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BORON, COPPER, MANGANESE, AND ZINC REQUIREMENT TESTS OF TOBACCO
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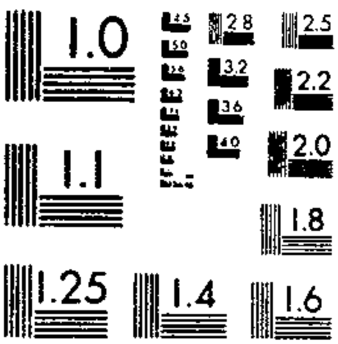


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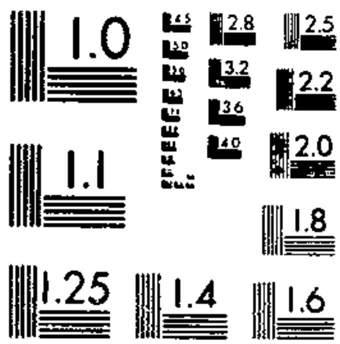


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NATIONAL BUREAU OF STANDARDS-1963-A

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# Boron, Copper, Manganese, and Zinc Requirement Tests of Tobacco[1]

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## INTRODUCTION

A great deal of research has been done in recent years on the mineral nutrition of tobacco insofar as this concerns the elements required by the plant in moderate or comparatively large quantities, including nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. Considerable progress has been made in determining the quantities of these elements required for normal growth of the plant (*10, 11*),[2] effects of variation in supply of each on the quality of the leaf, and the characteristic symptoms manifested by the plant when the supply of any one of them falls below the minimum requirement. Little information has been published, however, regarding yield and quality of tobacco as influenced by elements that are required by the tobacco plant in minute quantities only. A few determinations of the quantities of the trace elements boron, copper, manganese, and zinc in tobacco have been reported. Characteristic symptoms produced in the tobacco plant by deficiency of these elements have been described by McMurtrey (*21*). These four elements are referred to in this publication as "the trace elements."

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[2] Italic numbers in parentheses refer to Literature Cited, p. 26.

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The fact that boron is an essential element for the tobacco plant was shown by Swanback (*23*), in work on solution cultures and by McMurtrey (*19*) in work on solution cultures and also on special sand and soil cultures. The first recorded field observation of boron deficiency for tobacco was made on Sumatra tobacco by Kuijper (*14*), who reported it in 1930. Not until 1935 was the first such observation reported in this country, by McMurtrey (*20*), who had made it in 1934 at Upper Marlboro, Md. He made another such observation in 1940 on test plots near Raleigh, N. C. The normal boron content of tobacco was given by Anderson (*2*) as from 30 to 90 p. p. m. (parts per million). McHargue (*17*) reported, for Kentucky tobacco, 67 p. p. m. of boron in the Burley, and in the dark tobacco 29 p. p. m. in the leaves, 11 in the stalks, and 6 in the seed. Drake (*8*) found the boron content of Turkish tobacco grown in a greenhouse to be about 5 p. p. m. in normal plants and also in plants showing deficiency symptoms. Under similar conditions Jones (*13*) found about 20 p. p. m. of boron in normal tobacco plants and about 20 to 176 p. p. m. in plants grown in cultures to which borax had been added at rates of from 15 to 100 pounds per acre.

Published references to the copper content of tobacco are very few. Elvehjem (*9*) found 17 p. p. m. of copper in tobacco leaves. McHargue (*18*) found the range for four samples of low-grade dark-leaf Kentucky tobacco to be 30 to 60 p. p. m. and the proportion in a sample of Kentucky Burley stalks to be 10 p. p. m.

Manganese content of Connecticut tobacco has been reported on by several investigators. Bailey found in one study (*4*) a maximum of 2,664 and a minimum of 432 p. p. m., with an average of 1,368 p. p. m. In another study (*5*) he found a range of 2,448 p. p. m. to none. LeCompte (*15*) made an extensive study of the manganese content of this cigar tobacco in his work on the so-called "black" tobacco that is frequently found in Connecticut leaf. Testing a large number of samples, he found that manganese content averaged 1,152 p. p. m. in the "black" leaf and 360 p. p. m. in the normal leaf. Jacobson (*12*), working on Connecticut tobacco, found 160 p. p. m. of manganese in normal leaves, and in material showing manganese toxicity found these percentages: Middle leaves, 1.1; lower leaves, 0.8; upper leaves, 0.4; diseased roots, 0.32. Anderson (*2*) gave the manganese content of normal Connecticut tobacco as 70 to about 1,400 p. p. m. and that of tobacco showing manganese toxicity symptoms as about 2,800 p. p. m.

Working on Ohio cigar-leaf tobacco, Ames and Boltz (*1*) found that the manganese content of the plants on 19 fertilizer plots ranged from 77 to 500 p. p. m. Ward (*24*), having made very complete studies of the mineral absorption of cigar, flue-cured, and Burley tobaccos grown in Canada arrived at these estimates of manganese content at harvesttime, in parts per million: Middle leaves—cigar tobacco 72–770, flue-cured 166–922, and Burley 900; stalk material—cigar tobacco 14–259, flue-cured 50–202, and Burley 324. McHargue (*18*) found, on an average, 220 p. p. m. of manganese in four samples of low-grade dark (Kentucky) leaf, 30 p. p. m. in a sample of (Kentucky) Burley stalks, and (*16*) 70 p. p. m. in tobacco seed.

Zinc has only rarely been determined in tobacco. McHargue (*18*) found 50 p. p. m. in low-grade dark (Kentucky) leaf and 10 p. p. m. in (Kentucky) Burley stalks.

In short, according to the limited data available, the proportion of each of the elements boron, copper, and zinc in normal cured tobacco leaves is very small, usually about 50 p. p. m. or less, and the proportion of manganese, although sometimes very small, frequently amounts to several hundred or even 1,000 or more p. p. m. In leaves showing symptoms of manganese toxicity, this element has been found in a proportion of about 1 percent.

The field work and laboratory studies reported on here were conducted at the Pee Dee Experiment Station, Florence, S. C., in 1940–45. The field tests were made on an area of typical Marlboro fine sandy loam (an important flue-cured-tobacco soil of the Coastal Plain) selected for soil uniformity. The area had topsoil about 14 inches deep. Soil analysis indicated that the trace elements were present in the following proportions: Boron, 14.0 p. p. m.; copper, 13.5 p. p. m.; manganese, 93.0 p. p. m.; zinc, 15.5 p. p. m. The pH was 5.5. The plan of procedure was designed chiefly to obtain in field plot tests, under closely controlled test conditions, information on the tobacco plant's requirements of the trace elements boron, copper, manganese, and zinc and any influence application of these elements may have on yield and on the quality of the tobacco leaf. It was designed also to permit observation of any symptoms of deficiency or toxicity of these elements and the quantities of the elements associated with any such symptoms. Tobacco plants were grown on plots to which different boron, copper, manganese, and zinc treatments had been applied and representative samples of the product were analyzed.

To supplement the data obtained in these field plot tests, tobacco material grown in connection with other experiments at various locations was studied. In some cases, soil from the plots on which a sample had been grown was analyzed so as to throw light on the relation of soil content to absorption of the trace elements by the plants.

## PLOT TECHNIQUE AND TREATMENTS

The experimental area was divided into two sections, and these were used alternately for growing the tobacco, one section each year. In each year when a section was not used for tobacco a crop of peanuts was grown on it, without applying fertilizer. At harvest all the peanut plant material, including the roots, was removed to avoid addition of organic matter to the soil. The purpose of growing peanuts in rotation with the tobacco was to lessen the danger of injury from root knot, peanuts being in general resistant to some of the causal nematodes, and to deplete the soil of plant nutrients.

Each section was divided into 4 blocks of 15 plots each. Each individual plot was 32×32 feet (1/42.5 acre). The plots in each section formed a rectangular area 6 plots wide and 10 plots long. Between each 2 adjacent ranks of 6 plots an unused strip 4 feet wide was provided.

All the trace elements are commonly present in the usual fertilizer materials in unknown and varying amounts. For this reason, and because some of the trace elements have been found in the tobacco plant in very small quantities only, it was necessary to prepare the basal fertilizers largely from reagent-grade chemicals in order to avoid adding unknown amounts of these elements. All fertilizer materials considered for use on the plots were analyzed. None of those that were used, as is shown in table 1, contained any of the trace elements in a concentration higher than 13 p. p. m. The content of macro fertilizer elements in the compounds used is shown in table 2, and the quantities applied per acre in table 3.

TABLE 1.—*Range of trace-element content of salts used as fertilizers in 1940–45*

| Salt | Grade | Boron | Copper | Manganese | Zinc |
|---|---|---|---|---|---|
| | | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* |
| Potassium chloride | Reagent | 0 –3. 6 | 0 –1. 3 | 0 | 0–3. 2 |
| Potassium nitrate | do | 0 –3. 3 | 0 –1. 1 | 0 | 0–1. 2 |
| Potassium sulfate | do | 0. 5–7. 9 | 0 –2. 0 | 0 | 0–3. 6 |
| | Commercial (Carlsbad, N. Mex.). | 2. 2–6. 5 | 5. 6–10. 4 | 4. 5–11. 0 | 0–6. 6 |
| | Crude German | 1. 3–12. 7 | 0. 7–3. 3 | 2. 2–13. 0 | 0–3. 0 |
| Magnesium sulfate | Reagent | 0 –1. 4 | 0 –2. 4 | 0 | 0–5. 2 |
| Dicalcium phosphate | Commercial | 0. 4–3. 2 | 0 –6. 3 | 0 –12. 5 | 0–11. 8 |
| Urea | do | 0. 7–6. 2 | 0 –3. 6 | 0 | 0 |

TABLE 2.—*Average macro-element content of salts used as fertilizers in 1940–45*

| Salt | Grade | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|---|
| | | *Percent* | *Percent* | *Percent* |
| Potassium chloride | Reagent | 0 | 0 | 63. 2 |
| Potassium nitrate | do | 13. 9 | 0 | 46. 5 |
| Potassium sulfate | do | 0 | 0 | 54. 0 |
| | Commercial (Carlsbad, N. Mex.). | 0 | 0 | 54. 0 |
| | Crude German | 0 | 0 | 48. 5 |
| Magnesium sulfate | Reagent | 0 | 0 | 0 |
| Dicalcium phosphate | Commercial | 0 | 40. 7 | 0 |
| Urea | do | 46. 3 | 0 | 0 |

| Salt | Grade | CaO | $SO_3$ | MgO | Cl |
|---|---|---|---|---|---|
| | | *Percent* | *Percent* | *Percent* | *Percent* |
| Potassium chloride | Reagent | 0 | 0 | 0 | 47. 5 |
| Potassium nitrate | do | 0 | 0 | 0 | 0 |
| Potassium sulfate | do | 0 | 45. 9 | 0 | 0 |
| | Commercial (Carlsbad, N. Mex.). | 0 | 45. 9 | 0 | 0 |
| | Crude German | 0 | 42. 0 | 0 | 0 |
| Magnesium sulfate | Reagent | 0 | 32. 5 | 16. 4 | 0 |
| Dicalcium phosphate | Commercial | 32. 5 | 0 | 0 | 0 |
| Urea | do | 0 | 0 | 0 | 0 |

TABLE 3.—*Amounts of salts applied per acre in basal-fertilizer mixture in 1940–45*

| Fertilizer material | Grade | Treatment | | |
|---|---|---|---|---|
| | | 1–13 | 14 | 15 |
| | | *Pounds* | *Pounds* | *Pounds* |
| Potassium chloride | Reagent | 33.6 | 33.6 | 33.6 |
| Potassium nitrate | do | 57.4 | 0 | 0 |
| Potassium sulfate | do | 0 | [1] 256.7 | 0 |
| | Commercial (Carlsbad, N. Mex.). | [2] 53.1 | [3] 256.7 | 0 |
| | Crude German | 0 | 0 | 289.0 |
| Magnesium sulfate | Reagent | 97.9 | 97.9 | 97.9 |
| Dicalcium phosphate | Commercial | 155.1 | 155.1 | 155.1 |
| Urea | do | 34.4 | 51.7 | 51.7 |

[1] In 1940–43 only.
[2] In 1944–45 only. Applied as a side dressing at the first cultivation.
[3] In 1944–45 only.

