TRACE ELEMENTS IN CROP PRODUCTIO[N]

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FROM LIEBIG'S TIME in the 1850's, research workers on plant nutrition had number to reduce to the minimum the labored of elements needed for plant production in sand and water cultures. By 1910 they had resolved the list to nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and iron and had developed what was known then as the three-salt solution for the growth of plants. About this time, Mazé, one of the brilliant French research men of the time, developed the idea that other things were necessary, but were present as impurities in the chemicals which were used. Purifying his chemicals with extreme care, he was able to produce evidence of deficiencies of copper, zinc, and manganese and show recovery when these were applied, thus reducing the trend toward reduction in the number of elements felt necessary for plant growth and causing considerable head-shaking in the field of plant nutrition. Even in the mid-20's, the teaching of Mazé's ideas was considered heresy in some quarters and was little discussed or frequently left unmentioned in courses on plant physiology.

Actually, the beginnings of the idea were much earlier than this and recommendations had been made as early as 1890 for the inclusion of zinc sulfate in culture solutions for *Aspergillus niger* in the production of citric acid from sugar. In 1892, Javillier had recommended zinc sulfate as a fertilizer for corn production, though this recommendation went unnoticed until the minor element field began to develop in the 1930's.

The widespread use of organic fertilizers, which contain minor or trace elements, was an important factor in preventing the discovery of the importance of these elements in the field, just as impurities in the laboratory chemicals had delayed identification in the laboratory. For many years in Florida, organic nitrogen and phosphate showed a pronounced advantage over inorganic salts in the production of citrus. This was generally credited to the slower availability, resulting in a higher percentage use of the elements supposedly applied. More recently, long-time experiments on the sands of Florida have shown rather conclusively that an organic material like castor pomace is actually no more efficient as a source of nitrogen for citrus trees than chemical materials such as sodium nitrate, ammonium sulfate, or ammonium nitrate. However, if no minor elements are added to the fertilizer to take care of these deficiencies, the organic material will show a pronounced advantage over the others mentioned because of the traces of needed elements that it contains. In Table I is a comparison of yields of oranges produced under a modern fertilizer program using different sources of nitrogen and it will be that castor pomace in general has not produced quite as well as the chemical sources of nitrogen, such as Uramon, ammonium nitrate, ammonium sulfate, or sodium nitrate. The margin is not great, but certainly the great supe-

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The minor elements have no magic or tonic properties, as some think. They are plant nutrients as necessary as nitrogen, phoshorus, or potash. But the amounts in which they are required are so small in some cases that even in scientific work they were overlooked for many years because of the inability of research workers to purify their chemicals to the degree required to produce a deficiency effect

riority originally credited to organics is not evident in these figures.

High Cost of Organic Fertilizers

Today citrus could be grown well with a fertilizer made up of a variety of organics, such as tankage, bird guano from Peru, bone meal, and low grade potassium sulfate, such as we used to get from Germany. Such a fertilizer probably would contain fairly adequate quantities of the so-called minor elements, but its cost would make it prohibitive for anyone except a dooryard gardener. Moreover, a properly balanced program supplying all the needed elements, either in fertilizer or sprays, would surpass in all probability the best organic mixtures that were ever available in Florida—or, I believe, anywhere else. This has a considerable bearing upon the subject of organic gardening, which seeks in effect to apply all these elements through natural organics rather than identifying and treating the individual deficiencies.

The importance of traces of minor elements extends beyond applied fertilizers. When the tung tree was transplanted from China to Florida, it grew well if planted on newly cleared land, but on adjacent old corn and cotton land the growth was poor and frequently the trees died in their first or second year. Research showed that the failure of the tung trees on the previously cultivated land was caused by a deficiency of zinc in a form available to the trees—even though the soils were not extremely low in total zinc. Further investigations revealed that the native growing plants apparently

Figure 1. The effects of the freeze of 1940. The trees in the foreground which were completely defoliated were fertilized only with nitrogen, phosphorus, and potash, while the larger undamaged trees in the background had received the minor element treatment plus the same fertilizer for three years

