain	160	.087

Analyses of 243 Alabama soils collected by the Soil Testing Laboratory at this station showed that more water-soluble boron is present in fine-textured soils than in coarse-textured soils. Crops grown on sandy soils will be more likely to need added boron than those grown on clay soils. Therefore, boron deficiency is more prevalent on the Coastal Plain and Sand Mountain soils than on those of the Limestone Valley, Black Belt, and Piedmont regions, Tables 3 and 4.

RELATIONSHIP OF LIME AND BORON

Previous work in Alabama showed that excessive liming caused injury to vetch, turnips, oats, cabbage, tomatoes, and soybeans on sandy soils with pH values above 6.8 and low base-exchange capacities. Additions of small amounts of boron prevented over-liming injury and increased yield *(6)*. Since these studies on over-liming were conducted on relatively light-textured soils of the Coastal Plain, tests were initiated to determine the effect of lime and boron on yield of vetch, sorghum, soybeans, and cotton grown on 20 soils representing 15 soil series, Table 5. These tests were conducted using (1) zero, (2) moderate, and (3) excessive

TABLE 5. EFFECTS OF BORON ON YIELDS OF SUCCESSIVE CROPS FROM SOIL EXCESSIVELY LIMED, GREENHOUSE STUDY

Soil type	Relative yields of successive crops[1]							
	Vetch		Sorghum		Soybeans		Cotton	
	No B	With B	No B	With B	No B	With B	No B	With B
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Cecil sandy loam	46	92	60	73	49	85	78	108
Decatur clay	110	121	94	88	69	81	98	103
Davidson clay	67	100	48	88	75	106	117	107
Oktibbeha clay	97	76	105	109	117	104	204	237
Eutaw clay	83	110	121	110	102	117	129	151
Norfolk loamy sand	57	125	120	135	61	74	228	247

[1] Yields from untreated soils, no boron and no lime, as 100.

TABLE 6. EFFECTS OF BORON AND LIME ON YIELDS OF CRIMSON CLOVER, SOYBEANS, AND ALYCE CLOVER, AND ON BORON CONTENT OF CRIMSON CLOVER STRAW AND SOIL, MAIN STATION

Liming treatment		Minor element	Crimson clover[1]				Soybeans	Alyce clover
			Yield per acre		Boron content			
Source	Rate per acre		Seed[2]	Straw[3]	Straw[4]	Soil[4]	Yield per acre[5]	Yield per acre[6]
	Pounds		*Pounds*	*Pounds*	*p.p.m.*	*p.p.m.*	*Pounds*	*Pounds*
No lime	0	None	51	1,595	10.0	0.062	2,619	383
Dolomitic	1,500	None	62	1,136	10.7	.053	5,037	2,843
Dolomitic	3,000	None	53	3,453	10.1	.051	4,899	5,285
Dolomitic	4,000	None	74	3,158	9.7	.056	5,545	4,952
Dolomitic	8,000	None	50	2,558	9.5	.047	4,730	4,646
Calcitic	1,500	None	63	2,932	9.0	.047	4,284	2,032
Calcitic	3,000	None	58	3,365	8.7	.042	4,671	3,378
Average without boron			59	2,885	9.7	.051	4,540	3,360
No lime	0	Boron[7]	232	1,887	21.6	0.144	2,951	154
Dolomitic	1,500	Boron	433	4,013	18.2	.103	4,402	1,665
Dolomitic	3,000	Boron	482	4,534	23.0	.116	5,277	3,607
Dolomitic	4,000	Boron	552	4,487	20.5	.106	5,529	4,215
Dolomitic	8,000	Boron	696	4,920	21.5	.119	5,811	3,759
Calcitic	1,500	Boron	429	3,745	20.0	.112	3,933	1,775
Calcitic	3,000	Boron	418	3,808	19.5	.119	4,280	2,442
Average with boron			462	3,912	20.6	.117	4,598	2,517

[1] 300 pounds per acre of 0-14-0 was applied to crimson clover and the summer hay.
[2] 7-year average.
[3] 1944-45 average yields.
[4] Analyses made of 1942 crop and of soil in 1942.
[5] 3-year average.
[6] 1-year average.
[7] Boron was applied at rate of 10 pounds of borax per acre in 1941 and 15 pounds per acre in 1942-44.

amounts of lime ($CaCO_3$) with and without boron. Results of plant growth in pot cultures showed that excessive lime caused injury to plants on 15 of the 20 soils tested *(5)*. The injured plants showed evidence of boron deficiency, which was partially or completely overcome by early additions of boron. Typical examples of yields of four successive crops on several soils are given in Table 5. It was also shown that liming decreased the water-soluble boron in soils naturally low in boron.