In 1940–43 a 3–8–6 basal fertilizer was applied at the rate of 800 pounds per acre per year. In addition to supplying nitrogen, phosphorus, and potassium as shown in table 2, the fertilizer mixture used contained 2 percent MgO, 6.25 percent CaO, 2 percent Cl, and 4 percent $SO_3$. The trace elements were applied in the form of boric acid, copper sulfate, manganese sulfate, and zinc sulfate. In 1944 and 1945, because potash-deficiency symptoms had been observed, the rate of potash application was increased from 48 pounds to 80 pounds per acre. (As this change might affect the response to the trace-element treatments, the results of the 1944–45 tests were not averaged with those from the first 4 years but were considered separately.) In a test of sulfate of potash conducted simultaneously with the trace-element tests, a basal 3–8–20 fertilizer was used.

The trace elements were applied in 13 different combinations, each of which contained 3 or all 4 of them. The elements were represented in this series of combinations at 3 rates per acre each—a 1, or unit, rate, and rates twice and five times as great as the 1 rate, designated the 2 and 5 rates. The 3 per-acre rates for the individual elements were as follows: Boron, 0.5, 1, and 2.5 pounds; copper and zinc, 1, 2, and 5 pounds; manganese, 2, 4, and 10 pounds. One combination included all 4 of the elements at the 1 rate; each of the 12 others included 3 elements at the 1 rate and excluded the fourth or included it at the 2 or the 5 rate. Each of the 13 combinations was applied on 4 replicate plots. Crude 90-percent imported sulfate of potash and the high-grade salt were each applied to 4 plots which received none of the trace-element treatments, to determine whether the former contains trace elements in quantities that affect its fertilizer value. The 15 treatments were applied in randomized order on each of the blocks in each section of the experimental area.

The tobacco plants were set out in rows 4 feet wide, spaced 2 feet apart in the row. The methods of culture, harvesting, and fluecuring were those in common practice for flue-cured tobacco in South Carolina. After harvest all stalks and roots were removed from the plots, in order that some of this material might be analyzed and to reduce infestation with nematodes causing root knot.

The actual area per plot from which data were obtained was 1/64.8 acre, as all outside rows and end plants were eliminated from consideration.

## OBSERVATIONS ON DEFICIENCY AND EXCESS SYMPTOMS

Examination of the plants in the field at all stages of growth did not reveal any known symptoms of deficiency of any of the trace elements. (Such symptoms are seldom observed in the field, even on soils having extremely low fertility.)

Boron was repeatedly found to have injured tobacco plants where it was applied at the rates of 1.0 and 2.5 pounds per acre. The injury produced was more severe where the element had been applied at the higher rate. The plants were stunted during the early growth period. Later, those grown on plots that had received 1 pound per acre made normal growth and ceased to exhibit any toxicity symptoms. Those grown on plots that had received 2.5 pounds per acre, however, were permanently retarded in growth and still showed toxicity symptoms when harvested.

The first visible symptoms of boron toxicity are a slight thickening of the lower leaves and an upward curling of their edges. As growth advances, these conditions develop on progressively higher parts of the plant. Soon the edges of the leaves turn a pale yellow color. Then, in a few days, yellow spots develop along the leaf margins and in the raised portions of the leaf tissue between the veins. The leaves become thick and brittle, and restriction of growth around the edges causes an upward bulging of the entire leaf. Later, frequently, the margins of the leaf split. The yellow spots increase in size and turn brown. Eventually the brown, dead tissue falls away, leaving the leaf full of holes, with a ragged margin, and greatly reduced in potential market value.

No injurious effects on tobacco from application of manganese or zinc were observed. In 1940 only, there was an indication that copper produced visible leaf injury. At early stages of growth the lower leaves of the plants subjected to the highest copper treatment were longer, narrower, and more pointed than normal and in some cases had a shiny, glazed appearance. About 6 weeks after planting, a faint reddish-brown, or bronze, color was present on the raised portions of the leaf tissue, between the veins. This was especially noticeable on the leaves just below the middle of the plant. The symptoms did not continue to develop, and no abnormality of the mature tobacco was associated with them.

## EFFECTS OF TREATMENTS ON YIELD OF TOBACCO

The yields of tobacco produced in the trace-element tests over a period of 6 years are given in table 4, where each value is the mean of the results from four replicate plots. Differences in the yields are given in table 5. Marked seasonal variation appears in annual average

TABLE 4.—*Tobacco yield per acre, in 1940–45, of plots to which 13 different trace-element treatments and 2 sulfate of potash treatments were applied annually*

[Each value is an average for 4 replicate plots]

| Treatment [1] | Treatment number | 1940 | 1941 | 1942 | 1943 | Average of 1940–43 | 1944 | 1945 | Average of 1944–45 |
|---|---|---|---|---|---|---|---|---|---|
| Trace elements: | | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| 1 Each | 9 | 1,639 | 1,223 | 904 | 1,518 | 1,321 | 1,252 | 1,171 | 1,212 |
| 0 Boron | 5 | 1,651 | 1,237 | 904 | 1,464 | 1,314 | 1,114 | 1,101 | 1,108 |
| 2 Boron | 10 | 1,633 | 1,210 | 831 | 1,328 | 1,250 | 1,104 | 1,122 | 1,113 |
| 5 Boron | 1 | 1,454 | 1,024 | 795 | 1,228 | 1,125 | 1,100 | 1,013 | 1,056 |
| 0 Copper | 6 | 1,701 | 1,102 | 944 | 1,360 | 1,277 | 1,111 | 1,124 | 1,118 |
| 2 Copper | 11 | 1,513 | 1,178 | 961 | 1,502 | 1,288 | 1,273 | 1,192 | 1,232 |
| 5 Copper | 2 | 1,602 | 1,047 | 809 | 1,282 | 1,185 | 1,214 | 1,175 | 1,194 |
| 0 Manganese | 7 | 1,675 | 1,182 | 978 | 1,542 | 1,344 | 1,182 | 1,124 | 1,153 |
| 2 Manganese | 12 | 1,668 | 1,093 | [2] 969 | 1,511 | 1,310 | 1,173 | 1,208 | 1,190 |
| 5 Manganese | 3 | 1,617 | 1,146 | 875 | 1,375 | 1,253 | 1,069 | 1,163 | 1,116 |
| 0 Zinc | 8 | 1,699 | 1,159 | 887 | 1,408 | 1,288 | 1,188 | 1,220 | 1,204 |
| 2 Zinc | 13 | 1,793 | 1,219 | 980 | 1,437 | 1,357 | 1,253 | 1,231 | 1,242 |
| 5 Zinc | 4 | [2] 1,555 | 1,089 | 926 | 1,435 | 1,251 | 990 | 1,123 | 1,056 |
| Sulfate of potash: | | | | | | | | | |
| C. P. $K_2SO_4$ | 14 | 1,739 | 1,147 | 1,033 | 1,461 | 1,345 | 1,477 | 1,188 | 1,332 |
| Crude $K_2SO_4$ | 15 | 1,700 | 1,217 | 1,142 | 1,602 | 1,415 | 1,421 | 1,294 | 1,358 |
| Average | | 1,643 | 1,152 | 929 | 1,430 | 1,288 | 1,195 | 1,163 | 1,179 |

[1] The 1, 2, and 5 per-acre rates of treatment for the individual trace elements were as follows: Boron, 0.5, 1, and 2.5 pounds; copper and zinc, 1, 2, and 5 pounds; manganese, 2, 4, and 10 pounds. In treatments 1–8 and 10–13, the trace elements other than the ones named in this column were all applied at the 1 rate. In 1940–43, each of the treatments 1–13 was accompanied by 800 pounds per acre of a basal fertilizer made from pure chemicals in the following percentages: N, 3; $P_2O_5$, 8; $K_2O$, 6; MgO, 2; CaO, 6.25; Cl, 2; $SO_3$, 4. In 1944–45, 800 pounds per acre of a 3–8–10 mixture was substituted, the additional potash being applied as a side dressing of potassium sulfate. In treatments 14 and 15, application of potash was increased from 48 to 160 pounds per acre by using a 3–8–20 basal fertilizer, the nitrate of potash being omitted and the additional potash being applied in one case as the reagent-grade or selected-grade commercial sulfate and in the other as the 90-percent crude salt.

[2] This value represents data from three replicate plots only.

TABLE 5.—*Differences in per-acre yield of tobacco in 1940–45 between series of plots to which 13 different trace-element treatments and 2 sulfate of potash treatments were applied annually* [1]

[Each value is the difference between averages for 4 replicate plots each]

| Treatments compared | 1940 | 1941 | 1942 | 1943 | Average of 1940–43 | 1944 | 1945 | Average of 1944–45 |
|---|---|---|---|---|---|---|---|---|
| | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| Boron: | | | | | | | | |
| 0–1 | −12 | −14 | 0 | +54 | +7 | +138 | +70 | +104 |
| 0–2 | −18 | −27 | −73 | −136 | −64 | −10 | +21 | +6 |
| 0–5 | −197 | −213 | −109 | −236 | −189 | −14 | −88 | −51 |
| 1–2 | −6 | −13 | −73 | −190 | −71 | −148 | −49 | −98 |
| 1–5 | −185 | −199 | −109 | −290 | −196 | −152 | −158 | −155 |
| 2–5 | −179 | −186 | −36 | −100 | −125 | −4 | −109 | −56 |
| Copper: | | | | | | | | |
| 0–1 | −62 | +121 | −40 | +158 | +44 | +141 | +47 | +94 |
| 0–2 | −188 | +76 | +17 | +142 | +11 | +162 | +68 | +115 |
| 0–5 | −99 | −55 | −135 | −78 | −92 | +103 | +51 | +77 |
| 1–2 | −126 | −45 | +57 | −16 | −33 | +21 | +21 | +21 |
| 1–5 | −37 | −176 | −95 | −236 | −136 | −38 | +4 | −17 |
| 2–5 | +89 | −131 | −152 | −220 | −103 | −59 | −17 | −38 |
| Manganese: | | | | | | | | |
| 0–1 | −36 | +41 | −74 | −24 | −23 | +70 | +47 | +58 |
| 0–2 | −7 | −89 | −9 | −31 | −34 | −9 | +84 | +38 |
| 0–5 | −58 | −36 | −103 | −167 | −91 | −113 | +39 | −37 |
| 1–2 | +29 | −130 | +65 | −7 | −11 | −79 | +37 | −21 |
| 1–5 | −22 | −77 | −29 | −143 | −68 | −183 | −8 | −96 |
| 2–5 | −51 | +53 | −94 | −136 | −57 | −104 | −45 | −74 |
| Zinc: | | | | | | | | |
| 0–1 | −60 | +64 | +17 | +110 | +33 | +64 | −49 | +8 |
| 0–2 | +94 | +60 | +93 | +29 | +69 | +65 | +11 | +38 |
| 0–5 | −144 | −70 | +39 | +27 | −37 | −198 | −97 | −148 |
| 1–2 | +154 | −4 | +76 | −81 | +36 | +1 | +60 | +30 |
| 1–5 | −84 | −134 | +22 | −83 | −70 | −262 | −48 | −155 |
| 2–5 | −238 | −130 | −54 | −2 | −106 | −263 | −108 | −186 |
| C. P.—Crude $K_2SO_4$ | −39 | +70 | +109 | +141 | +70 | −56 | +106 | +25 |

