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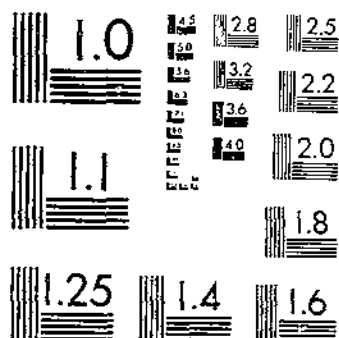
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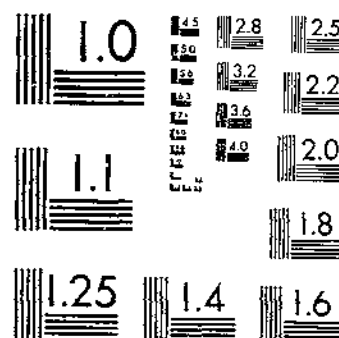
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SYMPTOMS ON FIELD-GROWN TOBACCO CHARACTERISTIC OF THE DEFICIENT SUPPLY  
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**SYMPTOMS ON FIELD-GROWN  
TOBACCO CHARACTERISTIC OF  
THE DEFICIENT SUPPLY OF  
EACH OF SEVERAL ESSENTIAL  
CHEMICAL ELEMENTS**

By

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Bureau of Plant Industry



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DEPARTMENT OF AGRICULTURE

UNITED STATES DEPARTMENT OF AGRICULTURE  
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INTRODUCTION

Possibly the most important contributions to plant growth which the soil furnishes are those chemical elements that the plant requires for normal development. It therefore becomes a matter of great practical importance to supply by means of manures or fertilizers those elements that the soil does not contain in adequate quantities. The question at once resolves itself into finding some simple, practical method for determining what is necessary to supply to obtain normal plant growth. The growing plant itself furnishes the most direct and the final evidence. In the past the final dry weight produced usually has been taken as the index of plant growth. It is true that dry weight is a final measure of growth obtained, but frequently the preceding growth manifestations furnish a basis for a more adequate understanding of the phenomena associated with growth. Final dry weight does not always present a true picture in

<sup>1</sup> Received for publication Oct. 18, 1937.

that it does not take into account that complex and elusive factor commonly designated as quality. This factor is one of great importance with the tobacco crop. Successful culture of the plant does not, therefore, depend simply on the tonnage produced, but this tonnage must have the desired characters as to color, aroma, fire-holding capacity, texture, elasticity, and body; the ability to undergo the aging process with improvement; and possess any of the other necessary prerequisites of quality. These requirements are different for the several so-called types or classes of tobacco produced; namely, cigar, flue-cured, burley, Maryland, dark air-cured, and dark fire-cured. These diverse demands emphasize the necessity for an adequate understanding of all factors affecting growth, in order to have a more comprehensive conception of the proper growing conditions for the crop. A better understanding of all factors entering into the complex requirements of plant growth are greatly to be desired.

The specific effects of each essential element of plant food on growth furnish a fundamental approach to the problem. It is now generally recognized that the higher plants require in suitable quantities and forms at least the following chemical elements in order to make normal growth: Carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, iron, manganese, and boron. The importance of zinc, copper, silicon, molybdenum, and aluminum in the growth of the tobacco plant under field conditions has not been definitely determined. These elements have been reported by some investigators to be of importance in the growth of other plants. The elements nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, iron, manganese, and boron are present in varying quantities and availability in agricultural soils. As their relative abundance and availability determine in a large measure the resulting growth of plants, the question at once arises as to what effects on the plant are produced when any one is deficient. Decreased growth results when the supply of any one is insufficient, but characteristic effects also accompany this manifestation which serve to accurately identify the element which is not available to the plant in sufficient quantity.

Since they are mainly growth phenomena, the distinctive effects on plant development produced by a deficiency of any one of the chemical elements essential for metabolism are modified to a certain extent by other conditions affecting growth. Among these modifying influences may be mentioned light, temperature, and particularly the amount and distribution of the rainfall or other sources of the water supply. It is to be recognized that while environmental conditions may modify rate of growth and, therefore, the rate at which the medium must supply necessary elements as well as the total quantities of these elements required, basically the characteristic symptoms due to deficiency of an element will be found to remain essentially the same. There is often a question as to whether the essential elements simply function in certain metabolic processes or also play a role in the phenomenon of antagonism which is nonspecific. A classic example of this situation which may be cited is that of magnesium which functions as an essential constituent of chlorophyll but also may antagonize calcium or other cation. There may be numerous other functions for magnesium, many of which are not

understood in the present state of our knowledge. However, it appears that only magnesium can function in the first instance in the manner indicated, while various other ions may take part in physiological antagonism. Therefore, the specific effects of magnesium on growth phenomena will in large measure be those effects which are not produced by any other element.

A deficient supply of a single element ordinarily implies a relatively excessive supply of other elements, and in the unbalanced condition of nutrition involved it may not be possible to make a satisfactory distinction between effects due to the deficiency as such and those attributable to the excess supply of the other elements. A mass-action effect also may result, as when a large excess of one element may interfere with the solubility, absorption, or utilization of another element, even to the extent of developing very acute deficiency effects. Similar effects may result at times from the reaction (pH) of the culture medium. At the same time, manifestations of a toxic origin may be superimposed upon typical deficiency symptoms. Another matter of considerable interest in this connection is that of the growth manifestation to be expected when more than one element is deficient. Although, as will be brought out later, there is a greater reduction in growth, the visible effects are essentially those characteristic of the element most deficient under the conditions.

From the foregoing discussion it is evident that the specific effects due to a shortage of any one of the essential elements furnishes an adequate and reliable approach for arriving at an understanding of and interpreting some of the phenomena of growth. At the same time, the practical remedy is usually obvious and more or less easily applied. It appears to be characteristic of deficiency effects that the initial growth manifestations produced by a shortage of any one of the essential plant nutrients are, as a rule, the most typical symptoms and serve best to distinguish these effects from one another. Neither the size nor age of the plant alters the effects due to a deficiency of an element, since, as will be shown later, these effects may take place at any time from the seedling stage to maturity. The relative reduction in growth, therefore, will necessarily be determined by the stage of growth at which the shortage becomes acute.

The most essential requirement in recognizing distinctive deficiency effects on plants is a thorough knowledge of all growth manifestations of the plant in question. It is desirable that something be known of the life history, growth habits, diseases, and insect pests affecting the crop, in order to adequately interpret symptoms due to plant-food deficiency. The successful grower of a crop always possesses this knowledge and is frequently better able to recognize these effects than the highly specialized scientist who may not be so familiar with the details of practical plant culture. It is to be recognized that even though an element is supplied, symptoms of deficiency may occur. The element may not have been supplied in quantities necessary for normal growth under the conditions, or some situation may render it unavailable and, therefore, deficiency effects may be apparent. The tobacco plant has a relatively high content of ash, consisting of all elements essential for growth, and characteristically it makes a rapid growth, so that adequate supplies

of essential elements must be available for normal growth to occur. The leaf, because of its large area, affords an excellent type of organ for study of typical growth manifestations due to any environmental factor. Since the leaf is the final commercial product in demand, studies concerning factors affecting leaf growth may have a wide practical application.

### REVIEW OF THE LITERATURE

The classical example of this type of study is that reported in 1844 by Gris (6)<sup>2</sup> in France on iron chlorosis of plants. This appears to be the first instance where a mineral nutritional deficiency effect based on field plants is described. The study of the effect of potassium, reported in 1902 by Wilfarth and Wimmer (13) on growth of tobacco and other plants, apparently is one of the first contributions describing characteristic growth effects on the tobacco plant due to a shortage of an element. The first case of magnesium deficiency under field conditions in tobacco or other plants was reported (1922) by Garner and others (5). This deficiency was described and illustrated by this author and associates in 1923 (3) in greater detail. This work furnished the background for the studies yielding material presented in this bulletin, since it was found at that time that the tobacco plant manifested strikingly characteristic effects due to a deficiency of magnesium. Studies of the same nature with all essential elements yielded equally striking results, when one effect was compared with another. A bulletin published in 1927 by Moss and others (12) presented the results of fertilizer studies and discussed deficiency effects under the conditions. Garner and others (4) in 1930 described and illustrated growth effects when calcium was deficient under field conditions. McMurtrey (8) in 1929 described and illustrated the effects of boron deficiency on tobacco in solution cultures, and in 1935 (10) this deficiency was described on tobacco with identical effects in the field as earlier reported with solution cultures under greenhouse conditions.