A field study was conducted to determine the effect of liming on the response of crimson clover, soybeans, and Alyce clover to boron and other minor elements *(1)*. The experiment was conducted for 7 consecutive years in small field plots on a Norfolk loamy sand located near Auburn, Table 6. Results of the study indicated that:

(1) The crops varied considerably in their sensitivity to and need for the minor elements.

(2) Crimson clover growth and seed production were markedly increased by addition of boron. Lime, in addition to boron, further increased the yield.

(3) There was no apparent effect of minor elements on soybeans with or without lime.

(4) Growth of Alyce clover was reduced by addition of the minor elements both in the presence and absence of added lime.

(5) The application of borax greatly increased the water-soluble boron content of the soil in all cases. Liming slightly decreased the amount of water-soluble boron.

Experimental Results with Crops

Alfalfa

Extensive field tests at eight locations in the State have shown conclusively that boron is needed for high yields, good quality, and maintenance of stands of alfalfa. Results of these tests are presented in Table 7. In all cases, 15 pounds of borax per year increased the yield of alfalfa; at four locations, 30 pounds of borax increased yields above the 15-pound rate. For more detailed information concerning these tests see Bulletin No. 300, "Alfalfa Production in Alabama," by this station. An adequate supply of boron not only is important for yield, but is necessary for high-quality hay. Alfalfa with insufficient boron will become yellow or chlorotic. This condition is usually more severe after

TABLE 7. RESPONSE OF ALFALFA TO BORAX IN ALABAMA

Location, soil type, and length of test	Hay yields per acre[1]		
	No borax	15 lb. borax	30 lb. borax
	Pounds	*Pounds*	*Pounds*
Sand Mountain			
Hartsells fine sandy loam 4-year average, 1949-52	5,552	6,815	7,812
Alexandria			
Decatur clay loam 5-year average, 1948-52	6,147	6,738	5,818
Upper Coastal Plain			
Atwood fine sandy loam 6-year average, 1949-54	6,149	6,609	6,826
Auburn			
Chesterfield sandy loam 7-year average, 1943-49	6,039	6,852	------
Prattville			
Greenville fine sandy loam 4-year average, 1949-52	5,055	6,137	9,575
Atmore			
Orangeburg fine sandy loam 5-year average, 1945-49	7,047	8,392	7,449
Gulf Coast			
Norfolk fine sandy loam 3-year average, 1945-47	------	7,712	8,282
Black Belt			
Sumter clay 7-year average, 1948-54	8,886	9,789	9,632

[1] Lime, P_2O_5, and K_2O applied in adequate amounts.

the first cutting or under drought conditions. On plots without borax, it has been noted that alfalfa stands become thin permitting growth of weeds and grass.

Crimson Clover

Considerable information has been obtained in Alabama concerning the effects of borax on crimson clover seed yields. Data presented in Table 6 show a large increase in crimson clover seed yields on a Norfolk loamy sand that was deficient in boron. A moderate increase in straw was also obtained. These results were obtained under a wide range of liming conditions *(1)*.

Eighteen field tests, predominantly on farmers' lands, were conducted from 1942 to 1946 on 16 coarse-textured soils and 2 fine-textured soils *(10)*. Sizeable increases in seed production were obtained on 15 of the coarse-textured soils. A relatively small response in seed yield was obtained from one of the fine-textured