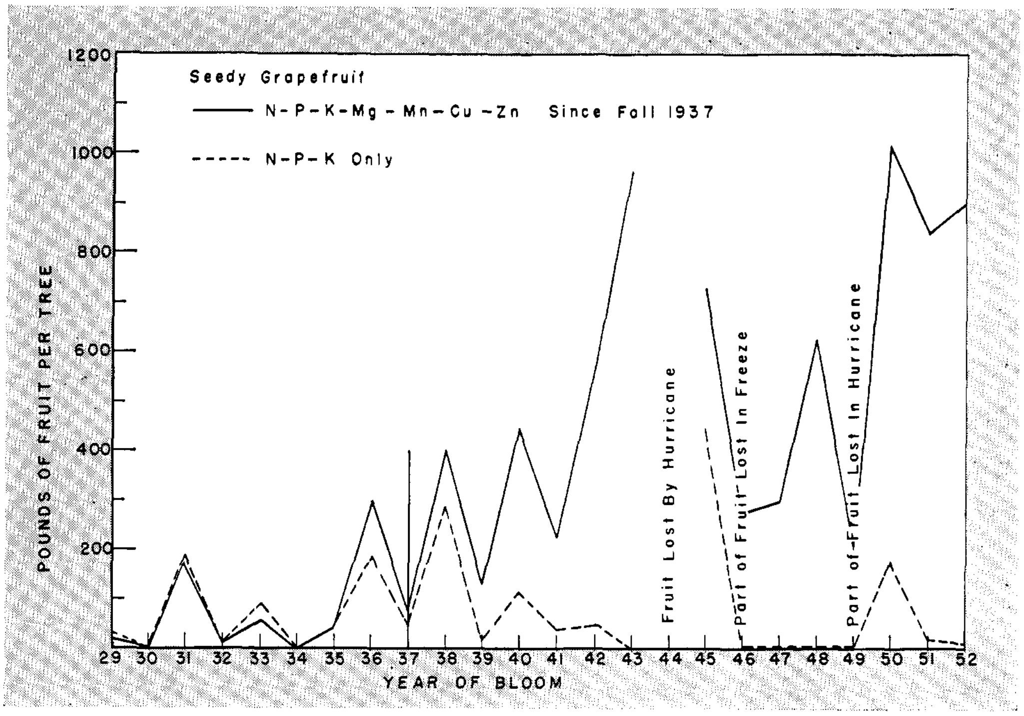


Figure 2. Production record of two grapefruit plots, side by side in a cold location. They were both on an inorganic N-P-K program until 1937 when one plot had the minor elements added to the program and the other was left on the old program. The latter plot has not produced any fruit suitable for the modern fresh fruit market for several years, and is an indication of what could have happened to Florida's citrus industry

were able to take zinc from the soil in the form in which it existed there. The litter they produced left the zinc in an organic form which could be taken up by the tung trees. Thus, where the forest litter was present in quantity, the tung trees grew well, but where crops had been removed from the land over a period of 40 to 50 years, this supply of available zinc had been exhausted.

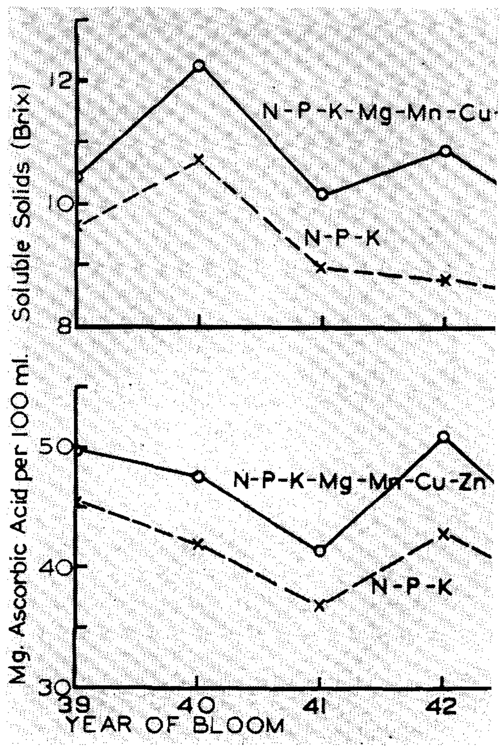
The investigation of the relation of zinc to the production of tung trees led to the clarification of another problem that had been plaguing corn growers in northern Florida for many years. The "Cracker" farmer had learned that on old cultivated soils he could grow corn only every second or third year and that he had to let weeds grow during the intervening years. On the poorer soils, the period of weed growth had to be longer. Chemical examination of the weeds showed a very high content of zinc, whereas corn grown continuously on that land was unable to meet its relatively low zinc requirements and White Bud (a symptom of zinc deficiency) resulted. The addition of 10 to 15 pounds of zinc sulfate per acre, in combination with the usual nitrogen, phosphorus, and potash fertilizer, made possible a better crop of corn than did the old plan of alternating with weeds or applying large amounts of manure.