Knijper (7) described boron deficiency in 1930 on tobacco as it occurred in Sumatra and called it topsickness (Topziekte). Anderson and coworkers (1) have discussed (1932) effects due to potassium. The nitrogen nutrition of tobacco was discussed in 1934 by Garner and collaborators (2). The distinctive effects on the growth of tobacco in solution cultures, when any one of the several essential elements was deficient, were described and illustrated in 1933 by McMurtrey (9). The same author, working with Lunn and Brown (11), reported in 1934 on fertilizer tests under Maryland conditions and described and illustrated growth effects due to deficiency of the common fertilizer elements under these conditions. There is surprisingly close agreement in growth manifestations due to deficiency of any one of the essential elements in the foregoing literature citations, even though the plants were grown under a variety of conditions.

### PROCEDURE

The observations upon which these studies were based were collected from numerous locations in the tobacco-producing areas in con-

<sup>2</sup>Italic numbers in parentheses refer to Literature Cited, p. 30.



nection with studies concerning the nitrogen and mineral nutrition of the tobacco plant. These observations cover a period of 20 years. Systematic studies to check field observations were conducted at Upper Marlboro, Md., using relatively pure chemicals to supply or withhold each of the several essential plant nutrients, as desired. For one series of tests the same salts were used in preparing the fertilizer mixtures as were employed in the solution culture studies previously reported (9). The various elements were supplied at the following rates in pounds per acre: Nitrogen, 60; phosphorus, 26; potassium, 50; calcium, 60; magnesium, 12; sulphur, 8; chlorine, 20; and boron, 1. When one element was withheld, the others were supplied at the same rate. There were evidences on the control plot where all elements were added that the amount of potassium used was not sufficient to prevent all evidences of shortage of this element. Additional tests were conducted using different rates and salt combinations. In some instances more than one element was omitted. The procedure of continuous culture of tobacco was adopted, in order to exhaust the available supply of the elements under study.

The methods used in growing the crop were essentially the same as previously reported (11). The observations made at other locations were from experimental plantings grown under the best prevailing local methods.

#### GROWTH MANIFESTATIONS DUE TO DEFICIENCIES OF ESSENTIAL CHEMICAL ELEMENTS

It is evident from the foregoing discussion and literature citations that the growing plant manifests distinctive effects when any one of the several essential elements is available in insufficient amounts. It has been customary to limit discussion of this subject to only three elements under field conditions, but in the present instance an attempt will be made to include all elements that have been found to produce effects on growth, when the supply is deficient as observed under field conditions; namely, nitrogen, phosphorus, potassium, magnesium, calcium, boron, sulphur, manganese, and iron.

It is characteristic of all effects due to a deficiency that the size or age of the plant does not determine or, as a rule, alter the distinctive manifestation. Since the individual plant constitutes the unit upon which the crop as a whole is based, the growth manifestations to be described in the following discussion will be given for the individual plant or parts of the plant.

Normal growth of plants is impossible in the absence of an essential element, but in practice complete absence of an element from the soil rarely, if ever, occurs. It is true that the seeds contain small quantities of essential nutrients as a part of their normal constituents, and it is the common practice with tobacco to grow the young seedlings on virgin soils liberally manured and fertilized. It is possible for the young plant to build up a small reserve, particularly of those elements that are readily mobile within the plant. Even the purest chemicals readily obtainable, and particularly the fertilizer grades, usually contain small quantities of various elements as impurities. The plant, therefore, is always grown under conditions such that the elements under consideration may be more or less deficient but not entirely lacking.

## NITROGEN

Shortage of nitrogen for plant development under field conditions is possibly the most common in occurrence of any of the nutrient deficiencies. The nitrogen supply for the tobacco crop must be controlled to produce leaf of a certain type. It is characteristic of some tobacco types that they must be grown under conditions of relative nitrogen starvation. The flue-cured is a striking example of a type having this requirement, and, to a greater or less extent, this is true for burley and Maryland types. The cigar leaf is an example of a type of leaf that can only be produced successfully with an abundant or luxury consumption of nitrogen. However, even with those kinds of tobacco that are grown under conditions of



FIGURE 1.—Effect of nitrogen supply on tobacco: *A*, Plant grown with a liberal supply of nitrogen; *B*, plant grown under conditions of nitrogen shortage. Note light-green color and firing of lower leaves in *B*.

relative nitrogen deficiency, it is necessary that the plant reach a sufficient size and stage of maturity before the nitrogen supply is depleted to the moderate deficiency stage. It appears that this condition is an important requirement in the complex ripening process.

Nitrogen deficiency may be manifested by the growing tobacco plant at any stage during growth from the seedling to maturity. The effect first becomes apparent as a decrease in the intensity of the normal green color of the growing plant. Accompanying this manifestation there is a cessation or slowing down of the growth rate. The first change in color is followed by the development of a lemon yellow to orange yellow of the lower leaves. The shade of yellow manifested by the lower leaves appears to be correlated with the intensity of green prior to the exhaustion of the nitrogen supply, with the deeper shades of yellow occurring on the greener



Tobacco plants manifesting distinctive effects on growth produced by shortages of the following elements: *B*, Nitrogen; *C*, phosphorus; *D*, potassium; *E*, boron; *F*, calcium; *G*, magnesium. Plant *A*, which was grown with an adequate supply of all these elements, shows normal growth.

plants. This yellowing is followed by a drying up or firing of the yellowed leaves. The number of leaves lost on each plant is determined by the size of the plant and the acuteness of the shortage of nitrogen under the conditions. A deficiency of nitrogen is shown in figure 1. *B*. Here the firing and yellowing of the lower leaves is evident. The remaining leaves on the plant tend to assume an erect position forming an acute angle with the stalk. This situation is evident in plate 1. *B*. and, in addition, it has a light-green color as compared with the control plant (pl. 1. *A*). These same symptoms have been reported in plants grown in solution cultures (9) when the materials supplied the plant were accurately controlled. The bud leaves tend to retain their normal condition, apparently at the expense of nitrogen which is transported from the older leaves. If the nitrogen shortage becomes acute at the flowering stage, flowering and fruiting is accomplished by means of translocation from the older tissues, although the quantity of seed obtained is reduced.

Nitrogen deficiency appears in some manner to produce a plant which shows a lower water content (2) than where nitrogen is supplied in liberal amounts. It appears, therefore, that nitrogen shortage and reduced water supply sometimes manifest much the same symptoms, although of course nitrogen shortage may occur in solution cultures (9) in the presence of abundant water.

Since the quality of the cured leaves of tobacco is the final measure of success in growing the crop, it is a matter of some interest to know something of the characteristics of cured leaf produced with an insufficient supply of an essential nutrient. The size of the leaf is reduced in proportion to the stage of growth at which nitrogen shortage becomes acute. The nitrogen supply also affects the color of the cured leaf, depending upon the type as controlled by method of curing. The flue-cured type of leaf is of the desired lemon-yellow color only when the nitrogen supply is reduced at the ripening stage to a point which in reality constitutes nitrogen deficiency. With the cigar type, nitrogen deficiency is decidedly injurious to growth and quality at any stage, resulting in undesirable colors and other attributes of quality not well understood. The nitrogen supply is known to influence nicotine content (2) to a great extent, low nitrogen producing a leaf which generally shows a low nicotine content.

#### PHOSPHORUS

Practically all virgin tobacco soils except those derived from phosphatic limestones are deficient in phosphorus. On such soils plants manifest a slow growth rate of a certain type which serves to identify the condition. The tobacco plant grown in the presence of a limited supply of phosphorus tends to assume the rosette condition and shows a very dark green color (pl. 1. *C*). Delayed growth is typical of phosphorus deficiency. The size and shape of the individual leaves are altered, as shown in figure 2. The leaves tend to be narrow in proportion to the length. In most instances there appears to be no abnormality other than size, shape, and color of leaves, but in a few instances spots (fig. 3) have been evident on the lower leaves of the plant. These spots have been previously

reported (9), but have not been found consistently to occur on plants grown either in the field or in solution cultures.