TABLE 8. RESPONSE OF CRIMSON CLOVER TO BORAX IN FIELD TESTS IN ALABAMA

Location of test			Per acre yield response to borax		
County	Soil type	Length of test	Increase	Increase	Related observations
		Years	*Pounds*	*Per cent*	
Lee	Norfolk l.s.	4	760(S)[1]	854	Seed crop practically failure without B
Lee	Norfolk l.s.	2	521(S)	362	Seed crop practically failure without B
Lee	Norfolk l.s.	1	158(S)	62	Response in seed yield but not in vegetative growth
Lee	Norfolk s.l.	1	n.d.	n.d.	Severe injury to stand by 15 pounds of borax per acre
Lee	Norfolk l.s.	1	n.d.	n.d.	Early maturity and better filled seed heads
Dale	Norfolk l.s.	1	–264	–16	Grazed heavily all winter
Geneva	Norfolk s.l.	1	604	127	Grazed heavily all winter; increased root growth where B was applied
Houston	Norfolk s.l.	1	1,029	148	Grazed heavily all winter; increased root growth where B was applied
Houston	Norfolk s.l.	1	59(S)	55	No effect on vegetative growth
Houston	Ruston s.l.	1	235(S)	129	Early maturity where B was applied
Geneva	Norfolk s.l.	1	137(S)	87	Borax decreased stand but increased seed yield
Geneva	Orangeburg s.l.	1	117(S)	70	No effect on vegetative growth
Geneva	Orangeburg s.l.	1	561	146	Grazed heavily all winter
Lee	Madison c.l.	2	135(S)	23	Response in seed yield but not in vegetative growth
Marengo	Cahaba l.s.	1	194(S)	380	Also a 200 per cent increase in straw yield
Wilcox	Wickham l.s.	1	270(S)	415	Also a 109 per cent increase in straw yield
Tallapoosa	Lloyd c.l.	1	n.d.	n.d.	No apparent response in vegetative growth
DeKalb	Hartsells s.l.	3	n.d.	n.d.	No apparent response in vegetative growth

[1] (S) Seed.

soils; the yield from the other was not reported. An increase in vegetative growth was obtained at only 2 of the 8 measured locations, Table 8.

Field tests were conducted at six locations in Alabama from 1950 to 1954 to determine the optimum rate of borax for crimson clover seed production *(15)*. The location, soil type, pH, and base exchange capacity are given in Table 9.

TABLE 9. SOIL DATA FROM CRIMSON CLOVER TESTS

Location	Soil type	pH[1]	Base exchange capacity, m.e. per 100 gm. soil
			m.e.
Auburn	Norfolk loamy sand	5.6	2.8
Tuskegee	Boswell clay	5.3	9.9
Crossville	Hartsells fine sandy loam	5.4	3.2
Camp Hill	Lloyd clay loam	5.3	6.0
Brewton	Kalmia loamy fine sand	5.5	3.4
Camden	Norfolk fine sandy loam	5.6	2.6

[1] At conclusion of test.

Results in Figure 7 show that 10 pounds of borax increased crimson clover seed yields on all four coarse-textured soils. Increases from rates of borax above 10 pounds were not significant. The native water-soluble boron content of these soils was 0.058 p.p.m. boron or less. Following crimson clover seed harvest, the

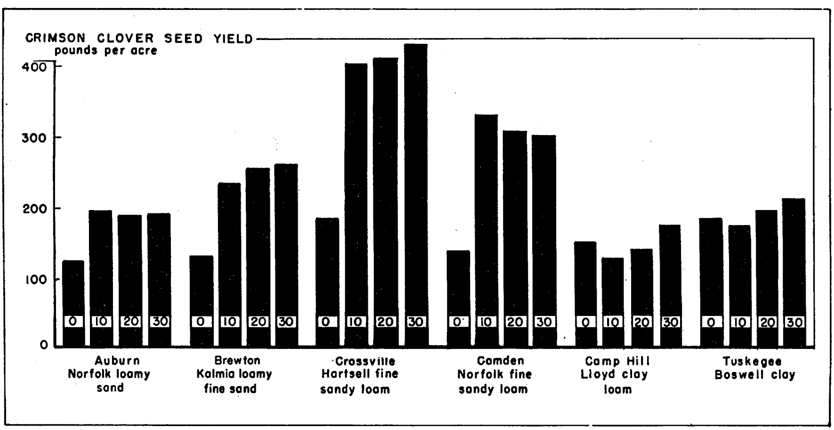

FIGURE 7. Yields of crimson clover seed from varying application rates of borax to six soils in Alabama. No yields were obtained from Camp Hill in 1953-54, Camden in 1954, and Crossville in 1955, due to drought or early freeze.

10-pound rate of borax applied each year increased the level of water-soluble boron.