[1] The 1, 2, and 5 per-acre rates of treatment for the individual trace elements were as follows: Boron, 0.5, 1, and 2.5 pounds; copper and zinc, 1, 2, and 5 pounds; manganese, 2, 4, and 10 pounds. Basal-fertilizer treatment per acre: In trace-element tests, 800 pounds of 3–8–6 in 1940–43 and 800 pounds of 3–8–10 in 1944–45; in sulfate of potash tests, 800 pounds of 3–8–20.

yield per acre, which ranged from 929 pounds in 1942 to 1,643 pounds in 1940. This variation may have been due in part to differences in rainfall. Rainfall during the growing season—April, May, June, and July—totaled 13.6 inches in 1940, 17.2 inches in 1941, 23.7 inches in 1942, and 17.1 inches in 1943. Although the number of observations is small, calculation of the correlation coefficient shows the inverse relation of yield and rainfall to be significant at odds of 19:1.

Statistical analysis of the annual and 4-year yields of tobacco for the period 1940–43 gave the results shown in table 6. The variance ratio, $F$, did not attain significance at odds of 19:1 for any single year but did so at odds of 99:1 for the 4-year period.

TABLE 6.—*Standard deviations and differences required for significance for per-acre yields of tobacco from trace-element plots, 1940–43*

| Item | 1940 | 1941 | 1942 | 1943 | Average of 1940–43 |
|---|---|---|---|---|---|
| | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| Standard deviation of single-plot yields | 132.9 | 152.5 | 129.2 | 157.0 | 143.6 |
| Standard deviation of means | 66.5 | 76.3 | 64.6 | 78.5 | 35.9 |
| Standard deviation of mean differences | 94.0 | 107.9 | 91.3 | 111.0 | 50.8 |
| Difference required for significance, odds 19:1 | 190.0 | 218.1 | 184.5 | 224.3 | 100.4 |
| Difference required for significance, odds 99:1 | ------- | ------- | ------- | ------- | 132.5 |

Neither annual yields nor average annual yields of the years 1940–43 showed any significant increases associated with addition of trace elements to the soil (tables 5 and 6). In some instances, significant decreases were associated with addition of trace elements.

Boron added at the 5 rate caused losses in 1940 and 1943. In 1940 the per-acre yield was 197 pounds less where boron had been applied at this rate than where it had been withheld. In 1943, per-acre yield was less by 290 pounds where boron had been applied at the 5 rate rather than the 1 rate. In that year, also, per-acre yields were significantly less where boron had been applied at the 5 rate than where it had been withheld. Yields in 1943 were significantly less where copper had been applied at the 5 rate than where it had been applied at the 1 rate. No significant yield differences were associated with differences in application of manganese. Loss in yield associated with application of zinc at the 5 rather than the 2 rate was observed in 1940.

Data for average annual yields in the 4-year period 1940–43 revealed the following: Yield where boron had been applied at the 5 rate was significantly less than yield where boron had been applied at the 2 rate and was less to a highly significant degree than yield where boron had been applied at the 1 rate or withheld. Yield where copper had been applied at the 5 rate was significantly less than yield where copper had been applied at the 2 rate and was less to a highly significant

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degree than yield where copper had been applied at the 1 rate. No significant yield differences were associated with differences in application of manganese. Yield was significantly less where zinc had been applied at the 5 rate rather than the 2 rate. Application of crude sulfate of potash did not result in yields differing significantly from those obtained where C. P. $K_2SO_4$ was applied.

The apparent responses to boron and copper applications when potash was applied at the rate of 80 pounds per acre (1944–45) differed considerably from those when it was applied at the rate of 48 pounds per acre (1940–43). The average per-acre yield differences found between plots where boron was not applied and plots where it was applied at the 1, 2, and 5 rates changed from +7, −64, and −189 pounds in 1940–43 to +104, +6, and −51 pounds, respectively, in 1944–45. The corresponding values in the case of copper were +44, +11, and −92 pounds for 1940–43 and +94, +115, and +77 for 1944–45. The values obtained in the two series of tests with application of manganese and of zinc were in closer agreement. It is possible that continued use of the plots may have led to reduction of the quantities of copper and boron available in the soil.

The yields of tobacco obtained show that under the conditions of the test at Florence, S. C., with application of 48 pounds of potash per acre, the tobacco plant's requirements of boron, copper, manganese, and zinc were met by the quantities present in the untreated soil and that addition to the soil of even such small amounts of these elements as 2.5 pounds of boron or 5 pounds of copper per acre is likely to cause considerable reductions in yields. These elements should be applied to the soil of tobacco fields only after careful consideration. However, when the amount of potash applied was increased to 80 pounds per acre the tobacco's tolerances for boron, copper, and manganese apparently were considerably increased. From the results of the tests with application of potash at this rate, it appears that addition of 0.5 pound of boron per acre to soil such as that of the study area may result in a yield increase of about 100 pounds per acre. Any greater addition, it appears, may be harmful. An increase in yield of more than 90 pounds was associated with application of 1 pound of copper per acre in the 2-year series. Application of 2 or 5 pounds of copper per acre was not accompanied by any greater apparent advantage. Use of 2 pounds of manganese per acre apparently increased yield by more than 50 pounds per acre.

## EFFECTS OF TREATMENTS ON QUALITY OF TOBACCO

The cured tobacco from the plots was graded and prepared for market in the usual way, and the commercial value determined from the weights of the material of the different grades and the average prices for the grades as given by the Production and Marketing Administration of the Department of Agriculture for type 13, South Carolina and Border North Carolina flue-cured tobacco. Inasmuch as the prevailing prices changed greatly within the study period, owing to economic conditions, comparison of values of the tobacco grown under the different treatments should be based on relative values rather than on the prices actually obtained. Table 7 gives the relative average values of the tobacco grown, expressed in per-

TABLE 7.—*Value of tobacco leaf produced in 1940–45 on plots to which 13 different trace-element treatments and 2 sulfate of potash treatments were applied annually*

[Values are percentages of those for tobacco leaf produced on plots where each of the trace elements was applied at the 1 rate]

| Treatment [1] | Treatment number | 1940 | 1941 | 1942 | 1943 | Average of 1940–43 | 1944 | 1945 | Average of 1944–45 |
|---|---|---|---|---|---|---|---|---|---|
| Trace elements: | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 1 Each | 9 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| 0 Boron | 5 | 96.58 | 90.95 | 102.13 | 101.69 | 97.84 | 99.27 | 99.68 | 99.48 |
| 2 Boron | 10 | 95.75 | 97.64 | 99.25 | 99.06 | 97.92 | 99.32 | 98.72 | 99.02 |
| 5 Boron | 1 | 90.16 | 84.64 | 99.58 | 95.27 | 92.41 | 98.44 | 97.11 | 97.78 |
| 0 Copper | 6 | 98.24 | 101.92 | 104.16 | 101.75 | 101.52 | 99.29 | 99.79 | 99.54 |
| 2 Copper | 11 | 100.00 | 102.63 | 102.60 | 100.05 | 101.32 | 100.34 | 99.98 | 100.16 |
| 5 Copper | 2 | 95.23 | 96.00 | 101.59 | 100.81 | 98.41 | 99.59 | 99.13 | 99.36 |
| 0 Manganese | 7 | 97.10 | 100.27 | 100.99 | 101.99 | 100.09 | 99.61 | 99.77 | 99.69 |
| 2 Manganese | 12 | 98.96 | 94.51 | 100.48 | 99.89 | 98.46 | 98.00 | 99.98 | 98.99 |
| 5 Manganese | 3 | 94.61 | 94.30 | 106.50 | 101.59 | 99.25 | 98.76 | 99.40 | 99.08 |
| 0 Zinc | 8 | 96.89 | 100.00 | 103.32 | 99.76 | 99.99 | 99.41 | 99.29 | 99.35 |
| 2 Zinc | 13 | 98.13 | 99.40 | 99.04 | 103.36 | 99.98 | 99.71 | 100.14 | 99.92 |
| 5 Zinc | 4 | 99.90 | 96.71 | 105.09 | 100.35 | 100.51 | 100.44 | 99.98 | 100.21 |
| Sulfate of potash: | | | | | | | | | |
| C. P. $K_2SO_4$ | 14 | 100.31 | 101.81 | 98.86 | 105.59 | 101.64 | 102.29 | 100.78 | 101.54 |
| Crude $K_2SO_4$ | 15 | 100.31 | 90.46 | 101.80 | 101.16 | 98.43 | 102.32 | 101.10 | 101.71 |
| Average | | 97.48 | 96.75 | 101.69 | 100.82 | 99.18 | 99.79 | 99.66 | 99.72 |

[1] In each of the treatments 1–8 and 10–13 the 3 trace elements other than that named in this column were applied at the 1 rate. Basal-fertilizer treatment per acre was as follows: In trace-element tests, 800 pounds of 3–8–6 in 1940–43 and 800 pounds of 3–8–10 in 1944–45; in sulfate of potash tests, 800 pounds of 3–8–20.

centage of the average price received for the tobacco grown on the plots that received the four trace elements at the unit rate each year.

The average prices received per 100 pounds of tobacco grown on these plots were: 1940, $9.65; 1941, $18.23; 1942, $33.40; 1943, $37.18; average 1940–43, $24.62; 1944, $41.01; 1945, $43.60; 1944–45, $42.30.

In 1940–43, when potash application was at the rate of 48 pounds per acre, no material difference in the relative value per unit of weight of the tobacco produced was associated with difference in treatment as regards trace elements except in one instance—an apparent reduction in value, averaging about 7.5 percent, was associated with application of boron at the rate of 2.5 pounds per acre. In 1944–45, when potash was applied at the rate of 80 pounds per acre, practically the same relative values of product were associated with all the trace-element treatments. Evidently the quantities of the trace elements required to produce good-quality tobacco were present in the soil of the experimental area.