Another illustration of the same point came from Australia. There it was found that a certain type of pine could be grown on old cultivated land only if forest litter was hauled in and added to the soil. Later it was discovered that the same result could be achieved without the litter by simply spraying the seedling pines with a zinc spray. Thus, again, a forest litter was responsible for a supply of zinc in an available form, that supply having been made possible by the ability of the native plants to take zinc from naturally occurring compounds and leave it in a form available to the pine tree.

This difference in the ability of plants to "graze" on the supply of nutrients in the soil explains many things. One cannot say that because one plant shows no deficiencies on a certain soil, another will be equally fortunate, because the second plant may have different food requirements and a different ability to obtain them. It may also help to explain why some plants grow better after certain crops than they do after others and emphasizes the importance of the composition of the cover crop as well as the tonnage of organic matter, which is usually the criterion.

Another influence which has entered into the picture is increasing purification of fertilizer chemicals. In the case of potash, for instance, old experiments in Florida showed that low-grade sulfate of potash, which contained from 2 to 8% magnesium, and kainit, which contained about the same amount of magnesium, were the best sources of potash for citrus and many other crops. Later we learned that high-grade sulfate of potash or muriate of potash could be made equal to the low grade materials by adding an equivalent amount of magnesium to the pure product. Chemists are very prone to look on purity as a criterion of quality and are continuously trying to increase the purity of the chemicals, but many times the purification tends to benefit the researcher more than the farmer.

Figure 3. Five-year record of juice analysis from grapefruit trees receiving all of the needed elements as compared with the juice from trees deficient in the minor elements. Note that the juice of the fruit from the trees with the complete treatment was higher in both total soluble solids and ascorbic acid in all years



Florida Citrus Decline

The trend to purified inorganic fertilizer materials, plus the use of a light sandy soil low in natural fertility, had begun to produce a decline in the condition of many Florida citrus groves by the late 20's. The trees would produce a good crop, but at the same time many of the leaves would turn yellow and fall, accompanied by the dying back of the twigs. The following year, there was little or no crop and a pronounced alteration was set up in the individual tree. The quality of the fruit was declining, sugar content of the juice was slowly falling, oranges were yellow instead of orange in color, and grapefruit bitter in taste. Intensive research starting about 1930 showed that the trees were suffering from deficiencies of zinc, copper, manganese, and magnesium. By 1935, it was possible to put this developing information in the form of a new fertilizer and spray program which included not only nitrogen, phosphorus, and potash, plus the incidental calcium and sulfur, but also all of the minor elements then known. This new program went into use with amazing rapidity and with it, production increased and the quality of fruit improved. Later boron and molybdenum were added to the list and then an available form of iron was developed.

In Figure 1 will be found a graphic history of the production from two plots of grapefruit located side by side, equally exposed to cold and on the same soil. The trees in both plots were planted in 1921 and fertilized with inorganic nitrogen, phosphorus, and potash mixtures until 1937. That year, one plot was changed to the new program of fertilization, including the minor elements, and the other was left on the old program until the present time. The latter has produced little or no marketable fruit for a number of years. In Figure 2 is shown a graphic demonstration of the difference in cold resistance between these two plots, the picture being taken after the freeze of 1940, when the trees deficient in minor elements were almost killed and the trees properly fertilized suffered little damage. In Figure 3 will be seen a record of the total soluble solids in the juice of the fruit of the two plots, and also the amount of ascorbic acid present. It will be noted that for the period from 1939 to 1943, which this covers, the fruit from the new fertilizer program was always higher in nutritional value than the fruit from the deficient plot.

All of the above, multiplied on an enormous scale, is the history of the Florida citrus industry since 1935. Frozen concentrate plants today request fruit with 12% solids or above and get large quantities of it, whereas a few years ago fruit with 12% soluble solids in the juice was very uncommon.