In these tests no significant increases in crimson clover seed were obtained from applications of borax on the two fine-textured soils. The native water-soluble boron in these soils was 0.092 p.p.m. boron or higher.

Boron is essential for high seed yields of crimson clover on coarse-textured soils. A boron application may not increase seed yield on some of the fine-textured soils, but it is recommended that a source of boron be added in doubtful cases because of the possibility of high return for only a few pounds of material.

Results indicate that hay or straw yields can be increased if the soil is very deficient in boron. In most cases, vegetative growth is not affected materially and the growth increase is not in proportion to seed yield increases.

Sericea

Field tests were conducted for periods of from 5 to 8 years at seven locations in the State to determine if borax would affect the yield or stand of sericea. Results of these tests showed that 15 pounds of borax per acre per year had no effect on the yield of hay, Table 10. Another test in Lee County showed the same results, Table 11. Reports have been made that borax can actually damage sericea in the seedling stage and is not recommended.

TABLE 10. EFFECT OF BORAX ON YIELD OF SERICEA HAY AT SEVEN LOCATIONS IN ALABAMA, 1948-55

Borax treatment per acre per year	Yield of dry weight of hay per acre								
	1948	1949	1950	1951	1952	1953	1954	1955	Average
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Sand Mt. Substation									
No borax	------	------	7,939	6,863	7,924	5,461	3,549	4,626	6,060
15 pounds borax	------	------	7,073	6,991	8,088	6,166	4,196	4,502	6,169
Monroeville Field									
No borax	5,684	6,460	6,755	7,249	6,987	6,968	7,017	5,510	6,579
15 pounds borax	6,207	6,967	6,609	7,227	7,061	7,728	7,131	4,961	6,736
Tuskegee Field									
No borax	2,767	9,436	8,418	7,816	6,057	6,995	8,070	8,548	7,264
15 pounds borax	3,119	9,398	9,013	7,668	5,923	7,054	7,869	8,188	7,280
Piedmont Substation									
No borax	5,619	5,481	6,482	3,107	6,579	5,875	------	------	5,524
15 pounds borax	5,040	4,969	6,632	3,317	7,499	6,454	------	------	5,652
Alexandria Field									
No borax	4,372	3,438	9,536	5,953	5,749	1,883	------	------	5,156
15 pounds borax	4,294	3,704	5,795	6,502	6,055	1,876	------	------	5,304
Brewton Field									
No borax	4,309	7,728	7,521	6,944	7,597	5,613	------	------	6,619
15 pounds borax	4,632	7,008	6,595	5,980	6,267	5,480	------	------	5,994
Prattville Field									
No borax	7,410	9,018	6,355	6,782	6,012	------	------	------	7,115
15 pounds borax	7,122	9,410	5,851	6,401	5,021	------	------	------	6,761

TABLE 11. RESPONSE OF LEGUMES TO BORAX IN FIELD TESTS IN ALABAMA

Location of test		Length of test	Per acre yield response to borax*		Related observations
County	Soil type		Increase	Increase	
		Years	*Pounds*	*Per cent*	
			Bur clover		
Lee	Norfolk l.s.	1	5,677(G)	214	Winter grazed, failure without B
Lee	Norfolk l.s.	1	11,350(G)	192	Poor stand, pinkish yellow leaves without B
Lee	Norfolk l.s.	1	7,945(G)	85	Poor stand, pinkish yellow leaves without B
Marengo	Cahaba l.s.	1	8,750(G)	------	Complete failure without B
Lee	Chesterfield s.l.	2	3,182(G)	67	Grazed during winter but marked response
Macon	Susquehanna c.	1	n.d.**	n.d.	No apparent response
Macon	Vaiden c.l.	1	n.d.	n.d.	No apparent response
Tallapoosa	Lloyd c.l.	1	n.d.	n.d.	No apparent response
Tallapoosa	Appling c.l.	1	6,050(G)	167	Marked chlorosis without B
Tallapoosa	Appling l.s.	1	n.d.	n.d.	Yields not taken but marked deficiency symptoms
			Red clover		
Lee	Norfolk l.s.	2	566	36	Severe injury but marked response
Lee	Madison c.l.	2	65	2	No apparent vegetative response
DeKalb	Hartsells s.l.	1	n.d.	n.d.	No apparent vegetative response
			White clover		
Lee	Norfolk l.s.	2	753	158	Severe injury to stand but marked response
			Austrian winter peas		
Lee	Norfolk l.s.	2	–4,500	–20	No response and no toxicity
Lee	Norfolk l.s.	1	–578	–7	Severe "burning" from 20 lb. of borax
Lee	Norfolk l.s.	1	794	21	Yields too low to be significant
Lee	Norfolk l.s.	1	–3,366	–71	Severe injury to stand from 15 lb. of borax per acre
Lee	Norfolk s.l.	1	–428	–16	No response but no injury from 10 lb. of borax per acre
Lee	Norfolk s.l.	1	–100	–11	No response but no injury from 12 lb. of borax per acre
Houston	Norfolk s.l.	1	530	27	Yields too low to be significant
Houston	Norfolk s.l.	1	n.d.	n.d.	No yields taken, but no apparent response
Houston	Orangeburg s.l.	1	453	10	No significant response