When phosphorus is deficient, the effects as observed under field conditions resemble very closely those reported in solution cultures (9), but under field conditions no firing of the lower leaves has appeared to any considerable extent. It will be apparent from the preceding and following discussion that tobacco plants suffering from phosphorus deficiency exhibit less characteristic growth effects than those resulting from shortages of any of the other essential elements. A slow growth rate and lack of maturity apparently are the dominant effects produced by lack of phosphorus as observed under field conditions. The bud leaves tend to retain their normal

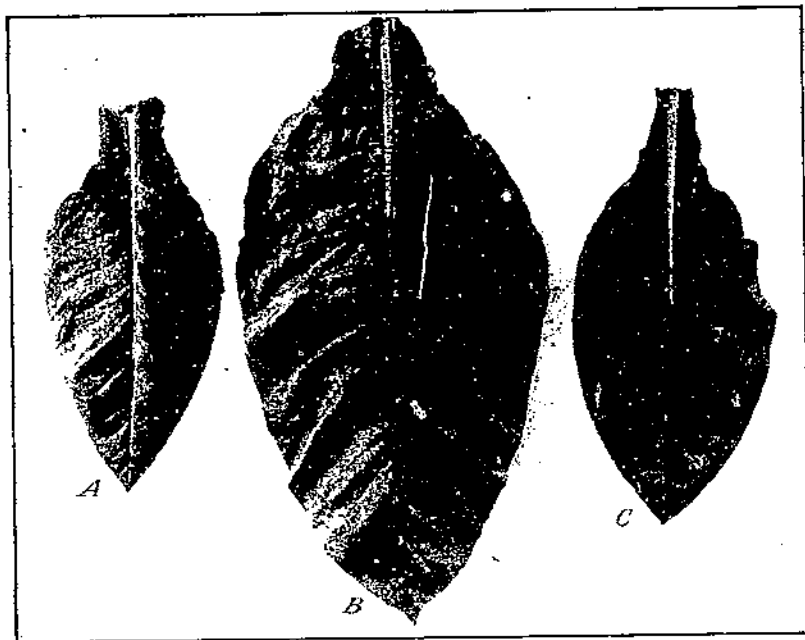


FIGURE 2.—Effect of phosphorus shortage on growth of tobacco leaves: A and C are from plants in which phosphorus was limiting to growth; B is from a plant liberally supplied with phosphorus.

appearance, possibly as a result of translocation of this element from the older plant parts. Flowering and fruiting are successfully accomplished, when the shortage becomes manifest at this stage of growth, through the aid of translocation from the older plant parts. The leaves form an acute angle with the stalk (pl. 1, C).

It is always essential that the leaf reach a certain stage of maturity before harvest, in order for it to have the desired quality when cured. Leaves from plants suffering from phosphorus deficiency are immature and, therefore, are of an undesirable quality. They are dark in color, tending to be dark brown, greenish, or black when cured. If phosphorus is lacking the crop is frequently delayed until late in the season when the prevailing weather is unfavorable for curing, especially in the case of the air-cured types of tobacco.

## POTASSIUM

The requirements of the tobacco plant for potassium are high, and the growing plant manifests strikingly characteristic effects when this element is not present in adequate quantity. It has been

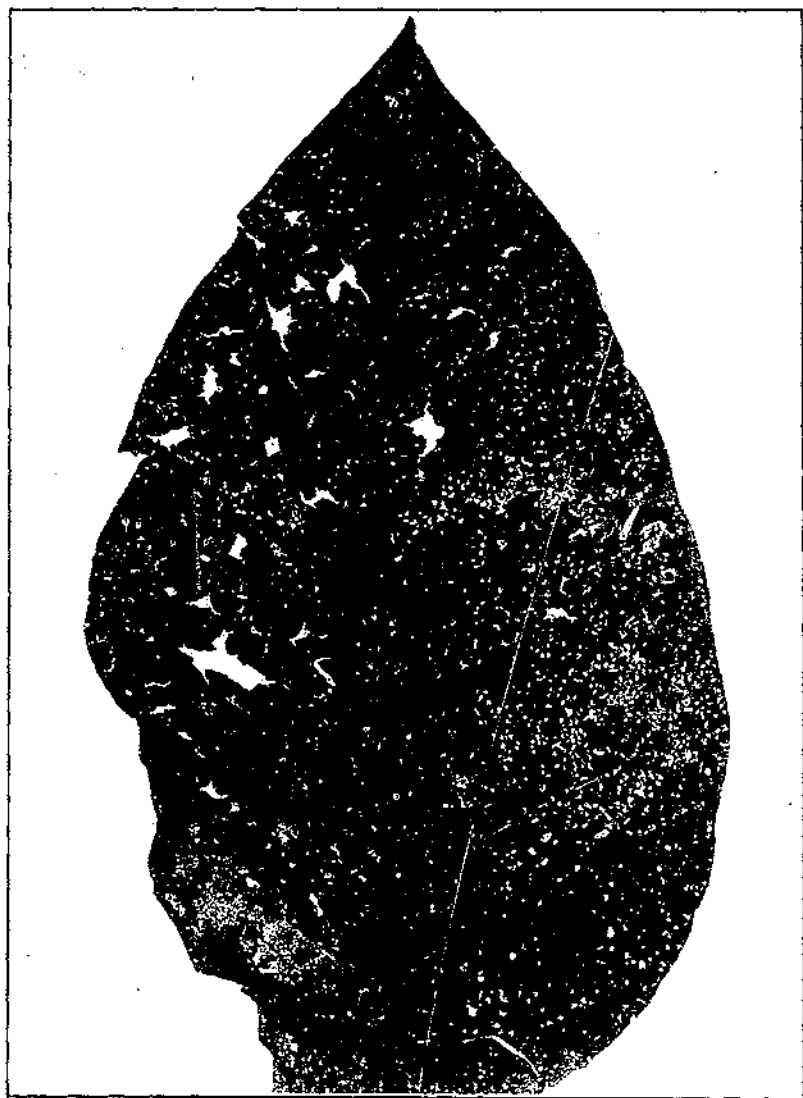


FIGURE 3.—Tobacco leaf manifesting a leaf spot sometimes occurring on plants grown with phosphorus shortage.

previously mentioned that this was possibly the earliest deficiency effect reported with tobacco (13). There appears to be a luxury consumption required for leaf of high quality. The shortage of this element under field conditions does not produce such striking effects

as to reduction in growth as do shortages of nitrogen and phosphorus. However, they are none the less characteristic. The lower leaves of the plant manifest a typical mottling or chlorosis (pl. 1,

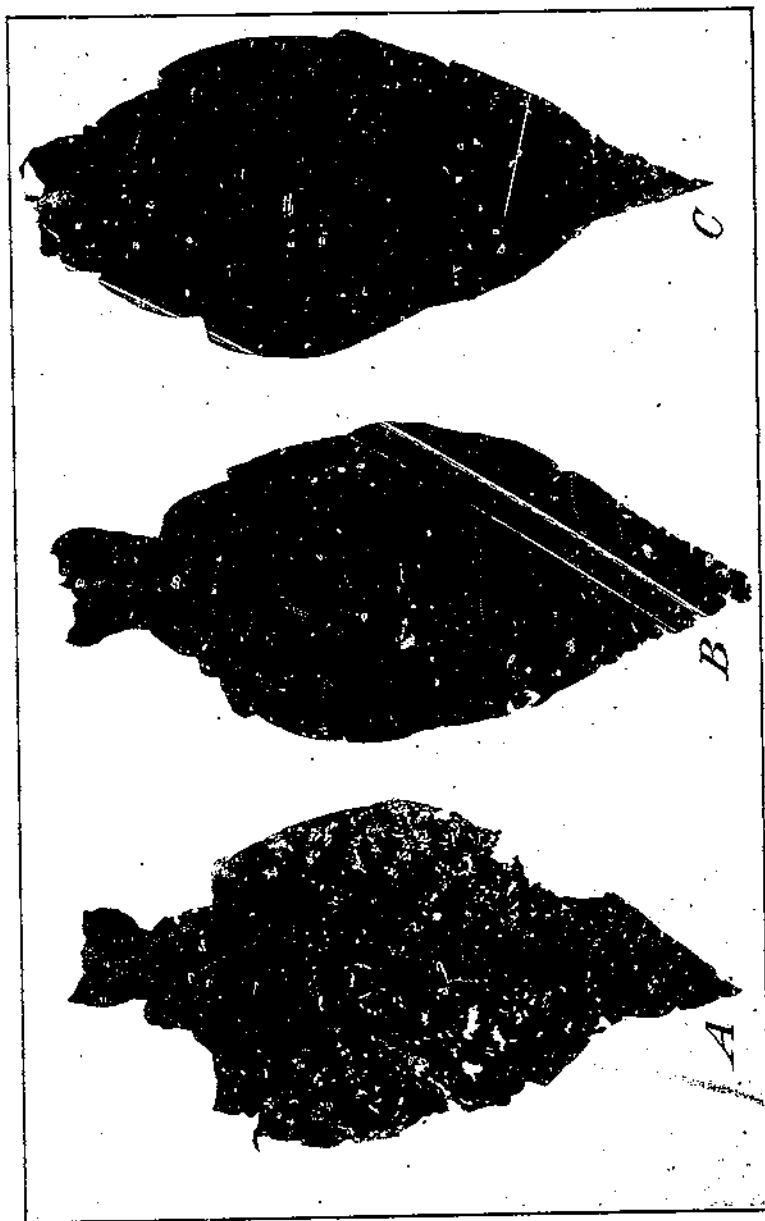


FIGURE 4.—A to C, Tobacco leaves from near the base and upward on the stalk, manifesting different stages of chlorosis, necrosis, and raggedness typical of potassium hunger.