## TRACE-ELEMENT CONTENT OF TOBACCO PLANT

### Plan of Sampling and Methods of Analysis

Two composite samples of cured leaves and one of stalks and roots combined were prepared for analysis from the crop produced under each of the treatments for every year except 1940, when a single leaf sample was prepared. The leaf samples were made by segregating one-tenth, by weight, of the leaves from each priming from each plot and dividing the segregated material into upper and lower halves on the basis of equal weight. For stalk-and-root samples one-tenth, by weight, of the stalk material and of the root material was taken from each of the four replicates. The samples were dried in a tobacco-curing barn.

The method given by Wilcox (*25*) for determining boron content was used, except that the final titration was completed according to the procedure of Rader and Hill (*22*). Copper, manganese, and zinc were determined colorimetrically on aliquots of the same solution, prepared by ashing the tobacco in a silica dish and then treating the ash with dilute nitric acid and filtering off the insoluble residue. Copper was determined by the carbamate method of Butler and Allen (*6*), manganese by the official periodate method (*3, p. 128*), and zinc by the dithizone procedure as given by Cowling and Miller (*7*).

### Results of Analyses

The results of the analyses of the composite tobacco samples for the 4-year and 2-year tests are given in table 8. The table presents trace-element-content averages for lower leaves, upper leaves, the two classes of leaves combined, and stalks and roots combined.

**TABLE 8.**—*Trace-element content of flue-cured tobacco produced in 1940–45 on plots to which 13 different trace-element treatments and 2 sulfate of potash treatments were applied annually*

BORON CONTENT (WATER-FREE BASIS), 1940–43

| Treatment [1] | Treatment number | 1940 | | 1941 | | | | 1942 | | | | 1943 | | | | Average of 1940–43 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | All leaves | Stalks and roots | All leaves | Lower leaves | Upper leaves | Stalks and roots | All leaves | Lower leaves | Upper leaves | Stalks and roots | All leaves | Lower leaves | Upper leaves | Stalks and roots | All leaves | Stalks and roots |
| | | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* |
| Trace elements: | | | | | | | | | | | | | | | | | |
| 1 Each | 9 | 48.3 | 11.6 | 42.4 | 33.6 | 51.1 | 12.2 | 63.0 | 69.1 | 57.0 | 9.7 | 49.2 | 44.1 | 54.4 | 9.4 | 50.7 | 10.7 |
| 0 Boron | 5 | 30.2 | 11.6 | 32.4 | 19.9 | 44.9 | 11.6 | 27.6 | 18.3 | 37.0 | 11.4 | 32.9 | 32.8 | 33.0 | 9.4 | 30.8 | 11.0 |
| 2 Boron | 10 | 77.2 | 10.5 | 53.8 | 48.8 | 58.9 | 11.9 | 124.0 | 167.6 | 80.5 | 10.5 | 77.9 | 81.1 | 74.7 | 12.4 | 83.2 | 11.3 |
| 5 Boron | 1 | 153.7 | 13.3 | 64.2 | 64.0 | 64.4 | 11.9 | 315.4 | 423.1 | 207.7 | 12.0 | 180.8 | 20[illegible].9 | 159.7 | 16.4 | 178.5 | 13.4 |
| 0 Copper | 6 | 50.4 | 10.2 | 44.7 | 34.7 | 54.7 | 11.6 | 74.1 | 94.0 | 54.2 | 8.8 | 48.8 | 44.1 | 53.6 | 9.4 | 54.5 | 10.0 |
| 2 Copper | 11 | 45.1 | 10.3 | 43.8 | 24.9 | 52.7 | 12.0 | 63.9 | 69.9 | 57.9 | 9.8 | 47.7 | 44.1 | 51.3 | 11.1 | 50.1 | 10.8 |
| 5 Copper | 2 | 42.2 | 11.3 | 42.2 | 33.1 | 51.3 | 9.8 | 63.0 | 77.2 | 48.8 | 10.8 | 48.4 | 41.0 | 55.8 | 8.9 | 49.0 | 10.2 |
| 0 Manganese | 7 | 50.5 | 10.6 | 42.8 | 34.0 | 51.7 | 12.2 | 66.3 | 74.8 | 57.8 | 10.7 | 43.8 | 41.7 | 46.0 | 8.4 | 50.8 | 10.5 |
| 2 Manganese | 12 | 45.3 | 11.3 | 41.9 | 33.6 | 50.2 | 12.0 | 61.8 | 69.8 | 53.8 | 9.4 | 50.6 | 49.9 | 51.3 | 10.0 | 49.9 | 10.7 |
| 5 Manganese | 3 | 57.2 | 11.5 | 41.8 | 33.5 | 50.1 | 11.9 | 73.2 | 82.6 | 63.7 | 10.4 | 49.7 | 48.1 | 51.3 | 8.3 | 54.0 | 10.5 |
| 0 Zinc | 8 | 50.6 | 11.4 | 43.7 | 33.9 | 53.5 | 11.1 | 65.2 | 75.6 | 54.8 | 10.0 | 44.6 | 41.0 | 48.2 | 10.0 | 51.0 | 10.6 |
| 2 Zinc | 13 | 47.1 | 12.0 | 43.4 | 33.8 | 53.1 | 11.5 | 63.8 | 73.2 | 54.4 | 10.2 | 47.2 | 42.8 | 51.7 | 9.5 | 50.4 | 10.8 |
| 5 Zinc | 4 | 54.0 | 11.7 | 41.4 | 31.7 | 51.2 | 11.4 | 72.2 | 86.8 | 57.6 | 10.6 | 49.0 | 44.9 | 53.1 | 9.5 | 54.2 | 10.8 |
| Sulfate of potash: | | | | | | | | | | | | | | | | | |
| C. P. $K_2SO_4$ | 14 | 29.3 | 10.6 | 28.2 | 17.7 | 38.7 | 11.8 | 24.6 | 17.3 | 31.8 | 9.9 | 19.2 | 17.2 | 21.2 | 7.6 | 25.3 | 10.0 |
| Crude $K_2SO_4$ | 15 | 27.6 | 10.2 | 33.2 | 22.0 | 44.4 | 12.0 | 34.4 | 20.6 | 48.2 | 10.9 | 25.2 | 19.1 | 31.4 | 7.0 | 30.1 | 10.0 |

[1] See footnote at end of table.

TABLE 8.—*Trace-element content of flue-cured tobacco produced in 1940–45 on plots to which 13 different trace-element treatments and 2 sulfate of potash treatments were applied annually*—Continued

COPPER CONTENT (WATER-FREE BASIS), 1940–43

| Treatment [1] | Treatment number | 1940 | | 1941 | | | | 1942 | | | | 1943 | | | | Average of 1940–43 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | All leaves | Stalks and roots | All leaves | Lower leaves | Upper leaves | Stalks and roots | All leaves | Lower leaves | Upper leaves | Stalks and roots | All leaves | Lower leaves | Upper leaves | Stalks and roots | All leaves | Stalks and roots |
| Trace elements: | | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* |
| 1 Each | 9 | 11.9 | 11.0 | 10.4 | 10.0 | 10.8 | 9.6 | 10.0 | 10.1 | 9.8 | 8.0 | 9.0 | 7.2 | 10.8 | 7.8 | 10.3 | 9.1 |
| 0 Boron | 5 | 12.0 | 11.0 | 11.8 | 11.8 | 11.7 | 8.0 | 9.8 | 9.7 | 9.8 | 7.3 | 10.6 | 8.5 | 12.7 | 8.4 | 11.0 | 8.7 |
| 2 Boron | 10 | 12.0 | 10.2 | 10.2 | 10.2 | 10.3 | 8.9 | 8.7 | 8.2 | 9.2 | 7.5 | 11.2 | 9.0 | 13.5 | 8.0 | 10.5 | 8.6 |
| 5 Boron | 1 | 12.6 | 9.1 | 12.0 | 13.8 | 10.3 | 8.4 | 8.4 | 8.0 | 8.9 | 7.4 | 14.8 | 12.7 | 16.3 | 8.5 | 12.0 | 8.4 |
| 0 Copper | 6 | 12.0 | 10.1 | 10.5 | 10.3 | 10.7 | 6.7 | 7.0 | 5.4 | 8.6 | 5.3 | 7.4 | 6.5 | 8.2 | 6.5 | 9.2 | 7.2 |
| 2 Copper | 11 | 14.1 | 10.3 | 11.7 | 11.2 | 12.2 | 10.4 | 10.8 | 10.2 | 11.3 | 10.7 | 12.4 | 10.5 | 14.3 | 10.8 | 12.2 | 10.6 |
| 5 Copper | 2 | 20.0 | 10.5 | 13.0 | 13.9 | 12.1 | 9.4 | 13.4 | 13.2 | 13.7 | 11.3 | 16.6 | 13.7 | 19.5 | 11.3 | 15.8 | 10.6 |
| 0 Manganese | 7 | 13.6 | 10.2 | 11.2 | 10.2 | 12.1 | 8.5 | 9.0 | 8.3 | 9.8 | 6.9 | 8.9 | 7.9 | 9.9 | 8.1 | 10.7 | 8.4 |
| 2 Manganese | 12 | 16.3 | 9.7 | 11.2 | 11.1 | 11.2 | 8.7 | 9.2 | 8.1 | 10.3 | 7.1 | 9.6 | 8.1 | 11.1 | 9.3 | 11.6 | 8.7 |
| 5 Manganese | 3 | 13.0 | 8.4 | 12.0 | 12.2 | 11.7 | 8.2 | 8.1 | 7.2 | 9.0 | 7.9 | 11.8 | 10.6 | 13.0 | 8.5 | 11.2 | 8.2 |
| 0 Zinc | 8 | 17.0 | 9.8 | 11.4 | 11.2 | 11.5 | 9.0 | 8.0 | 6.6 | 9.3 | 6.5 | 10.8 | 9.6 | 12.0 | 7.3 | 11.8 | 8.2 |
| 2 Zinc | 13 | 16.3 | 9.5 | 10.1 | 10.0 | 10.2 | 8.6 | 9.3 | 8.5 | 10.1 | 9.0 | 12.6 | 11.7 | 13.6 | 11.8 | 12.1 | 9.7 |
| 5 Zinc | 4 | 16.3 | 8.8 | 11.6 | 11.7 | 11.4 | 12.9 | 9.3 | 6.9 | 11.7 | 8.7 | 10.1 | 9.6 | 10.6 | 7.6 | 11.8 | 9.5 |
| Sulfate of potash: | | | | | | | | | | | | | | | | | |
| C. P. $K_2SO_4$ | 14 | 13.3 | 10.5 | 10.2 | 10.2 | 10.3 | 6.9 | 6.4 | 5.9 | 6.9 | 5.8 | 5.7 | 5.3 | 6.1 | 6.8 | 8.9 | 7.5 |
| Crude $K_2SO_4$ | 15 | 9.9 | 11.2 | 10.4 | 10.3 | 10.4 | 8.4 | 6.3 | 6.1 | 6.5 | 5.6 | 6.2 | 5.6 | 6.8 | 4.6 | 8.2 | 7.4 |