(Continued)

TABLE 11 *(Continued)*. RESPONSE OF LEGUMES TO BORAX IN FIELD TESTS IN ALABAMA

Location of test			Per acre yield response to borax*		Related observations
County	Soil type	Length of test	Increase	Increase	
		Years	*Pounds*	*Per cent*	
		Austrian winter peas *(continued)*			
Henry	Ruston s.l.	1	87	3	No significant response
Henry	Ruston s.l.	1	n.d.	n.d.	No significant response
Lee	Madison c.l.	1	3,000	18	Possible response, but no deficiency symptoms
		Blue lupine			
Henry	Ruston s.l.	1	436	5	Yields too low to be significant
Houston	Norfolk s.l.	1	n.d.	n.d.	Yields not taken, but no apparent response
Lee	Norfolk l.s.	1	n.d.	n.d.	Injured by cold, no apparent response
Henry	Norfolk s.l.	2	n.d.	n.d.	No apparent response
		Vetch			
Lee	Norfolk l.s.	2	427(S)	170	Boron increased cold resistance
Lee	Norfolk l.s.	1	144(S)	73	Reddish-yellow foliage without B
Lee	Norfolk s.l.	1	26(S)	41	Low yields, but consistent increase from B
Lee	Madison c.l.	2	344(S)	38	No apparent vegetative response
		Soybeans			
Lee	Norfolk l.s.	3	609(H)	13	No response where crimson clover failed without B
		Alyce clover			
Lee	Norfolk l.s.	1	–846(H)	–25	B requirement very low
		Peanuts (Spanish)			
Lee	Norfolk s.l.	5	–32(S)	–2	No response
Lee	Norfolk s.l.	1	–101(S)	–7	No response
		Sericea			
Lee	Norfolk l.s.	1	–330	–12	No response and injury from annual applications

* Rate of borax varied from 10 to 20 pounds per acre.
** Yields not determined.
(S) Seed.
(H) Dry hay.
(G) Green weights.

Other Legumes

From 1942 to 1946, field tests were conducted to determine the response of legumes to boron in central and southern Alabama on areas where difficulty had been experienced in growing these crops *(10)*. Legumes tested included bur clover, red clover, white clover, Austrian winter peas, blue lupine, vetch, soybeans, and Alyce clover, Table 11.

Legumes responding to borax included vetch for seed, red clover, white clover, and bur clover.

Austrian winter peas were tested at 12 locations. At five of these locations, reduction in yield from boron toxicity resulted. Others showed no significant increases. Blue lupine, soybeans, and Alyce clover did not show a response to borax.

Severe injury to stands of Austrian winter peas and crimson, red, and white clover was reported on sandy soils from the application of 15 pounds of borax per acre **at time of seeding.** Soybeans also showed low tolerance for borax.

Permanent Dallisgrass-White Clover Pastures

A minor element treatment has been included in pasture fertility experiments for several years. As a general rule, this treatment was an annual or biennial application of a mixture containing boron, manganese, copper, and zinc. The minor element treatment was applied in conjunction with adequate amounts of lime, phosphorus, and potassium. A survey of yield results from about 25 of these experiments over a wide range of soil types and textures shows that in no case was the growth significantly increased by addition of the minor elements, including boron.