D) at their tips and margins. This is rapidly followed by a necrotic specking usually in small areas in the center of the mottled tissue. The necrotic areas may later enlarge and coalesce to such an extent

that most of the leaf tissues between the veins are involved. These dead areas may fall out, producing a ragged appearance of the leaf, as shown in figure 4. The parts of the leaf that retain their green color appear to manifest a darker color than normal, of a bluish-green shade. The necrotic areas, as they enlarge and involve more of the tissue, produce a brown color in drying and give the plant a rusty or brownish color. Even prior to the appearance of the chlorosis and necrosis the leaves manifest a cupped appearance, doubtless due to a slowing down of the growth rate in the marginal areas, causing the leaves to roll toward the lower surface at the tips and margins. This condition becomes more pronounced as the chlorosis and necrosis develop, due to the living tissue continuing to grow



FIGURE 5.—Tobacco seedling plant from the plant bed showing typical symptoms of potassium deficiency.

around the chlorotic and dead areas. Potassium shortage tends to be accentuated by dry weather conditions.

The mottling appears to progress rapidly from the lower leaves to the upper leaves of the plant, but in all cases observed the bud leaves tend to retain their normal appearance, apparently because of the translocation of this element from the older to the newer leaves. There may be some loss of older leaves, but this is not characteristic of this deficiency as is the case with nitrogen. The age of the plant does not determine the manifestation, since it may be observed on young seedlings from the seedbed (fig. 5) as well as on larger plants in the field (pl. 1, *D*).

It has been previously reported (11, 12) that under field conditions liberal potassium supplies enable the plant to withstand or ward off attacks of leaf spot disease caused by bacteria. It is pos-



sible that the previously described necrosis due to simple potassium deficiency allows the organisms causing certain leaf spot diseases to gain entrance into the leaf tissues and hasten their break-down. It is well recognized that potassium in some manner aids in maintaining the general vigor of the plant. There appears to be a potassium-nitrogen relation in this connection since with cigar tobaccos (?) where high nitrogen fertilization is practiced it is difficult to obtain the protective action of potassium found with Maryland (11) and flue-cured (12) types.

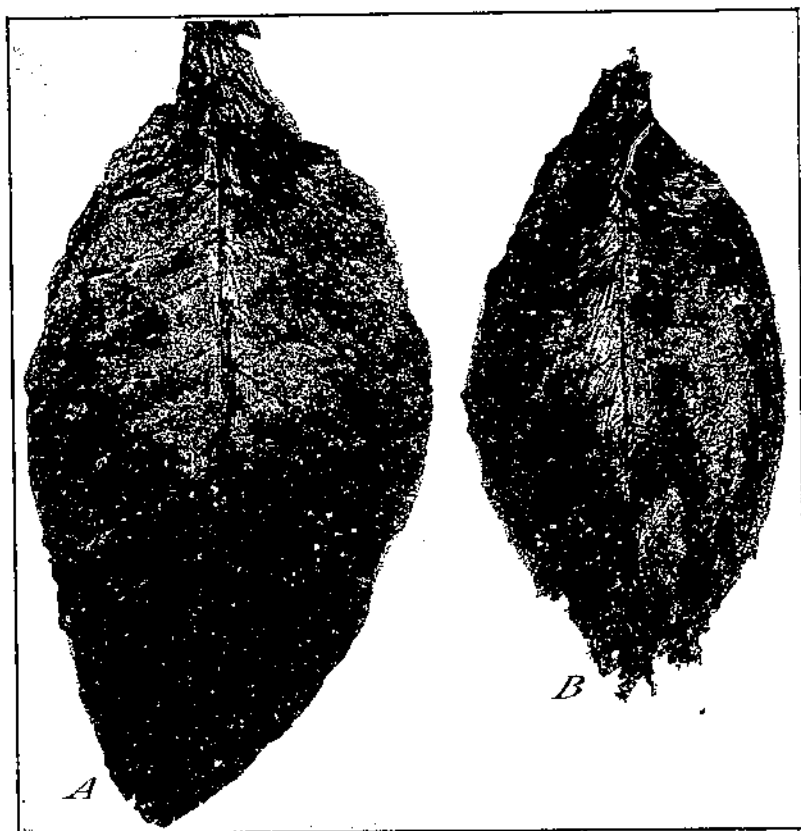


FIGURE 6.—Cured leaves of tobacco (Maryland type): *A*, From plant grown with liberal supply of potassium; *B*, from plant showing characteristic potassium-deficiency effects.

The cured leaves of tobacco from plants grown with a shortage of potassium are not only reduced in size but ragged in appearance, as shown in figure 6, *B*. They are offtype as to color, but not in the distinctive patterns described above on the growing leaves. They lack body, elasticity, aroma, ability to condition when exposed to moist air, and manifest a poor fire-holding capacity.

#### MAGNESIUM

The growth manifestations of the tobacco plant suffering from magnesium deficiency are strikingly distinctive. Since magnesium

enters into the chlorophyll molecule, a shortage of this element produces a chlorosis. This chlorosis progresses commonly in a definite manner. The lowermost leaves of the plant first lose their normal green color at the tips and margins (fig. 7) and between the veins. The veins of the leaf, as well as the tissue immediately adjoining

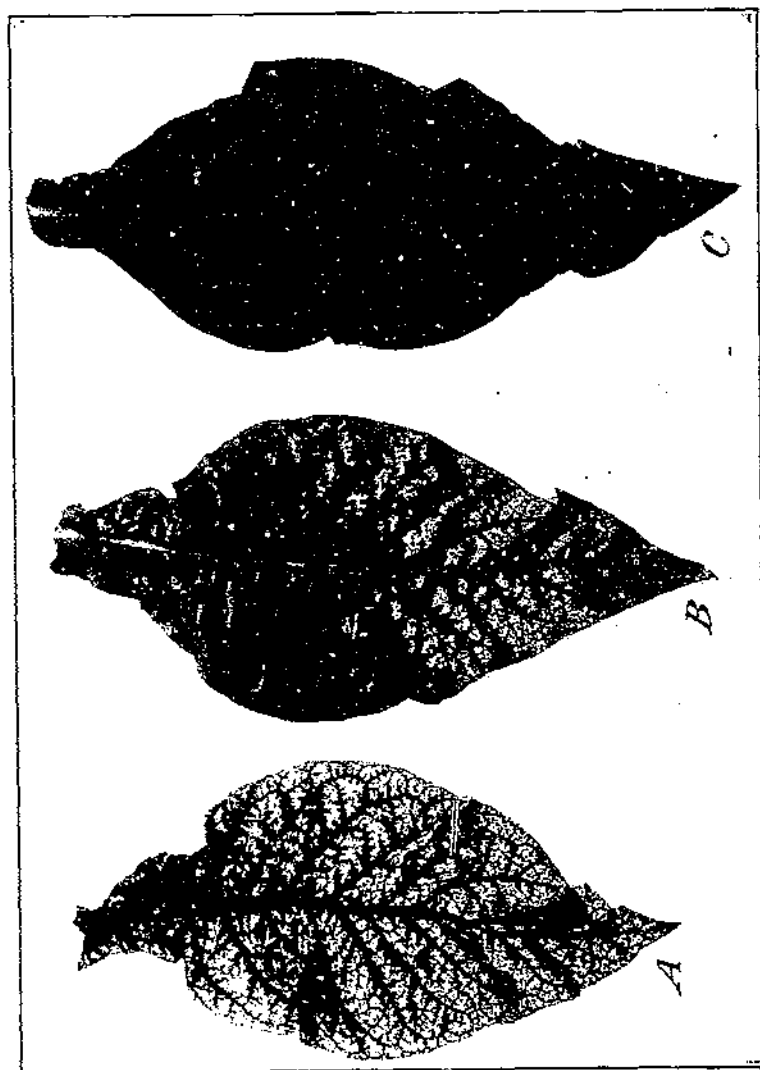


FIGURE 7.—Tobacco leaves showing chlorosis distinctive of magnesium shortage. These three leaves represent stages of chlorosis which may be found on an individual plant from its base upward.

the veins, show a tendency to retain the normal green color long after the remaining leaf tissue has lost practically all the green pigments. The color of the chlorotic tissue may vary from a pale green to almost white, depending upon the acuteness of the deficiency. In extreme cases the lower leaves on the plant may lose practically all the green color, but even these leaves rarely dry up or develop any necrotic spots. Magnesium deficiency has been given the common

name of sand drown, since it is more prevalent in deep sandy soils and during seasons of excessive rainfall. This deficiency rarely appears in the field until the plants have attained considerable size,



FIGURE 8.—Tobacco seedlings from the plant bed: Plant A shows magnesium-deficiency symptoms, while plant B is normal.

more commonly after topping when the growth rate is rapid, so that the leaves usually attain almost normal size and shape.