MANGANESE CONTENT (WATER-FREE BASIS), 1940–43

| Treatment [1] | Treatment number | 1940 All leaves | 1940 Stalks and roots | 1941 All leaves | 1941 Lower leaves | 1941 Upper leaves | 1941 Stalks and roots | 1942 All leaves | 1942 Lower leaves | 1942 Upper leaves | 1942 Stalks and roots | 1943 All leaves | 1943 Lower leaves | 1943 Upper leaves | 1943 Stalks and roots | Average All leaves | Average Stalks and roots |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trace elements: | | | | | | | | | | | | | | | | | |
| 1 Each | 9 | 196 | 33 | 92 | 99 | 85 | 14.1 | 179 | 203 | 156 | 23.6 | 165 | 232 | 98 | 12.3 | 158 | 20.8 |
| 0 Boron | 5 | 204 | 32 | 93 | 107 | 79 | 15.2 | 175 | 188 | 163 | 24.1 | 145 | 191 | 100 | 14.9 | 154 | 21.6 |
| 2 Boron | 10 | 235 | 34 | 106 | 124 | 89 | 14.1 | 201 | 220 | 182 | 25.2 | 219 | 298 | 140 | 19.9 | 190 | 23.3 |
| 5 Boron | 1 | 199 | 30 | 84 | 89 | 80 | 19.4 | 198 | 221 | 175 | 28.6 | 199 | 266 | 132 | 21.0 | 170 | 24.8 |
| 0 Copper | 6 | 221 | 32 | 105 | 122 | 88 | 16.4 | 211 | 244 | 179 | 29.3 | 201 | 262 | 141 | 18.9 | 185 | 24.2 |
| 2 Copper | 11 | 204 | 31 | 109 | 124 | 95 | 14.2 | 185 | 203 | 167 | 28.3 | 184 | 245 | 124 | 13.0 | 171 | 21.6 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 Copper | 2 | 200 | 33 | 102 | 124 | 80 | 16.5 | 206 | 226 | 186 | 27.9 | 199 | 252 | 146 | 11.7 | 177 | 22.3 |
| 0 Manganese | 7 | 202 | 33 | 87 | 94 | 80 | 13.7 | 154 | 163 | 146 | 25.1 | 112 | 146 | 78 | 8.1 | 139 | 20.0 |
| 2 Manganese | 12 | 240 | 33 | 109 | 135 | 84 | 14.2 | 207 | 241 | 173 | 26.2 | 248 | 336 | 161 | 20.5 | 201 | 23.5 |
| 5 Manganese | 3 | 492 | 54 | 176 | 226 | 127 | 19.3 | 375 | 464 | 286 | 43.7 | 420 | 606 | 235 | 23.8 | 366 | 35.2 |
| 0 Zinc | 8 | 190 | 32 | 92 | 105 | 79 | 18.0 | 186 | 206 | 166 | 23.6 | 175 | 228 | 122 | 15.5 | 161 | 21.8 |
| 2 Zinc | 13 | 226 | 38 | 123 | 141 | 105 | 13.0 | 199 | 216 | 183 | 25.2 | 204 | 269 | 139 | 16.0 | 188 | 23.0 |
| 5 Zinc | 4 | 250 | 35 | 98 | 117 | 79 | 16.4 | 216 | 244 | 189 | 34.5 | 177 | 226 | 129 | 13.0 | 185 | 24.7 |
| Sulfate of potash: | | | | | | | | | | | | | | | | | |
| C. P. $K_2SO_4$ | 14 | 171 | 32 | 119 | 120 | 119 | 10.7 | 157 | 163 | 152 | 23.9 | 159 | 197 | 122 | 12.6 | 152 | 19.8 |
| Crude $K_2SO_4$ | 15 | 244 | 39 | 86 | 89 | 84 | 15.4 | 182 | 199 | 165 | 28.0 | 131 | 167 | 95 | 9.2 | 161 | 22.9 |

ZINC CONTENT (WATER-FREE BASIS), 1940–43

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trace elements: | | | | | | | | | | | | | | | | | |
| 1 Each | 9 | 25.0 | 15.2 | 27.4 | 31.2 | 23.5 | 9.0 | 28.8 | 36.0 | 21.5 | 7.7 | 43.8 | 46.3 | 41.3 | 11.6 | 31.2 | 10.9 |
| 0 Boron | 5 | 36.3 | 17.5 | 29.6 | 32.4 | 26.9 | 12.1 | 26.9 | 31.9 | 21.9 | 5.7 | [illegible] | 49.5 | 42.6 | 12.6 | 34.7 | 12.0 |
| 2 Boron | 10 | 38.5 | 15.7 | 26.7 | 27.8 | 25.6 | 8.1 | 33.2 | 44.4 | 22.0 | 8.4 | 39.8 | 44.4 | 35.3 | 11.4 | 34.6 | 10.9 |
| 5 Boron | 1 | 30.0 | 13.8 | 26.2 | 31.0 | 21.4 | 15.4 | 45.6 | 60.0 | 31.2 | 7.2 | 49.2 | 59.7 | 38.6 | 9.7 | 37.8 | 11.5 |
| 0 Copper | 6 | 34.4 | 12.6 | 27.5 | 31.1 | 23.9 | 7.5 | 31.0 | 37.7 | 24.3 | 6.4 | 47.0 | 53.1 | 41.0 | 12.9 | 35.0 | 9.8 |
| 2 Copper | 11 | 34.1 | 14.3 | 26.5 | 29.1 | 23.9 | 6.2 | 32.8 | 35.0 | 30.5 | 5.2 | 43.2 | 45.8 | 39.5 | 12.6 | 34.2 | 9.6 |
| 5 Copper | 2 | 42.8 | 15.6 | 30.0 | 33.6 | 26.3 | 16.9 | 29.1 | 39.5 | 18.7 | 6.8 | 41.4 | 44.2 | 38.6 | 11.0 | 35.8 | 12.6 |
| 0 Manganese | 7 | 41.2 | 14.0 | 28.0 | 32.1 | 23.8 | 5.1 | 49.6 | 64.4 | 34.9 | 4.0 | 40.2 | 44.9 | 35.6 | 13.0 | 39.8 | 9.0 |
| 2 Manganese | 12 | 42.6 | 14.5 | 25.4 | 30.6 | 20.1 | 8.4 | 23.9 | 31.0 | 16.8 | 5.7 | 43.4 | 49.3 | 37.6 | 13.4 | 33.8 | 10.5 |
| 5 Manganese | 3 | 44.8 | 14.5 | 33.6 | 41.1 | 26.2 | 15.2 | 36.0 | 45.0 | 26.9 | 10.5 | 45.6 | 53.5 | 37.8 | 13.0 | 40.0 | 13.3 |
| 0 Zinc | 8 | 29.7 | 12.1 | 24.0 | 24.0 | 24.0 | 6.0 | 8.9 | 8.6 | 9.2 | 0.6 | 24.6 | 25.6 | 23.6 | 8.2 | 21.8 | 6.7 |
| 2 Zinc | 13 | 44.1 | 18.3 | 33.4 | 35.5 | 31.2 | 11.6 | 56.2 | 69.7 | 42.6 | 12.9 | 56.3 | 66.7 | 45.9 | 19.2 | 47.5 | 15.5 |
| 5 Zinc | 4 | 84.0 | 28.3 | 43.4 | 55.5 | 31.4 | 34.5 | 82.0 | 92.2 | 71.8 | 35.1 | 84.8 | 97.4 | 72.2 | 25.5 | 73.6 | 30.8 |
| Sulfate of potash: | | | | | | | | | | | | | | | | | |
| C. P. $K_2SO_4$ | 14 | 29.0 | 11.4 | 26.0 | 30.1 | 21.8 | 9.3 | 9.4 | 8.8 | 9.9 | 1.1 | 24.8 | 25.9 | 23.8 | 7.7 | 22.3 | 7.4 |
| Crude $K_2SO_4$ | 15 | 15.7 | 9.9 | 20.2 | 24.1 | 16.3 | 6.9 | 17.5 | 15.6 | 19.4 | 3.1 | 29.4 | 31.1 | 27.7 | 7.6 | 20.7 | 6.9 |

See footnote at end of table.

TABLE 8.—*Trace-element content of flue-cured tobacco produced in 1940–45 on plots to which 13 different trace-element treatments and 2 sulfate of potash treatments were applied annually*—Continued

BORON CONTENT (WATER-FREE BASIS), 1944–45

| Treatment [1] | Treatment number | 1944 | | | | 1945 | | | | Average of 1944–45 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | All leaves | Lower leaves | Upper leaves | Stalks and roots | All leaves | Lower leaves | Upper leaves | Stalks and roots | All leaves | Stalks and roots |
| | | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* |
| Trace elements: | | | | | | | | | | | |
| 1 Each | 9 | 61.1 | 64.0 | 58.2 | 16.4 | 61.0 | 58.1 | 64.0 | 11.3 | 61.0 | 13.8 |
| 0 Boron | 5 | 23.8 | 20.8 | 26.7 | 14.2 | 25.6 | 20.5 | 30.9 | 11.7 | 24.7 | 13.0 |
| 2 Boron | 10 | 101.2 | 116.1 | 86.2 | 14.4 | 99.7 | 108.0 | 91.4 | 13.0 | 100.4 | 13.7 |
| 5 Boron | 1 | 291.7 | 257.4 | 326.0 | 16.9 | 240.8 | 276.3 | 205.2 | 16.2 | 266.2 | 16.6 |
| 0 Copper | 6 | 62.3 | 66.3 | 58.3 | 16.8 | 59.7 | 58.2 | 61.2 | 11.5 | 61.0 | 14.2 |
| 2 Copper | 11 | 54.8 | 58.1 | 51.4 | 17.7 | 54.8 | 56.5 | 53.1 | 11.3 | 54.8 | 14.5 |
| 5 Copper | 2 | 53.7 | 57.4 | 50.0 | 12.9 | 54.7 | 56.7 | 52.7 | 12.3 | 54.2 | 12.6 |
| 0 Manganese | 7 | 60.2 | 64.5 | 56.0 | 16.4 | 59.6 | 60.3 | 58.8 | 12.9 | 59.9 | 14.6 |
| 2 Manganese | 12 | 53.7 | 55.4 | 52.0 | 16.0 | 57.2 | 58.9 | 55.6 | 11.6 | 55.4 | 13.8 |
| 5 Manganese | 3 | 58.7 | 54.2 | 63.2 | 16.6 | 54.4 | 50.7 | 58.0 | 12.3 | 56.6 | 14.4 |
| 0 Zinc | 8 | 63.2 | 66.2 | 60.3 | 17.8 | 62.4 | 64.5 | 60.2 | 13.2 | 62.8 | 15.5 |
| 2 Zinc | 13 | 62.2 | 65.4 | 59.0 | 19.6 | 63.8 | 60.9 | 66.6 | 12.5 | 63.0 | 16.0 |
| 5 Zinc | 4 | 56.2 | 57.8 | 54.5 | 15.8 | 64.9 | 61.9 | 67.9 | 11.4 | 60.6 | 13.6 |
| Sulfate of potash: | | | | | | | | | | | |
| C. P. $K_2SO_4$ | 14 | 27.0 | 24.4 | 29.7 | 14.8 | 27.2 | 24.6 | 29.9 | 11.1 | 27.1 | 13.0 |
| Crude $K_2SO_4$ | 15 | 22.2 | 18.1 | 26.3 | 13.4 | 23.8 | 20.6 | 27.0 | 10.3 | 23.0 | 11.9 |