Although this problem has not been thoroughly explored with experiments on rates, kinds, and times of application of boron, the data obtained do not indicate that boron is a seriously limiting factor in forage production of white clover-Dallisgrass pastures.

Potatoes

Fertility tests were conducted on 11 farmers' potato fields in Baldwin County during the period of 1952-54. Using 10 pounds of borax per acre resulted in a small yield increase on six of the fields and a small decrease on the other five fields *(4)*. None was significantly different. The average yield for the 11 tests (3 replications in each test) for borax was 10,680 pounds of potatoes per acre and the average without borax was 10,486 pounds.

Cotton, Corn, and Peanuts

A 3-year rotation of cotton, peanuts, and corn was begun in 1941 at the Main Station, Auburn, on a Chesterfield sandy loam to determine the minor element needs of these crops. From 1941 through 1945, the cotton and corn received 600 pounds of 6-8-4 per acre per year and the peanuts received 100 pounds of concentrated superphosphate and 150 pounds of gypsum. From 1946 through 1951, cotton and corn received 1,000 pounds of 8-8-8 and peanuts received 75 pounds of muriate of potash in addition to the concentrated superphosphate and gypsum. A comparison of the results with and without borax is presented in Table 12.

COTTON. Results showed that some increase in seed cotton was obtained from 5 pounds of borax during the first 5-year period, when the cotton was fertilized with 600 pounds of 6-8-4. No increase in seed cotton was obtained for the last 6-year period. It is difficult to explain these results and additional tests are needed before a recommendation can be made.

CORN. There was no yield response of corn to borax in this 11-year test at Auburn. This soil is low in boron and large yield increases of crimson clover seed and alfalfa have been obtained

TABLE 12. EFFECT OF BORAX ON YIELD OF COTTON, PEANUTS, AND CORN, MAIN STATION, 1941-51

Year	Yield per acre[1]					
	Seed cotton		Peanuts		Corn	
	No borax	Borax[2]	No borax	Borax	No borax	Borax
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Bushels*	*Bushels*
1941	840	988	2,696	2,742	42.4	37.2
1942	968	1,148	722	716	41.8	39.8
1943	1,012	1,220	1,151	1,250	30.7	26.7
1944	1,306	1,132	1,378	1,090	40.6	39.0
1945	242	564	976	966	25.9	20.0
1941-45 average	874	1,010	1,385	1,353	36.3	32.6
1946	595	354	1,696	1,353	83.8	81.0
1947	1,580	1,369	1,400	1,338	59.9	64.9
1948	2,353	2,364	1,380	1,365	77.0	75.2
1949	1,909	2,017	691	879	73.1	75.6
1950	1,598	1,524	1,381	1,429	57.0	50.6
1951	2,190	2,465	1,213	1,246	52.1	53.5
1946-51 average	1,738	1,682	1,294	1,268	67.2	66.8

[1] Cotton and corn received 600 pounds of 6-8-4 first 5 years, 1,000 pounds of 8-8-8 last 6 years. Peanuts received 100 pounds of concentrated superphosphate and 150 pounds of gypsum; the last 6 years, 75 pounds of potash were applied in addition to superphosphate and gypsum. All treatments received Zn, Cu, and Mn.
[2] 5 pounds per acre per year.

from borax at this location. These data indicate that corn has a low boron requirement.

PEANUTS. No yield response of peanuts to borax was obtained in the 3-year rotation. The 11-year average was 1,307 pounds of peanuts per acre with borax and 1,335 pounds without.

Corn-Minor Element Test

In 1954 and 1955 minor element tests with corn were conducted at 15 locations in Lee, Macon, Bullock, Monroe, Tallapoosa, DeKalb, and Barbour counties. The corn was fertilized with 400 pounds of 4-12-12 and sidedressed with 100 pounds of nitrogen per acre. For 1954, the average yield of corn with and without boron for the eight locations was the same, 28.8 bushels per acre each. The low yield was due to a dry season. For the seven tests in 1955, the average yield for the treatment with boron was 68.6 bushels per acre and the average yield without boron was 68.2 bushels. Ten pounds of borax per acre was applied in these tests. Both treatments contained zinc, copper, manganese, and molybdenum. There was no significant increase at any location for the 2 years.