The yellow as well as the green pigments of the leaf appear to be involved in the dominant symptoms of magnesium shortage. The

chlorosis characteristic of magnesium deficiency progresses uniformly, as a rule, from the base of the plant upward (pl. 1, *G*) and on the individual leaf from the tip and margin toward the base and central zone of the leaf. This may be contrasted with symptoms which have been sometimes observed in solution cultures (*H*) if the element is suddenly withdrawn from the rapidly growing plant.

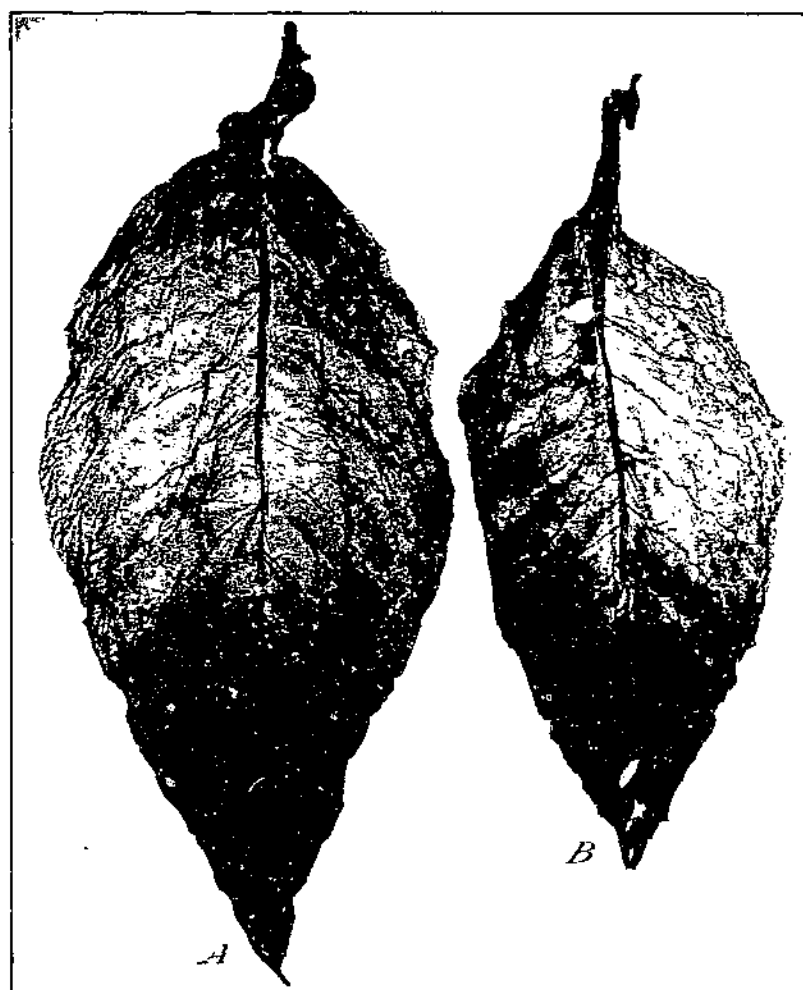


FIGURE 9.—Flue-cured leaves of tobacco. *A*, From a normal plant; *B*, showing typical magnesium-deficiency symptoms, when placed in the curing barn.

when some of the senile lower leaves may not lose the green color. Moreover, the appearance of necrotic spots even prior to development of chlorosis has been reported (*H*) as occurring on plants grown in solution cultures. This spotting has also been observed on soil cultures in the greenhouse when excessive leaching with nutrient solutions lacking magnesium were applied, but it has not been observed to any extent in field cultures. It is possible, however, that it could

occur under field conditions with rapidly growing plants and excessive rainfall.

It is again evident that the age of the plant (fig. 8) is not a determining factor in the characteristic symptoms exhibited by the tobacco plant. This is one of several instances where the tobacco plant in the seedling stage has been observed to exhibit distinctive symptoms of magnesium shortage. The extent of dwarfing which occurs as a result of insufficient magnesium appears to be simply a question of the stage of growth at which the shortage operates and how acute the deficiency. The tendency is for the bud to remain normal, but in extreme cases the entire area of the individual leaf may be involved and all the leaves of the plant may be affected. The contrast between the chlorotic and green tissue is sharper in a growing plant which manifests a dark-green color. When the nitrogen or sulphur supply is low and the plant is of a light-green color, the chlorosis resulting from magnesium deficiency is not so strikingly evident.

The yield is reduced and the quality of the crop is lowered when the growing plant exhibits the previously described growth manifestations due to magnesium deficiency. It is evident that the yield will vary, depending chiefly upon the stage of growth at which the shortage becomes acute. Symptoms in the cured leaf are more readily recognized in the flue-cured (fig. 9) than in the air-cured types of leaf. The quality is more seriously affected than is the yield. The reduction in quality is due to irregular colors, loss in weight, and lack of body and elasticity. The tissue of such leaves is dry, and the color tends to be dark and irregular. It has been reported that magnesium is an important constituent in cigar tobacco, since it appears to have a marked effect on the color of the ash. When the magnesium content of the leaf is low the ash tends to be dark in color.

#### CALCIUM

Calcium has long been recognized as an essential plant nutrient. There has been a general assumption that all agricultural soils contain sufficient calcium for the nutrition of plants and that this element when added as the hydrate or carbonate brings about optimum soil reaction for plant growth. The ability of the calcium ion to antagonize or render harmless to growth other objectionable ions is well recognized, and this appears to be one of the chief functions of this element with light as well as heavy rates of application.

When the supply of calcium is deficient, the tobacco plant manifests distinctive abnormalities in growth. The type of abnormality produced appears to be influenced by what other ions are present under the conditions. The most striking example of this is the magnesium relation in which quantities of this element producing normal growth in the presence of calcium appear to become toxic in its absence. This relation for all practical purposes may be considered as typical of calcium deficiency. The first manifestation of calcium deficiency is the development of a light-green color, followed by a peculiar hooking downward at the tips of the young leaves making up the terminal bud (fig. 10, A). This is followed typically by death of the young leaves with the break-down taking

place initially at the tips and margins, and if complete break-down does not occur and later growth takes place a portion of the tips and margins of such leaves are missing, giving the leaf a cut-out appearance (fig. 11). The affected leaves are distorted as shown. The older leaves on the plant may be normal in shape (pl. 1, *F*). The plant as a whole exhibits an abnormally dark-green color and some thickening of the older leaves as a result of the topping effect due to death of the terminal bud, which takes place in the later stages of extreme shortage of calcium. In some instances of acute shortage of calcium, necrotic spots and chlorosis may develop on the older leaves, though these effects have been rarely observed. When lateral shoots or suckers begin to develop in the leaf axils of plants suffering from calcium shortage, after death of the terminal bud, these shoots



FIGURE 10.—Terminal growth of tobacco plants as affected by calcium and boron deficiency: *A*, The first stage of calcium shortage on the young leaves making up the bud; *B*, an early stage of boron deficiency as it affects the young leaves composing the terminal growth.

tend immediately to develop the above-described terminal growth effects and die back. These effects, which have been typically observed in the field, are identical with effects previously reported on plants grown in solution cultures (9).

If a calcium shortage does not become acute until the flowering stage, the floral parts on greenhouse-grown plants exhibit striking effects (fig. 12). In this illustration the floral parts from a normal plant are shown in *A* and from a plant grown with a shortage of calcium in *B*. There is a tendency to shed the blossoms and buds in *B*, but those flowers that have remained show a dieback of the corolla, with the pistil protruding and, in most instances, the calyx lobes typically show necrotic spots.