Yield of Hamlin Oranges in Pounds per Tree As Produced by Various Sources of Nitrogen

Source of Nitrogen	1944–45	1945–46	1946–47	1947–48	1948–49	1949–50	1950–51	1951–52	8-yr. Ave. 1944–45 to 1951–52
Uramon	160	584	505	740	420	570	843	880	588
Ammonium nitrate	210	412	510	712	425	545	795	920	566
Ammonium sulfate	279	685	615	760	510	420	780	880	616
Sodium and potassium nitrate	238	584	523	582	448	522	686	944	566
Castor pomace	120	492	460	620	468	419	733	944	532

For several years after 1935, Florida was considered a freak area with regard to minor elements and considerable fun was poked in certain quarters at practices that became standard in Florida by the mid-30's. Actually, Florida was forced into this research and its use, mainly by circumstances—the circumstances being a soil that was remarkably deficient in almost every plant nutrient, plus an early change to inorganic phosphate and nitrogen. As a result, we were confronted with the necessity for changing our practices or losing a large part of our citrus industry. Our store of forest litter or forest soil was very scant, because of the light soils and the regular burning of the woods, and what little was left when the forest was cleared was rapidly consumed or leached under the tropical conditions which exist in Florida. In the cooler zones, where the destruction of the organic forest soil is slower and where the soils are naturally richer in minerals, the development of these deficiencies is much slower and in many areas no evidence of deficiencies has yet appeared. This does not mean that they will not appear, because as we farm the land year after year, the reserves left by the forests will gradually disappear and our use of inorganic fertilizer materials in the nitrogen, phosphorus, and potash class and without adequate amounts of minor elements will eventually lead to the development of many and serious deficiencies.

New Jersey Soil Conditions Similar to Florida

Some of this evidence is already appearing. New Jersey, for instance, is becoming a center of research on minor elements because it has much the same soil conditions in many areas as Florida. Some peach growers in North Carolina are now using zinc, manganese, and magnesium in their peach fertilizers for sandy soils, with what they believe to be highly beneficial results. Boron and magnesium are being used in a routine way on apples in some sections. In the tropics, deficiencies of zinc, boron, and perhaps some other elements have become a controlling factor in the production of coffee on very old coffee lands in the highlands.

Depletion of Organic Matter in Brazilian Coffee Lands

In Brazil, we have a classic example of what happens to rich forest lands under cultivation plus tropical conditions. Coffee has been grown on new land for many generations in Brazil. The tropical forest is cut down; the coffee is planted. At that time, there is about a foot of high organic soil, frequently with 20% organic matter, which provides an ample supply of all the needed elements. After 20 to 30 years, the coffee plants start declining and the grower clears and plants new lands. By this practice, the land in the province of São Paulo has been exhausted and instead of containing 20 or even 30% of organic matter it may contain only 2 or 3%. The province of Parana now is being developed—but it, too, is not inexhaustible and the same procedures are used. The problem of the use of the old land is becoming acute; the organic soil has disappeared, leaving a soil with only 2 or 3% organic matter, and with a tremendous fixing power for phosphate. This soil is very low in copper and zinc and a fertilizer program is needed to make it profitably useful. Because of the disappearance of the supply of new soils available at altitudes and climates suitable to coffee, it may be necessary within a generation to develop a fertilizer program which will make possible coffee production on the now depleted soils and it would be my prophecy that that program may look very much like the fertility program used in Florida today.

It is reasonable to assume that within the next 10 to 20 years, evidence of deficiencies will become widespread and the use of some or all of the elements needed by the plants will become necessary in many areas. Possibly one of the factors that will help this along, along with the turn to inorganic fertilizer materials, will be the tendency to use introduced cover crops rather than native cover crops.

There is a good deal of evidence that native cover crops are able to use the native elements or minerals quite efficiently, but frequently the introduced cover crop has little ability to use these or may not have much of a requirement for them. In the case of Florida, again, the use of Crotalaria, an introduced legume, in alternate years between corn crops was not nearly as satisfactory as the use of native weeds. The native weeds accumulated large amounts of zinc, while the Crotalaria accumulated extremely small amounts, insufficient to produce a crop of corn.

It occurs to me that we slavishly follow "tonnage of organic matter" produced by cover crops as a criterion to their value, without ever examining very critically the composition of the organic matter produced, and this is perhaps the most important point of all.

The development of an understanding of the basic principles involved in the use of minor elements should reduce the resistance to changes in fertilizer practices as they become necessary. A continuation of the idea that minor elements are magic potions which accomplish marvels under any condition is a handicap to the sensible development of the program. We have no evidence that consumption beyond need will accomplish anything valuable. Correction of a deficiency may increase cold resistance of a grove to the point that it will go unharmed while an adjoining grove is killed back to stumps; it will increase the sugar and vitamin content as well as general food value of fruit produced. But an excess may be toxic or may cause antagonistic action toward other necessary elements, thus causing other deficiencies. All of these points have already been mentioned and illustrated in Table I and Figures 1, 2, and 3. The pictures and data given are for citrus, but the effect of the deficiencies in increasing cold susceptibility has been noted in other crops as well, notably tung oil, and data on the effect of deficiencies in reducing the quality of fruit is constantly coming to light.