Horticulture Crops

Much of the research data obtained in this country and in Europe show that cauliflower, broccoli, turnips, rutabagas, beets, and carrots require an added source of boron for good quality and high yields. Some of these crops, such as cauliflower, are almost a complete failure without added boron, Figure 1. Boron deficiency of these crops in Alabama is common where boron has not been applied.

In a survey of 34 apple orchards in the State, some boron-deficient orchards were observed. Forty-four per cent of these orchards had leaves below the national average for boron content. Generally, boron-deficient orchards were found on light-textured soils.

TOLERANCE OF CROPS TO BORON

Need for boron by a crop is closely correlated with the ability of that crop to tolerate an excess of soil boron. Some crops are very sensitive to excess soluble boron. For example, 10 pounds of borax applied in the drill can result in serious damage to cotton.

The following soil properties are important in determining a plant's tolerance for boron:

(1) Tolerance is less on coarse-textured soils than on fine-textured soils.
(2) Tolerance is less on acid soils than on limed soils.
(3) Tolerance is less on soils low in organic matter than on soils high in organic matter.

A general guide is given here to show tolerance of some common crops to borax.

VERY SENSITIVE CROPS. Not more than 5 pounds of borax per acre broadcast should be applied to:

Cotton	Peas	Soybeans
Cucumbers	Snapbeans	Strawberries

SENSITIVE CROPS. Ten pounds of borax per acre broadcast or 5 pounds per acre in the drill to the following:

Barley	Clover	Squash
Celery	Oats	Wheat
	Potatoes	

TOLERANT. Twenty pounds of borax per acre broadcast or 10 pounds per acre in the drill to the following:

Cabbage	Lettuce	Radish
Carrots	Lima beans	Rye
Corn	Onions	Spinach
	Peppers	

VERY TOLERANT. Not more than 30 pounds of borax per acre broadcast or 15 pounds per acre in the drill to the following:

Apples	Beets	Tomatoes
Alfalfa	Cauliflower	Turnips

SUMMARY AND RECOMMENDATIONS

A small continuous supply of boron is required by plants. This supply can be furnished by Alabama soils in most cases. Some plants, however, require larger amounts than the soil can provide. Therefore, boron must be added to the soil for adequate growth and seed production.

Boron-deficient plants can be recognized usually by internal or external symptoms. An exception is crimson clover, seed production of which can be drastically reduced without any noticeable deficiency symptoms.

The most common source of boron for fertilizer use is a commercial grade of borax, such as fertilizer borate or fertilizer borate high grade. Other sources include Polybor, Colemanite, and the less soluble boron slags and frits. Colemanite and other less soluble boron compounds differ from borax in that they are less soluble in the soil, less toxic to sensitive crops, and leach out of sandy soils more slowly.

Borax added to sandy soils leaches out rapidly and does not accumulate in the soil to any extent. Borax leaches out of clay soils slowly and may accumulate in the upper 12 inches. The accumulated boron from four annual applications of 30 pounds of borax was not toxic to sensitive crops. Analyses of 243 Alabama soils showed that more water-soluble boron is present in clay soils than in sandy soils. Crops on sandy soils are more likely to be boron deficient than those on clay soils. Boron deficiency is more prevalent on Coastal Plain and Sand Mountain soils than on Limestone Valley, Black Belt, and Piedmont soils.

Liming decreases the water-soluble boron in soils and high rates of lime can cause boron deficiency on soils low in boron.

Experimental results in Alabama show that boron is necessary for good quality and high yields of alfalfa. Twenty to 25 pounds of borax per acre per year is recommended.

Boron is essential for high yields of crimson clover seed. Ten pounds of borax per acre has proved to be the optimum rate for crimson clover seed production. Higher rates may damage the plants so that stand and production are reduced.

Other legumes responding to boron applications include vetch and white clover for seed and red clover. Legumes that have not responded to boron include sericea, blue lupines, soybeans, Alyce clover, and peanuts.

Yields of potatoes, cotton, peanuts, corn, and Dallisgrass-white clover pasture have not been increased with applications of boron.

Ten to 15 pounds of borax is recommended for cauliflower, broccoli, turnips, rutabagas, beets, and carrots, especially on sandy soils.

Care must be taken when applying borax or chicken manure containing polybor to boron-sensitive crops.

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