COPPER CONTENT (WATER-FREE BASIS), 1944–45

| Treatment [1] | Treatment number | 1944 All leaves | 1944 Lower leaves | 1944 Upper leaves | 1944 Stalks and roots | 1945 All leaves | 1945 Lower leaves | 1945 Upper leaves | 1945 Stalks and roots | Average All leaves | Average Stalks and roots |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Trace elements: | | | | | | | | | | | |
| 1 Each | 9 | 15.2 | 15.5 | 14.8 | 14.8 | 17.9 | 17.6 | 18.2 | 9.3 | 16.6 | 12.0 |
| 0 Boron | 5 | 15.9 | 16.1 | 15.7 | 11.4 | 13.8 | 12.7 | 15.0 | 7.9 | 14.8 | 9.6 |
| 2 Boron | 10 | 15.4 | 16.3 | 14.5 | 12.5 | 13.4 | 12.4 | 14.5 | 9.3 | 14.4 | 10.9 |
| 5 Boron | 1 | 14.6 | 13.4 | 15.9 | 15.2 | 17.8 | 18.4 | 17.1 | 7.1 | 16.2 | 11.2 |
| 0 Copper | 6 | 7.2 | 7.1 | 7.4 | 8.0 | 8.8 | 8.3 | 9.4 | 9.2 | 8.0 | 8.6 |
| 2 Copper | 11 | 17.0 | 18.1 | 15.8 | 13.4 | 17.8 | 19.3 | 16.4 | 11.0 | 17.4 | 12.2 |
| 5 Copper | 2 | 28.5 | 27.3 | 29.7 | 15.7 | 24.6 | 22.5 | 26.8 | 9.9 | 26.6 | 12.8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 Manganese | 7 | 13.8 | 13.4 | 14.1 | 12.8 | 16.9 | 15.1 | 18.7 | 9.4 | 15.4 | 11.1 |
| 2 Manganese | 12 | 14.6 | 15.1 | 14.1 | 13.5 | 13.7 | 13.3 | 14.1 | 11.7 | 14.2 | 12.6 |
| 5 Manganese | 3 | 18.4 | 16.3 | 20.6 | 11.8 | 16.0 | 17.0 | 15.0 | 9.7 | 17.2 | 10.8 |
| 0 Zinc | 8 | 13.4 | 13.1 | 13.6 | 11.1 | 15.1 | 12.7 | 17.5 | 9.4 | 14.2 | 10.2 |
| 2 Zinc | 13 | 19.3 | 18.3 | 20.3 | 15.9 | 15.4 | 14.1 | 16.8 | 10.0 | 17.4 | 13.0 |
| 5 Zinc | 4 | 17.7 | 17.2 | 18.2 | 11.8 | 14.4 | 14.8 | 13.9 | 8.8 | 16.0 | 10.3 |
| Sulfate of potash: | | | | | | | | | | | |
| C. P. $K_2SO_4$ | 11 | 11.2 | 9.3 | 13.1 | 9.5 | 9.6 | 9.4 | 9.9 | 6.4 | 10.4 | 8.0 |
| Crude $K_2SO_4$ | 15 | 13.5 | 10.2 | 16.8 | 8.0 | 9.2 | 8.3 | 10.0 | 8.5 | 11.4 | 8.7 |

MANGANESE CONTENT (WATER-FREE BASIS), 1944–45

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Trace elements: | | | | | | | | | | | |
| 1 Each | 9 | 669 | 818 | 521 | 74.3 | 268 | 339 | 238 | 46.1 | 479 | 60.2 |
| 0 Boron | 5 | 679 | 791 | 568 | 78.9 | 286 | 359 | 213 | 30.5 | 483 | 54.7 |
| 2 Boron | 10 | 672 | 816 | 529 | 69.5 | 404 | 455 | 354 | 46.0 | 538 | 57.8 |
| 5 Boron | 1 | 685 | 770 | 600 | 75.2 | 370 | 420 | 312 | 32.9 | 528 | 54.0 |
| 0 Copper | 6 | 727 | 883 | 571 | 79.1 | 341 | 345 | 337 | 29.7 | 534 | 54.4 |
| 2 Copper | 11 | 623 | 749 | 497 | 68.3 | 339 | 386 | 293 | 55.6 | 481 | 62.0 |
| 5 Copper | 2 | 753 | 951 | 556 | 77.0 | 402 | 430 | 374 | 34.7 | 578 | 55.9 |
| 0 Manganese | 7 | 513 | 640 | 387 | 60.1 | 216 | 239 | 193 | 37.0 | 365 | 48.6 |
| 2 Manganese | 12 | 744 | 880 | 609 | 74.4 | 472 | 611 | 334 | 57.2 | 608 | 65.8 |
| 5 Manganese | 3 | 1,630 | 2,050 | 1,200 | 186.0 | 754 | 851 | 658 | 76.9 | 1,190 | 131.4 |
| 0 Zinc | 8 | 616 | 761 | 472 | 74.3 | 319 | 330 | 309 | 46.3 | 468 | 60.3 |
| 2 Zinc | 13 | 677 | 780 | 574 | 74.9 | 422 | 456 | 389 | 59.9 | 550 | 67.4 |
| 5 Zinc | 4 | 752 | 857 | 647 | 111.2 | 356 | 403 | 310 | 50.5 | 554 | 80.8 |
| Sulfate of potash: | | | | | | | | | | | |
| C. P. $K_2SO_4$ | 14 | 429 | 498 | 360 | 51.2 | 369 | 409 | 330 | 47.9 | 399 | 49.6 |
| Crude $K_2SO_4$ | 15 | 493 | 535 | 452 | 60.4 | 277 | 318 | 237 | 42.5 | 385 | 51.4 |

See footnote at end of table.

TABLE 8.—*Trace-element content of flue-cured tobacco produced in 1940–45 on plots to which 13 different trace-element treatments and 2 sulfate of potash treatments were applied annually*—Continued

ZINC CONTENT (WATER-FREE BASIS), 1944–45

| Treatment [1] | Treatment number | 1944 | | | | 1945 | | | | Average of 1944–45 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | All leaves | Lower leaves | Upper leaves | Stalks and roots | All leaves | Lower leaves | Upper leaves | Stalks and roots | All leaves | Stalks and roots |
| Trace elements: | | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* |
| 1 Each | 9 | 71.2 | 81.4 | 61.0 | 29.5 | 52.4 | 60.3 | 44.6 | 22.2 | 61.8 | 25.8 |
| 0 Boron | 5 | 57.6 | 64.0 | 51.3 | 26.0 | 65.0 | 66.3 | 63.6 | 22.7 | 61.3 | 24.4 |
| 2 Boron | 10 | 72.6 | 86.7 | 58.5 | 22.7 | 61.7 | 68.4 | 55.0 | 23.4 | 67.2 | 23.0 |
| 5 Boron | 1 | 86.8 | 94.2 | 79.3 | 31.4 | 64.4 | 73.2 | 55.6 | 18.9 | 75.6 | 25.2 |
| 0 Copper | 6 | 70.2 | 82.1 | 58.4 | 32.5 | 63.6 | 68.2 | 58.9 | 24.0 | 66.9 | 28.2 |
| 2 Copper | 11 | 65.6 | 81.4 | 49.7 | 21.3 | 62.4 | 71.3 | 53.5 | 22.2 | 64.0 | 21.8 |
| 5 Copper | 2 | 76.8 | 85.8 | 67.8 | 27.0 | 60.6 | 64.0 | 57.1 | 21.2 | 68.7 | 24.1 |
| 0 Manganese | 7 | 65.2 | 81.1 | 49.2 | 30.9 | 61.1 | 75.6 | 46.6 | 28.5 | 63.2 | 34.2 |
| 2 Manganese | 12 | 63.6 | 69.9 | 57.4 | 24.9 | 65.8 | 79.1 | 52.6 | 25.4 | 64.7 | 25.2 |
| 5 Manganese | 3 | 79.5 | 93.4 | 65.6 | 34.0 | 65.4 | 74.2 | 56.6 | 31.6 | 72.4 | 32.8 |
| 0 Zinc | 8 | 21.4 | 25.4 | 17.5 | 15.3 | 31.5 | 31.3 | 31.7 | 17.2 | 26.4 | 16.2 |
| 2 Zinc | 13 | 110.4 | 128.0 | 92.8 | 47.5 | 83.9 | 98.0 | 69.8 | 32.1 | 97.2 | 39.8 |
| 5 Zinc | 4 | 162.3 | 173.8 | 150.8 | 67.3 | 133.8 | 158.7 | 109.0 | 51.3 | 148.9 | 60.8 |
| Sulfate of potash: | | | | | | | | | | | |
| C. P. $K_2SO_4$ | 14 | 29.8 | 35.0 | 24.7 | 8.3 | 35.8 | 41.7 | 30.0 | 16.0 | 32.8 | 12.2 |
| Crude $K_2SO_4$ | 15 | 28.1 | 26.1 | 30.1 | 12.7 | 35.9 | 42.2 | 29.6 | 16.3 | 32.0 | 14.5 |

[1] In each of the treatments 1-8 and 10-13 the three trace elements other than the one named in *this column* were applied at the 1 rate. Basal fertilizer applied to plots given treatments 1-13 was 800 pounds per acre of 3-8-6 in 1940-43 and the same amount of 3-8-10 in 1944-45. Plots given treatments 14 and 15 received 800 pounds per acre per year of 3-8-20 fertilizer.

### FOUR-YEAR TESTS, 48 POUNDS OF POTASH PER ACRE

In the 4-year trace-element tests, the boron content of the tobacco leaves averaged about 31 p. p. m. for the plots on which this element was not applied and varied directly with quantity of boron applied. The boron content of the stalks and roots did not vary correspondingly; it was greater by only 2.4 p. p. m. where boron had been applied at the 5 rate than where this element had been withheld. On the whole, the lower leaves contained less boron than the upper where boron had been withheld or applied at the 1 rate, and the difference was reversed where boron had been applied at the 2 and 5 rates. On the plots subjected to the treatments that included boron at the 1 rate and the other trace elements at various rates, the differences in application of the other elements did not affect the absorption of boron by the leaves. The boron content of the leaves averaged about 51 p. p. m. both for these plots and for the plots where all four trace elements had been applied at the 1 rate.

The amount of copper found in the tobacco leaves was very small, even where copper had been applied at the rate of 5 pounds per acre. The proportion ranged from 7 to 20 p. p. m. In general, the leaves as compared with the stalks and roots combined contained very much more boron, manganese, and zinc but not much more copper. The copper content of the leaves varied consistently with the rate at which copper had been added to the soil; where the rates of application had been 0, 1, 2, and 5, respectively, the leaf content averaged about 9, 10, 12, and 16 p. p. m. Absorption of copper did not vary according to variations in application of other trace elements.