It is evident from the foregoing description of growth manifestations that the calcium ion shows little or no translocation from the

older tissues to the growing points or meristematic tissues. A continuous supply of this element, therefore, must be available to the plant for normal growth to occur. The topmost leaves sometimes

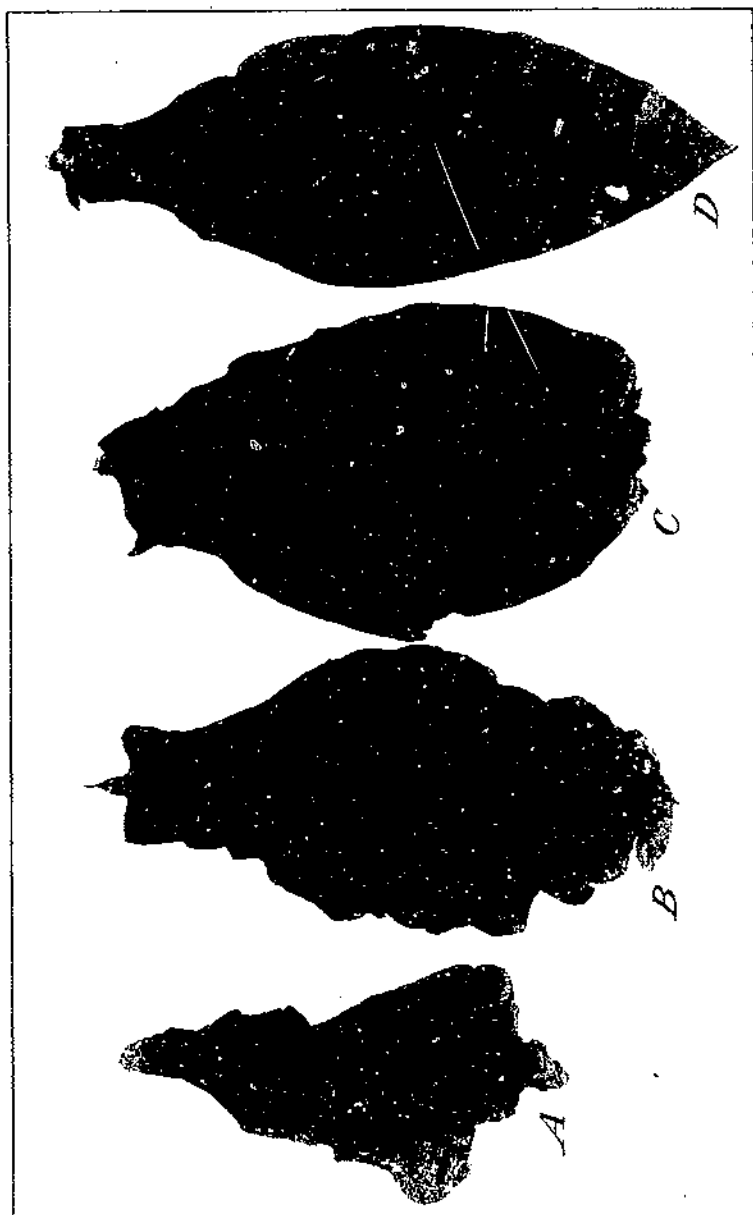


FIGURE 11. A to C, Young leaves from a tobacco plant showing abnormalities in growth produced by calcium shortage; D, leaf from a normal plant.

manifest no abnormality (fig. 13) when calcium-deficiency symptoms are evident on the middle leaves of the plant. This situation appears to be associated with dry periods, when the roots may have pene-

trated to greater depths, enabling the plant to draw on the subsoil reserves of calcium.

There is sometimes another symptom evident on plants growing in soil when the calcium supply is deficient. Tobacco plants grown under these conditions show chlorosis of the young leaves, followed



FIGURE 12.—Plural parts of tobacco plants: A, flower head of a normal plant; B, flower head from a plant grown with a shortage of calcium. Note the drying up of the petals and the distortions of the calyx in B.

by more or less necrotic spotting. This condition has been experimentally reproduced by adding excess manganese in the presence of calcium, but it could be corrected by applications of limestone.

The effects on growth when calcium is deficient are disastrous for commercial culture of the crop. The quality of the cured leaf is



extremely poor, due to the marked physiological disturbance to growth resulting from a shortage of this element. The leaf malformations, death of the terminal bud, thickening of the leaf, and



FIGURE 13.—Tobacco plant showing recovery of top leaves which sometimes occurs during dry periods when the calcium supply of the soil is limited.

associated phenomena result in a cured leaf which is extremely undesirable in character.

#### BORON

The effects of boron shortage on plant growth have only recently been reported as occurring under field conditions (7, 10). The

effects obtained under field conditions are identical with those earlier reported in solution cultures (8, 9). The tobacco plant develops a characteristic dieback which involves the terminal growth when boron shortage becomes acute. This phenomenon is preceded by definite changes in the appearance of the growing plant. The young leaves composing the bud exhibit a light-green color, the bases of the individual leaves manifesting a lighter green than the tips. When this condition occurs, the bud leaves have ceased to grow and exhibit a somewhat drawn appearance. Following these manifestations, the tissues at the base of the young leaves show a break-down (fig. 10, B). When the break-down does not involve all the leaf tissues and later growth takes place, such leaves are distorted because of growth around the injured tissue. This distortion is usually one-sided or twisted. In the same fashion the stalk toward the top of the plant may show a distorted or twisted type of growth.

The death of the terminal bud (pl. 1, E) is the final result of the progressive stages described above. This automatic topping of the plant causes the individual leaves to thicken and increase in area. The upper leaves of the plant tend to roll in a half circle downward from the tip toward the base. They show an abnormal light-green color, become glabrous, stiff, and brittle, and when the midrib or secondary veins are broken the vascular tissue shows a dark discoloration. Lateral buds (suckers) may develop in the axils of the leaves or at the base of the stalk, but they typically break down in the above-described stages. When boron shortage does not become acute until the flowering stage is reached the flower buds are shed, and no seed pods are set. Hence, there appears to be little or no translocation of this element from the older plant parts to the younger growing points. A continuous supply, which it is advisable to point out should only be a trace, must always be available for normal growth to occur. Boron when applied in any considerable quantity becomes toxic, and the amount supplied must be small for normal growth.

It has not been possible to make extensive observations of the effect on cured leaf when boron is deficient for the growing tobacco plant. However, it is evident from the observations available that marked effects are to be expected, due to the striking modifications in growth which occur when this element is not supplied under conditions where shortage becomes evident.

#### MANGANESE

Distinctive symptoms resulting from manganese shortage have only been observed in a few instances on the tobacco plant growing under field conditions. The effects are essentially identical with those previously reported for plants grown in solution cultures (9). It was because of the previous studies with sand and solution cultures that it was possible to identify the cause of the trouble when plants were submitted from a grower's farm apparently manifesting some new disease conditions. This identification was later substantiated by field trials on the area from which the plants were taken. A possible reason for the rare occurrence of manganese deficiency of tobacco under field conditions is that this deficiency is usually associated with a neutral or alkaline soil reaction which is unfavorable for tobacco from the standpoint of the black root rot (*Thielaviopsis*

*basicola* (Berk. and Br.) Ferraris) disease. As a rule, this disease operates to limit growth, so that the effects of manganese deficiency would not become so apparent on soils manifesting a neutral or alkaline reaction.

A shortage of manganese results in abnormal growth effects. The first symptom becoming apparent is a chlorosis of the young leaves of the plant wherein the loss of color follows out the minutest branches of the vascular system. The tissue between the veins is light green to almost white (fig. 14, *A*). The contrast between the chlorotic and green tissues gives the leaf a checkered appearance. The plant as a whole may be considerably dwarfed (fig. 15, *B*) and shows a light-

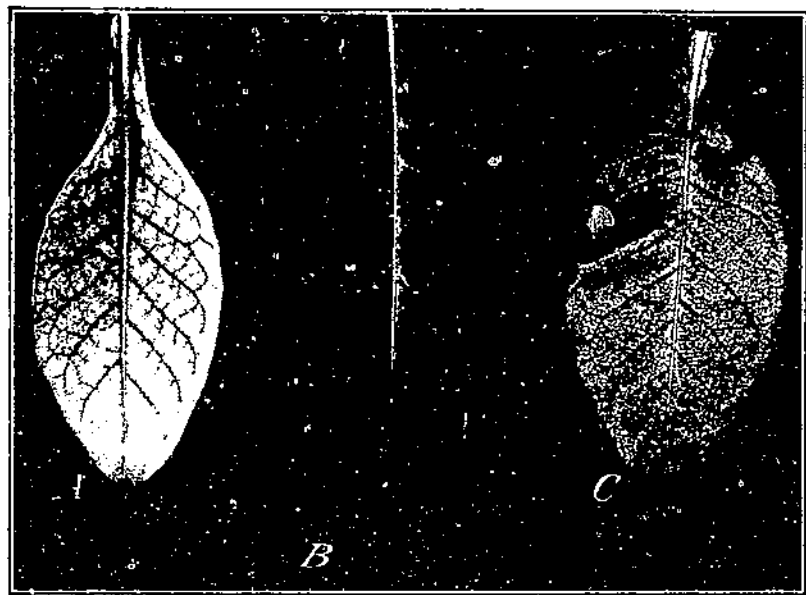


FIGURE 14.—Tobacco leaves: *A*, Leaf exhibiting iron chlorosis; *B*, normal leaf; *C*, leaf showing chlorosis and necrosis typical of manganese deficiency.

green color produced by the definite patterns of chlorosis. The above-described chlorosis is followed by necrotic spotting and the affected tissue may drop out, producing a ragged appearance. This spotting usually involves portions of the entire leaf and is not confined to the leaf tip and margins as with potassium deficiency. It is desirable to point out that the quantity of manganese necessary is small, and that large amounts become toxic, producing undesirable effects, as discussed under calcium deficiency.