Manganese was found in larger amounts than any of the other trace elements, both in the leaves and in the stalks and roots. According to rate of application the manganese content of the leaves averaged as follows: 5 rate, 366 p. p. m.; 2 rate, 201 p. p. m.; 1 rate, 158 p. p. m.; 0 rate, 139 p. p. m. For roots and stalks combined, the corresponding values were 35, 24, 21, and 20 p. p. m. The manganese content of the lower leaves consistently exceeded that of the corresponding upper leaves, averaging about 1.75 times as great. For the series of plots that had received manganese at the 1 rate and the three other trace elements at various rates the manganese content of the leaves averaged about 175 p. p. m., compared with 158 p. p. m. where the four elements had all been applied at the 1 rate. Thus it appears that variation in the rates of application of the other trace elements had no material effect on the absorption of manganese.

Zinc, on the whole, was found in the tobacco leaves in proportions intermediate between those of boron and copper, and was found in the stalks and roots in proportions that were within a few parts per million of being the same as those of boron and copper. The zinc found in the leaves from plots where applications of this element had been at the 0, 1, 2, and 5 rates, respectively, amounted to 22, 31, 48, and 74 p. p. m. Zinc content was somewhat greater in the lower than in the upper leaves. Again, uptake of the one element apparently was independent of application of the others; the average zinc content of leaves for the plots subjected to the nine treatments in which zinc was applied at the 1 rate and the other elements at various rates was

36 p. p. m., and that for the plots subjected to the "1 each" treatment was 31 p. p. m.

The tobacco from the two series of plots subjected to special potassium sulfate treatments had nearly the same trace-element content. This indicates that the crude salt did not supply any of the trace elements in important quantities.

### TWO-YEAR TESTS, 80 POUNDS OF POTASH PER ACRE

Where potash had been applied at the rate of 80 pounds per acre, in the 1944–45 tests, proportions of trace elements found in the leaves and in the stalks and roots were different from what they were where potash had been applied at the rate of 48 pounds per acre only. Boron, copper, and zinc were present in decidedly greater proportions than in the 1940–43 tests, and manganese in very much greater proportions (table 8).

When the content of a given trace element, in parts per million, in the leaves produced in the 4-year tests was divided into that in the leaves produced in the 2-year tests under the same treatment as regards that trace element, the results were as follows: Boron—0 rate, 0.8; 1 and 2 rates, 1.2; 5 rate, 1.5. Copper—0 rate, 0.9; 1, 2, and 5 rates, from 1.5 to 1.7. Manganese—0 rate, about 2.5; 1, 2, and 5 rates, about 3. Zinc—0 rate, 1.2; 1, 2, and 5 rates, about 2.

### EVIDENCE AS TO TOBACCO'S REQUIREMENTS OF TRACE ELEMENTS

The results of analysis of the tobacco produced in the study at Florence, S. C., contribute to the evidence as to what quantities of the trace elements suffice for normal growth of the tobacco plant.

The boron content of the leaf material produced on plots from which this element was withheld ranged from about 33 down to about 24 p. p. m. In related investigations, the results of which have not previously been published, it was found that tobacco grown near Raleigh, N. C., and showing symptoms of boron deficiency contained 6.4 p. p. m. of that element, whereas normal plants grown in the same field contained 9.1 p. p. m.; and that plants from Upper Marlboro, Md., showing boron deficiency contained 22 p. p. m. of boron.

According to the results of this study about 10 p. p. m. of copper is sufficient for normal growth of tobacco. The minimum requirement of zinc apparently is somewhat less than 10 p. p. m., since the zinc content of normal plants grown in 1942 without application of that element and of normal plants produced in that year in the sulfate of potash test was under 10 p. p. m.

The manganese value of about 85 p. p. m. obtained in this study at Florence, S. C., in 1941 is one of the lowest recorded. Analysis of manganese-deficient tobacco plants grown in solution cultures by J. E. McMurtrey, of the Bureau of Plant Industry, Soils, and Agricultural Engineering, the results of which have not previously been published, showed the presence of only 22 p. p. m. of manganese.

## SUPPLEMENTAL TRACE-ELEMENT DETERMINATIONS

In order to obtain information on the amounts of the trace elements present in tobacco grown under conditions different from those of this trace-element study and tobacco of all the major types, samples were obtained from field test plots in several of the important tobacco-producing areas. The material sampled had been grown in connection with various studies in which none of the trace elements were intentionally applied but varying amounts of these elements were undoubtedly contained in the commercial fertilizers used.

Prevailingly, the proportions of the individual trace elements found in the leaf tobacco from other areas did not differ widely from those found in the leaf tobacco from the "1 each" trace-element plots (table 9). Again, the manganese values were considerably higher than the others. All the trace elements were notably higher in the tobacco from Arlington, Va. The Arlington test plots on which this

TABLE 9.—*Trace-element content of tobacco leaf of different types from several tobacco-growing districts* [1]

[Data on water-free basis]

| Type of tobacco material and source | Boron | Copper | Manganese | Zinc |
|---|---|---|---|---|
| Burley: | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* |
| Greeneville, Tenn. | 25. 6 | 22. 5 | 358 | 47. 4 |
| | 32. 4 | 21. 0 | 384 | 28. 1 |
| Lakin, W. Va. | 36. 3 | 46. 9 | 72 | 93. 3 |
| Cigar-binder: Madison, Wis. | 42. 2 | 21. 2 | 187 | 26. 8 |
| | 35. 1 | 18. 4 | 160 | 21. 6 |
| Cigar-filler: Lancaster, Pa. | 25. 0 | 11. 7 | 165 | 47. 6 |
| | 24. 5 | 8. 0 | 141 | 32. 9 |
| Cigar wrapper: | | | | |
| Arlington, Va. | 52. 1 | 40. 2 | 307 | 89. 1 |
| | 58. 0 | 149. 3 | 444 | 173. 3 |
| Windsor, Conn. | 44. 4 | 17. 7 | 85 | 42. 7 |
| | 44. 5 | 13. 8 | 98 | 37. 3 |
| Flue-cured: | | | | |
| Florence, S. C.[2] | 29. 3 | 13. 3 | 171 | 29. 0 |
| | 27. 6 | 9. 9 | 244 | 15. 7 |
| Oxford, N. C. | 32. 3 | 15. 1 | 98 | 15. 0 |
| | 44. 4 | 18. 2 | 136 | 36. 5 |
| | 40. 7 | 14. 3 | 140 | 39. 4 |
| | 56. 1 | 25. 6 | 161 | 58. 9 |
| Tifton, Ga. | 18. 7 | 9. 1 | 84 | 43. 4 |
| | 19. 9 | 11. 6 | 98 | 20. 5 |
| Maryland: | | | | |
| Arlington, Va. | 47. 7 | 32. 6 | 350 | 97. 4 |
| | 49. 0 | 129. 6 | 544 | 162. 6 |
| Upper Marlboro, Md. | 21. 9 | 37. 3 | 373 | 88. 4 |
| Seed: Upper Marlboro, Md. | 12. 1 | 22. 6 | 76. 8 | 54. 7 |

[1] The Arlington, Va., source was experimental plots only, not a regular tobacco-growing district.

[2] The Florence, S. C., data in this table are those obtained in 1940 in the sulfate of potash test.

tobacco was grown had been in use for many years, and the soil of one of them had originally been pumped from the Potomac River. With three exceptions, the proportions of boron found were below 52 p. p. m., which was the average of the proportions found in this study in leaf material produced on plots subjected to the nine treatments including boron at the unit rate. A number of the samples contained less boron than was found in the tobacco grown at Florence on plots where boron had not been applied.

If the figures for copper content given in table 9 other than those for tobacco grown at Arlington, Va., are averaged, the result is 17 p. p. m., which is practically the same as the corresponding value obtained in the 4-year tests at Florence on plots where copper was applied at the rate of 5 pounds per acre.

The manganese content of tobacco grown on plots at Florence where this element was applied at the 5 rate, 366 p. p. m., was exceeded by those of only four of the samples. In the other samples of tobacco manganese content averaged 170 p. p. m., or only 12 p. p. m. more than in the 1940–43 product from Florence plots where this element was applied at the rate of 2 pounds per acre. Samples from only three localities—Arlington, Va., Lakin, W. Va., and Upper Marlboro, Md.—contained zinc in proportions greater than the 74 p. p. m. found in material grown on Florence plots where this element had been applied at the 5 rate. In the 16 other samples zinc amounted on an average to 34 p. p. m., a value that practically matches the corresponding value for Florence material grown in 1940–43 on plots where zinc had been applied at the rate of 1 pound per acre.

Analysis of tobacco seed showed that the seed's content of manganese and of boron was much smaller than the average value found for tobacco leaf, but did not show that the seed's content of copper or zinc differed greatly from the leaf-tobacco average.

Analyses were made (table 10) of soil samples taken from the plots on which some of the leaf material analyzed had been grown. These samples were of the surface 7 inches only. The methods of analysis used for copper, manganese, and zinc were the same as those used on the tobacco samples, except that the soils were first fused with potassium pyrosulfate and the silica decomposed with hydrofluoric acid. Total boron was determined by the official method for soils (*3, p. 12*).

The values are for the most part within the range usually found for the different soil types represented. Possibly some of the higher values are due in part to previous fertilizing or other soil treatment. The soil's content of manganese was in all cases decidedly higher than that of any of the other trace elements and was subject to rather wide variations. For the most part the soils were decidedly acid, as is usually the case with good tobacco soils.

The data obtained do not indicate close correspondence between the trace-element content of soil and that of tobacco plants grown on the soil.

TABLE 10.—*Trace-element content and pH value of soils on which tobacco samples represented in table 9 were grown*

[Data on water-free basis]

| Location [1] | Soil type | Boron | Copper | Manganese | Zinc | pH |
|---|---|---|---|---|---|---|
| | | *P. p. m.* | *P. p. m.* | *P. p. m.* | *P. p. m.* | |
| Arlington, Va | Keyport silt loam, clay phase | 17. 6 | 70. 7 | 722 | 72. 2 | 4. 8 |
| | Keyport silt loam, gravel phase | 20. 3 | 102. 0 | 1, 195 | 69. 0 | 4. 8 |
| | Soil pumped from river, sandy | 9. 5 | 96. 0 | 521 | 76. 8 | 6. 0 |
| Greeneville, Tenn | Shackelton silt loam | 13. 1 | 22. 6 | 297 | 18. 6 | 4. 7 |
| Lancaster, Pa | Hagerstown silt loam | 15. 5 | 76. 6 | 1, 960 | 191. 0 | 7. 0 |
| Oxford, N. C | Durham coarse sandy loam | 6. 8 | 16. 0 | 101 | 10. 1 | 5. 6 |
| Tifton, Ga | Tifton sandy loam | 7. 7 | 23. 6 | 200 | 6. 0 | 5. 7 |
| Upper Marlboro, Md | Collington sandy loam | 12. 7 | 46. 0 | 269 | 27. 7 | 4. 3 |

[1] The Arlington, Va., location was experimental plots only, not a regular tobacco-growing district.

## SUMMARY AND CONCLUSION

A series of plot tests on the boron, copper, manganese, and zinc requirements of tobacco was carried on over a period of 6 years at Florence, S. C., on typical Marlboro fine sandy loam, which is an important flue-cured-tobacco soil of the Coastal Plain. These trace elements were applied at 3 different rates in 13 different combinations, each of which contained 3 or all 4 of the individual elements. A 3–8–6 basal fertilizer, which contained an adequate supply of magnesium, calcium, chlorine, and sulfur, was applied to all the plots at the rate of 800 pounds to the acre in each of the years 1940–43; in 1944 and 1945 a 3–8–10 fertilizer was substituted. A parallel 6-year test was made with crude German sulfate of potash in comparison with the high-grade salt, to determine whether the former contains trace elements in quantities that affect its fertilizer value. In that test a 3–8–20 fertilizer was used throughout. To avoid adding unknown amounts of the trace elements, the basal fertilizers used were prepared from tested chemicals largely of reagent grade.

The tobacco plants grown on the plots where the individual elements were withheld did not exhibit symptoms of deficiency of any of them. Apparently the supply of each of the trace elements in question in the soil of the experimental area was sufficient at least to meet the minimum requirement of the tobacco plants for the duration of the experiments. Symptoms of boron toxicity were repeatedly shown by tobacco on the plots receiving that element at the rates of 1 and 2.5 pounds per acre, the more severe injury being associated with the heavier treatment.

Statistical analysis of the yield data for the 1940–43 tests does not indicate that any increase in yields of tobacco resulted from adding the trace elements. Use of boron at the rate of 2.5 pounds per acre caused a loss in yield amounting to about 190 pounds per acre; and copper at 5 and manganese at 10 pounds per acre apparently caused yield losses of about 90 pounds per acre.

The results from the 1944–45 tests, in which the trace elements were used as in 1940–43 but with an increased amount of potash, differed considerably from those of the 4-year tests. In the case of boron, apparently the 0.5-pound-per-acre treatment gave a considerable increase in yield and the 1-pound and 2.5-pound treatments produced practically no losses. Copper apparently gave increases in yields at all rates of application, and manganese at the rate of 2 pounds per acre apparently gave a small increase in yield; where zinc was applied the yields were similar to those of the first series.

Application of crude sulfate of potash did not result in yields differing significantly from those obtained where high-grade $K_2SO_4$ was applied. The quality of the tobacco produced was very nearly the same in all tests. Where boron had been applied at the rate of 2.5 pounds per acre in 1940–43, the value of the product was apparently reduced by 8 percent.

Each of the trace elements was taken up by the leaves of the tobacco plants in amounts varying directly with the amounts applied; the differences were very large for boron, large for manganese and zinc, and somewhat smaller for copper. In samples of the stalks and roots combined, likewise, the trace-element content was greater where greater quantities had been applied, the difference being most pronounced for zinc. With the exception of copper, the trace elements were present in the stalks and roots combined in far smaller proportions than in the leaves. The lower leaves usually contained considerably higher percentages of manganese and somewhat higher percentages of zinc than the upper leaves.

In the 1940–43 tests in which boron was not applied, the boron content of the tobacco leaves averaged about 31 p. p. m. The minimum requirement of boron for normal development of tobacco plants was found in related investigations at another place to be less than 10 p. p. m. Boron content of about 51, 83, and 179 p. p. m. was found in the tobacco leaves grown where boron had been applied at the rates of 0.5, 1, and 2.5 pounds per acre, respectively. The copper found in tobacco leaves on any set of plots in any year of the 4-year tests was within the range of 7 to 20 p. p. m.

Manganese was found in the tobacco in considerably larger proportions than the other trace elements. The maximum average leaf content of manganese for the 4-year series was about 365 p. p. m., found where this element had been applied at the rate of 10 pounds per acre. Where manganese had been withheld the leaf contained, on an average, about 140 p. p. m. In one year manganese values of about 85 p. p. m. were associated with several of the treatments. In a field sample of leaf tobacco obtained from a tobacco-growing district other than Florence, S. C., the manganese content was 72 p. p. m. Plants growing in nutrient solutions that showed symptoms of manganese deficiency were found to contain 22 p. p. m. of manganese.

Average content of zinc in 1940–43 ranged from 22 p. p. m. where this element was withheld to 74 p. p. m. where it was applied at the rate of 5 pounds per acre. The minimum requirement of zinc apparently is less than 10 p. p. m.

Stalks and roots combined, in the 4-year tests, contained in general about 10 p. p. m. each of boron, copper, and zinc and about 20 p. p. m. of manganese.

In the 2-year tests, in which potash was applied at the per-acre rate of 80 rather than 48 pounds, larger quantities of each of the trace elements were taken up, except that less boron and slightly less copper were taken up where these elements were not applied. The increases over the amounts taken up in the 4-year series ranged from about 20 to about 200 percent.

Absorption of the several trace elements seemed to be entirely or almost independent of the presence of the others; about the same concentration of any particular element occurred in the tobacco grown where each element was applied at the unit rate as where the other elements were applied at various rates.

Analyses were made of samples of tobacco of various types grown in several different localities and of the soils upon which they were grown. None of the tobaccos were found to contain less than what are believed to be tobacco's minimum requirements of the trace elements. Prevailingly, the proportions of the individual trace elements found in the leaf tobacco from other areas did not differ widely from those found in the leaf tobacco from the "1 each" trace-element plots.

No close correspondence was found between the trace-element content of soil and that of tobacco plants grown on the soil.

The results of these tests do not indicate need of making special provision for the trace elements in fertilizing tobacco, from the standpoint of either yield or quality of crop. Such a need may exist in special cases. The results definitely show that on some soils application of boron may have serious toxic effects, unless the quantities added are carefully controlled.

## LITERATURE CITED


(1) AMES, J. W., and BOLTZ, G. E.
1915. TOBACCO. INFLUENCE OF FERTILIZERS ON COMPOSITION AND QUALITY. Ohio Agr. Expt. Sta. Bul. 285, pp. 173–209, illus.

(2) ANDERSON, P. J., SWANBACK, T. R., and STREET, O. E.
1938. MALNUTRITION SYMPTOMS DUE TO DEFICIENCIES OR EXCESSES OF PLANT FOOD ELEMENTS. Conn. (State) Agr. Expt. Sta. Bul. 410, pp. 393–406, illus.

(3) ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS.
1940. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS . . . Ed. 5, 757 pp., illus. Washington, D. C.

(4) BAILEY, E. M., and ANDERSON, P. J.
1928. CHEMICAL ANALYSES OF TOBACCO FROM THE NITROGEN PLOTS. Conn. (State) Agr. Expt. Sta. Tobacco Sta. Bul. 10, pp. 35T–50T.

(5) ——— and ANDERSON, P. J.
1930. CHEMICAL COMPOSITION OF A POOR BURNING TOBACCO CROP COMPARED WITH A GOOD BURNING CROP. Conn. (State) Agr. Expt. Sta. Bul. 311, pp. 228–233.

(6) BUTLER, L. I., and ALLEN, H. O.
1942. REPORT ON COPPER AND COBALT IN PLANTS. Assoc. Off. Agr. Chem. Jour. 25: 567–573.

(7) COWLING, H., and MILLER, E. J.
1941. DETERMINATION OF SMALL AMOUNTS OF ZINC IN PLANT MATERIALS. Indus. and Engin. Chem., Analyt. Ed., 13: 145–149, illus.

(8) DRAKE, M., SIELING, D. H., and SCARSETH, G. D.
1941. CALCIUM-BORON RATIO AS AN IMPORTANT FACTOR IN CONTROLLING THE BORON STARVATION OF PLANTS. Amer. Soc. Agron. Jour. 33: 454–462, illus.

(9) ELVEHJEM, C. A., and HART, E. B.
1929. THE COPPER CONTENT OF FEEDINGSTUFFS. Jour. Biol. Chem. 82: 473–477.

(10) GARNER, W. W., BACON, C. W., BOWLING, J. D., and BROWN, D. E.
1934. THE NITROGEN NUTRITION OF TOBACCO. U. S. Dept. Agr. Tech. Bul. 414, 78 pp., illus.

(11) ——— McMURTREY, J. E., Jr., BOWLING, J. D., Jr., and MOSS, E. G.
1930. MAGNESIUM AND CALCIUM REQUIREMENTS OF THE TOBACCO CROP. Jour. Agr. Res. 40: 145–168, illus.

(12) JACOBSON, H. G. M., and SWANBACK, T. R.
1932. MANGANESE CONTENT OF CERTAIN CONNECTICUT SOILS AND ITS RELATION TO THE GROWTH OF TOBACCO. Amer. Soc. Agron. Jour. 24: 237–245.

(13) JONES, H. E., and SCARSETH, G. D.
1944. THE CALCIUM-BORON BALANCE IN PLANTS AS RELATED TO BORON NEEDS. Soil Sci. 57: 15–24, illus.

(14) KUIJPER, J.
1930. BOORZUUR TEGEN DE TOPZIEKTE VAN DE TABAK. Deli Proefsta. te Medan [Sumatra] Vlugschr. 50, 7 pp., illus.

(15) LECOMPTE, S. B., Jr.
1941. STUDIES ON BLACK TOBACCO. Conn. (State) Agr. Expt. Sta. Bul. 444, pp. 270–278.

(16) McHargue, J. S.
1923. IRON AND MANGANESE CONTENT OF CERTAIN SPECIES OF SEEDS. Jour. Agr. Res. 23: 395-399.

(17) ——— Hodgkiss, W. S., and Offutt, E. B.
1940. THE BORON CONTENT OF SOME IMPORTANT FORAGE CROPS, VEGETABLES, FRUITS, AND NUTS. Amer. Soc. Agron. Jour. 32: 622-626.

(18) ——— Woodmansee, C. W., and Rapp, K. E.
1942. NEW USES FOR LOW-GRADE TOBACCO. Ky. Agr. Expt. Sta. Bul. 439, 12 pp., illus.

(19) McMurtrey, J. E., Jr.
1929. THE EFFECT OF BORON DEFICIENCY ON THE GROWTH OF TOBACCO PLANTS IN AERATED AND UNAERATED SOLUTIONS. Jour. Agr. Res. 38: 371-380, illus.

(20) ———
1935. BORON DEFICIENCY IN TOBACCO UNDER FIELD CONDITIONS. Amer. Soc. Agron. Jour. 27: 271-273, illus.

(21) ———
1941. PLANT-NUTRIENT DEFICIENCY IN TOBACCO. In Hambidge, G., ed., Hunger Signs in Crops, pp. 15-54, illus. Washington, D. C.

(22) Rader, L. F., Jr., and Hill, W. L.
1938. DETERMINATION AND OCCURRENCE OF BORON IN NATURAL PHOSPHATES, SUPERPHOSPHATES, AND DEFLUORINATED PHOSPHATE ROCKS. Jour. Agr. Res. 57: 901-916, illus.

(23) Swanback, T. R.
1927. THE EFFECT OF BORIC ACID ON THE GROWTH OF TOBACCO PLANTS IN NUTRIENT SOLUTIONS. Plant Physiol. 2: 475-485, illus.

(24) Ward, G. M.
1942. PHYSIOLOGICAL STUDIES WITH THE TOBACCO PLANT. Canada Dept. Agr. Pub. 729, Tech. Bul. 37, 100 pp., illus.

(25) Wilcox, L. V.
1940. DETERMINATION OF BORON IN PLANT MATERIAL. Indus. and Engin. Chem., Analyt. Ed., 12: 341-343, illus.

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