The cured leaves from plants manifesting manganese shortage are of poor quality. The most apparent effects are the necrotic spots and the lack of desirable color (fig. 16, *B*). Such leaf lacks body, elasticity, aroma, and is decidedly poor in quality.

#### SULPHUR

The typical effects on growth resulting from a shortage of sulphur have not been observed to occur extensively under field conditions.

This may be explained chiefly by the fact that most commercial fertilizers contain ample sulphur, since many of the common ingredients



FIGURE 15.—A, Tobacco plant normal in appearance and growth; B, plant manifesting chlorosis and necrosis, due to manganese deficiency.

are high in this element. In addition, the rainfall in the tobacco-growing regions usually brings down considerable quantities of sul-

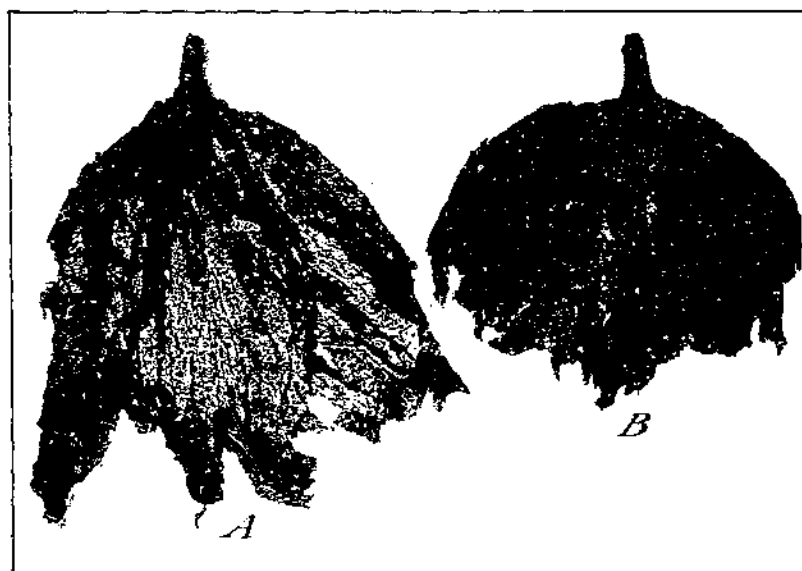


FIGURE 16.—Hands of cured tobacco: A, From normal plants; B, from plants showing typical chlorosis and necrosis due to manganese shortage, which can be seen on the cured leaves.

phur. The relation of rainfall to the occurrence of sulphur deficiency can be frequently observed, for it only becomes evident during dry periods, even in those treatments in which it has been intentionally withheld.

The first effects of sulphur shortage on growth appear as a light-green color on the plant as a whole, although there is a tendency for the young leaves to be lighter green than the older ones. This effect may be contrasted with effects previously reported on plants grown in solution cultures (9) where the light-green color was largely confined to the younger leaves. It is characteristic of plants suffering from sulphur shortage that they do not lose the lower leaves by firing. This feature serves to distinguish a deficiency of sulphur from the effects due to nitrogen shortage where firing is commonly evident. There may be some reduction in growth (fig. 17), due to a



FIGURE 17.—Effect of sulphur supply on growth: A, Tobacco plant normal in appearance and growth; B, plant manifesting effects on growth due to sulphur shortage.

shortage of sulphur associated with the light-green color. A characteristic crimping downward of the leaves at the tips frequently occurs (fig. 17, B). The effects of sulphur shortage, as previously stated, are evident only during dry periods and, as a rule, have been apparent only during the early growth stages under field conditions. It was again (9) strikingly evident that recovery from sulphur deficiency took place rapidly and completely when rains occurred after a dry period, the rain apparently supplying the needed sulphur to the growing plant.

The cured leaf of plants suffering from sulphur shortage manifests color effects which may be desirable or undesirable, depending upon the situation. Provided the yields are not seriously reduced, it appears that sulphur deficiency may produce more desirable colors in flue-cured leaf than when an overabundance of this element is supplied. The Maryland type is an example of cured leaf in which an

abundant sulphur supply apparently produces more desirable colors than those of cured leaf from plants suffering from a shortage of this element.

#### IRON

While iron deficiency has not been observed as occurring on the tobacco plant under field conditions up to the present time, it is important to know something of the symptoms caused by a shortage of this element. It is in much the same category as manganese, since it has been found to occur in other plants on neutral or alkaline soils and might not occur commonly for the same reason as was given in the case of manganese. The effects produced in sand and solution cultures are identical and are shown on an individual leaf in figure 14, A.

The effects of iron shortage on plant growth were early recognized (6), and the typical chlorosis produced on plants by a deficiency of this element was for a long time almost the only recognized type of chlorosis occurring on plants. Iron deficiency first becomes evident on the plant as a chlorosis of the young leaves. The young leaves, making up the terminal bud, lose the green color between the veins and become light green to white in color. In extreme cases the veins lose the green color and the bud may become almost white. The lower leaves and principal veins of the younger leaves tend to restrain the green color. The chlorotic leaves characteristically show no lesions or necrotic areas, but under some conditions apparently characterized by bright sunlight and dry air the chlorotic young leaves may dry up.

A continuous supply of available iron appears to be essential for normal development.

#### COMBINATION OF DEFICIENCY EFFECTS

The question arises as to effects on growth when more than one element is present in limited amounts. This frequently appears to be the situation on unfertilized plots. Most commonly on untreated plots the effects are characteristically those of nitrogen deficiency, although many cases have been observed where potassium-deficiency symptoms are dominant, with little or no appearance of nitrogen shortage. Also, phosphorus shortage, in some instances, has been observed to be the dominant distinctive symptom on plants growing on unfertilized areas. Sulphur deficiency may sometimes be observed on plants growing in untreated soil.

Certain trials have been conducted in which the treatments were made with a view to inducing effects of a shortage of more than one element. When potassium, calcium, and magnesium were withheld, the resulting effects were essentially those of potassium deficiency, with more extreme reductions in growth than commonly are induced by simple potassium shortage. When the potassium was supplied and the calcium and magnesium withheld, reduction in growth was marked, but the plants manifested typical symptoms of magnesium shortage alone, with no evidences of calcium-deficiency growth effects. A combination of magnesium and sulphur shortage produced effects which were not distinctly one or the other, but a blending of the two. This was the only instance observed of this sort of result,

but as has been previously pointed out under discussions of magnesium deficiency, plants of a light-green color fail to show the usual striking type of chlorosis due to a deficiency of magnesium.

It is true that all deficiency combinations have not been tested under field conditions, but insofar as observations have been made, with the one exception mentioned, there is commonly little or no blending of deficiency symptoms. This tends to simplify the problem of diagnosis, since it is possible to recognize the characteristic effects due to a shortage of any one element and to correct each deficiency as it is observed to occur. These features are of great importance in practical plant culture where the recognition of symptoms is essential, since frequently the field history and treatments are unknown.

#### COMPARISON OF DEFICIENCY EFFECTS

It is evident from the foregoing discussion that the dominant effect of a deficiency of any essential element is a reduction in growth. Since this effect is common to all elements it does not furnish an adequate basis for distinguishing one deficiency from the other. However, when all the previously described effects are considered it is evident that there are certain features that serve to distinguish one from the other. These effects fall broadly into two groups. The first group of elements, including nitrogen, phosphorus, potassium, and magnesium, typically manifest distinctive effects on growth of the older leaves. The second group of elements, including calcium, boron, sulphur, iron, and manganese, manifest characteristic symptoms on the new growth. While there is possibly no such phenomenon as absolute immobility of an element from one plant part to another, it appears that the elements of the second group are relatively immobile, while those of the first group move readily from the older plant parts to supply demands for these materials by the growing points.

The first group may be subdivided into those effects that are more or less general and those that are local. The effects that are general, resulting usually in considerable dwarfing, are the ones induced by nitrogen and phosphorus. Under field conditions a plant suffering from nitrogen shortage typically shows more or less firing of the lower leaves, while if the decrease in growth is due to phosphorus shortage such plants typically manifest little or no firing of the lower leaves. When the plant is abnormally light green and firing is evident, nitrogen deficiency is indicated, and if phosphorus is deficient the plant will be abnormally dark green in color, with the leaves narrow in proportion to the length. The leaves tend to assume an erect position, forming a more or less acute angle with the stalk, with either nitrogen or phosphorus shortage.

When the lower leaves of the tobacco plant manifest localized effects characterized by chlorosis and possibly necrosis, magnesium or potassium shortage is to be suspected. If the chlorosis surrounds small necrotic spots or specks at the tips and margins of the leaves and between the veins the symptoms are typical of potassium deficiency. Magnesium hunger, on the other hand, characteristically manifests little or no spotting of the leaf under field conditions. The early stages of potassium deficiency are characterized by a crimping down-

ward of the lower leaves of the plant at the tips and margins. The plant manifests a bluish-green color, with the exception of the mottled areas, which are yellowish in color, but when the necrotic spots occur and dry a rusty appearance develops. The cupping under of the leaf tips and margins becomes more pronounced as the deficiency of potash is more acute, due to the rim-bound effect produced by growth around the dead and dying tissues. The contrast with these effects is found in magnesium deficiency where the leaf tissue is of usual green except in the chlorotic areas between the principal veins, which are of a light-green to almost white color. The leaf tips and margins show little or no cupping under in typical magnesium deficiency.

Boron, calcium, manganese, iron, and sulphur constitute the second group of elements and produce effects on the young leaves or terminal growth when the supply becomes insufficient for normal development. A chlorosis of the young leaves denotes sulphur, iron, or manganese deficiency, while decomposition of the terminal bud preceded by certain changes is indicative of boron or calcium shortage.

The distinctive chlorotic effects due to deficiency of sulphur, manganese, or iron may be separated by differences as to loss of green color and necrosis. The veins tend to retain the green color if iron or manganese is deficient, but tend to manifest a light-green color if sulphur is lacking. The chlorosis typical of iron deficiency takes place between the principal veins, and in extreme cases even these lose the green pigment, although no necrotic spots are characteristically evident. In the case of chlorosis induced by manganese shortage the minutest branches of the vascular system tend to retain the green color, producing a leaf with a checkered appearance. Such leaves later develop necrotic spots distributed over the leaf surface. The loss of green color due to sulphur shortage has not been observed to give chlorotic tissue of as light a color as that due to iron and manganese deficiency, while in addition the veins are as light, and in some instances even appear lighter green than the remaining leaf tissue. The development of necrotic spots has not been observed as characteristic of sulphur deficiency.

The dieback involving the terminal bud, preceded by loss of green color of the bud leaves, is distinctive for growth effects induced by boron and calcium shortage. The loss of green color accompanied by a peculiar hooking downward, involving about one-third of each young leaf making up the bud, is characteristic for calcium shortage. This effect is followed by necrosis at the tips and margins of such leaves, so that the later growth exhibits a cut-out and distorted appearance. A loss of green color at the base of the young leaves, which manifest a drawn appearance, rapidly followed by decomposition of the tissue, is commonly associated with boron deficiency. In some instances the decomposition does not involve all the tissue, and later growth may take place, but distorted or twisted leaves develop because of growth around the injured tissues. When the decomposition appears to involve all the tissue at the base of the young leaf the tip may remain green for some time. Death of the terminal bud is the final result of both calcium and boron shortage. However, the plants under field conditions survive in both instances. The plants assume a dark-green color when calcium is deficient, but the upper leaves on the boron-deficient plants roll downward in a semicircle



from the tip toward the base and manifest an unhealthy light-green color. The principal veins and the midrib of leaves suffering from boron shortage are extremely brittle, breaking readily when folded, and the vascular tissue is discolored brown to black. Plants suffering from calcium shortage do not manifest these symptoms.

The following key based upon field material is given as a guide for quickly determining an unknown deficiency.

#### FIELD KEY TO PLANT-FOOD DEFICIENCY SYMPTOMS ON TOBACCO

- A. Causal parasites or viruses present (not included in present discussions). *Parasitic and virus diseases.*
- A. Causal parasites or viruses absent. More or less localized effects and decreased growth. Commonly classed with nonparasitic diseases.
- B. Effects localized on older or lower leaves or more or less general on whole plant. *(Group 1.)*
  - C. Local, occurring as mottling or chlorosis with or without necrotic spotting of lower leaves, little or no drying up of lower leaves.
    - D. Lower leaves curved or cupped under with yellowish mottling at tips and margins. Necrotic spots at tips and margins. *Potassium.*
    - D. Lower leaves chlorotic between the principal veins at tips and margins of a light-green to white color. Typically there are no necrotic spots. *Magnesium.*
  - C. General; also yellowing and drying or "firing" of lower leaves.
    - D. Plant light green, lower leaves yellow, drying to light-brown color. *Nitrogen.*
    - D. Plants dark green, leaves narrow in proportion to length; plants immature. *Phosphorus.*
- B. Effects localized on terminal growth, consisting of upper and bud leaves. *(Group 2.)*
  - C. Dieback involving the terminal bud, which is preceded by peculiar distortions and necrosis at the tips or base of young leaves making up the terminal growth.
    - D. Young leaves making up the terminal bud first light green followed by a typical hooking downward at tips, followed by necrosis, so that if later growth takes place tips and margins of the upper leaves are missing. *Calcium.*
    - D. Young leaves constricted and light green at base, followed by more or less decomposition at leaf base; if later growth takes place leaves show a twisted or distorted development; broken leaves show blackening of vascular tissue. *Boron.*
  - C. Terminal bud remains alive, chlorosis of upper or bud leaves, with or without necrotic spots, veins light or dark green.
    - D. Young leaves with necrotic spots scattered over chlorotic leaf, smallest veins tend to remain green, producing a checkered effect. *Manganese.*
    - D. Young leaves without necrotic spots, chlorosis does or does not involve veins so as to make them dark or light green in color.
      - E. Young leaves with veins of a light-green color or of same shade as intervein tissue. Color light green, never white or yellow. Lower leaves do not dry up. *Sulphur.*
      - E. Young leaves chlorotic, principal veins characteristically darker green than tissue between the veins. When veins lose their color, all the leaf tissue is white or yellow. *Iron.*

#### SUMMARY

The tobacco plant manifests distinctive symptoms when the soil in which it is growing is deficient in any one of the several plant nutrients essential for development; namely, nitrogen, phosphorus, potassium, magnesium, calcium, boron, sulphur, manganese, and iron. A reduction in growth results when any one of these elements is

deficient, but typical pathological symptoms also are evident on close examination of the root, stem, leaf, or plant as a whole that serve to distinguish one deficiency from the other. The initial growth manifestations due to a shortage of any one of the essential plant nutrients are, as a rule, the most typical and furnish the most reliable basis for distinguishing one deficiency from another.

The symptoms produced by deficiencies fall broadly into two groups. One group of symptoms includes those due to lack of nitrogen, phosphorus, potassium, and magnesium, which appear to be readily mobile in the plant and are localized on the older or lower leaves or are more or less general on the plant. Another group consists of those due to lack of calcium, boron, manganese, sulphur, and iron, which, as judged by symptom manifestations, are relatively immobile and are localized on the terminal growth consisting of upper or bud leaves.

The effects produced on the older leaves or entire plant may be subdivided into those producing local symptoms and general effects. Local effects, such as chlorosis of the older leaves with or without necrotic spots, are due to potassium or magnesium shortage. Typical potassium hunger is distinguished from magnesium deficiency by the development of small necrotic spots at the tips and margins of the chlorotic leaves. General effects on the plant as a whole with the development of a light-green color represent nitrogen deficiency, in contrast with a dark-green immature plant, which is characteristic of phosphorus shortage. The drying up of the lower leaves also follows in nitrogen shortage, but is not commonly observed in the field when the phosphorus supply is deficient.

The symptoms appearing on the terminal growth consisting of the upper and bud leaves may be subdivided into those effects involving a dieback of the terminal growth and those in which the terminal growth becomes chlorotic but does not break down. Boron and calcium deficiency produce as a final result a dieback of the terminal growth, but different symptoms are apparent in the early stages. A shortage of calcium first becomes apparent as a light-green color, followed by a typical hooking downward, with the development of necrosis at the leaf tips and margins, so that if later growth takes place the tips and margins are missing. In contrast with these effects are those due to boron deficiency, first appearing as a light-green color followed by more or less break-down at the base of the bud leaves, which may later make some growth, producing a distorted or twisted leaf. The leaves break easily on plants suffering from boron shortage, and the vascular tissue shows a black color.

Chlorotic effects on the terminal growth or young leaves which are not followed by complete breakdown are typical for manganese, iron, and sulphur deficiencies. The chlorosis characteristic of lack of available manganese tends to follow out the minutest branches of the vascular system, giving the leaf a checkered effect. Accompanying the chlorosis typical of manganese deficiency is a necrosis consisting of small spots scattered over the leaf. The common chlorosis due to iron and sulphur shortage shows no necrotic spots. Iron chlorosis is typical only of the tissue between the veins, but the entire leaf in extreme cases becomes white or yellow. Sulphur shortage becomes evident as a loss of green color on the upper leaves,

but the veins are lighter green than tissue between the veins or of the same color, while the color has not been observed to be white or yellow.

A key is given based upon the foregoing contrasted effects, which may aid in determining an unknown deficiency under field conditions. It has been observed that when more than one element is deficient, while growth may be greatly reduced the evident symptoms are commonly those found to be typical for the element that is the most deficient under the conditions.

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**END**