Deficiencies will increase with time. If these are recognized and studied and the proper treatments are devised, crop production can be maintained and improved. Failure to recognize deficiencies and proceed sensibly will put us into the hands of the organic gardeners, for they hold the alternative, though more expensive, answer to the problem. It is the duty of the research men in experiment stations and industry to study this problem and to provide the answers, and it is up to industry to provide and sell the proper materials, and to both to educate the farmer concerning the problem. This is the sensible program that tends to eliminate the "sharpers" with the trick cures.

In attempting to bring some semblance of order to the thinking, the first thing to get rid of is the idea that a complete fertilizer contains only nitrogen, phosphorus, and potash. Actually a complete fertility program should include in available form all of those elements needed by a crop which cannot be taken from the soil in sufficient quantity by that crop. It was probably true that in the early experiments nitrogen, phosphorus, and potash, with their attendant calcium and sulfur, did constitute a complete fertilizer, but this term has hung on persistently and has strongly handicapped the development of the program of supplying the needed minor elements by putting them in a separate classification.

Useful Methods for Application Of Minor Elements

Minor elements may be applied to the soil as fertilizer or separately as nutritional sprays.

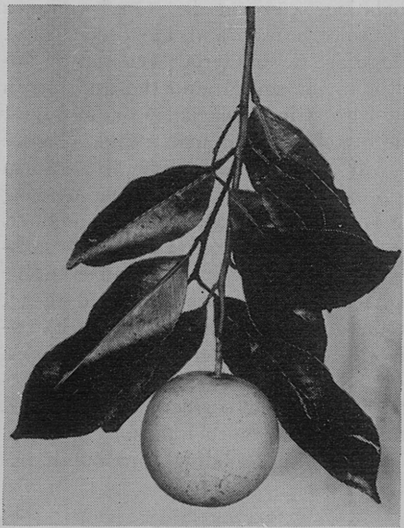
Spraying Sprays take advantage of the ability of the plants to absorb the elements through their leaves—an idea that for some time was considered heresy. Much of the early work in Florida was criticized severely on that basis. The idea is now well established and is common practice. Copper, zinc, manganese, molybdenum, and boron have been applied successfully as sprays in countless tests. Difficulty has been experienced in the application of magnesium as a spray on citrus plants, probably because the glossy surface of the leaf offers an impediment to sufficient absorption of an element needed in such large amount. On the other hand, spraying of magnesium salts on apple trees has met with success. More recently, nitrogen applications, in the form of urea, to the leaves of apple trees, has been successful and such sprays are now used commercially.

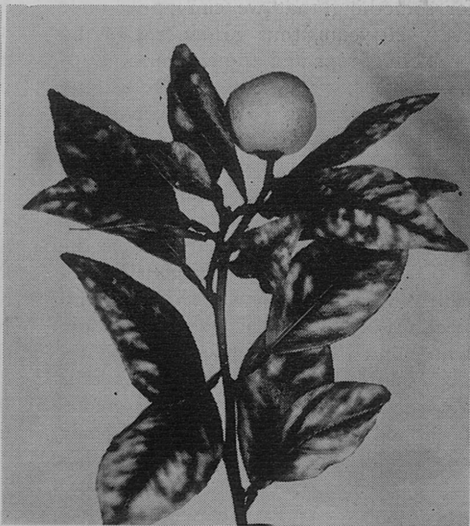
The above differences between plants are important factors and must not be disregarded. Where the apple has a relatively soft leaf without a pronounced cuticle, the citrus tree has a very hard leaf with a sort of varnished surface which offers little in the way of retentive power for spray materials and is undoubtedly a considerable barrier to easy absorption. For citrus, it has been found desirable to neutralize zinc and manganese before application and thus apply them in a slowly soluble form. Straight applications of solutions of the sulfates such as are used on beans in the everglades, are generally unsatisfactory on citrus. The need to retain an element on the leaf for a long period of absorption has resulted in the neutralized spray materials for zinc and manganese, widely used in citrus in Florida, the question of burn having been a secondary factor. The precipitated material can be depended upon to stay on the leaf and in the presence of dew, release minute quantities of the needed element in solution in the dew film. This allows the necessary long absorption period. If the sulfate is applied alone, it usually washes off almost immediately in rain or heavy dew. It is not safe to reason that because the neutralized spray is needed on citrus, however, that other plants such as beans and apples, with different types of leaves, should receive the same type of spray.

In general, for citrus, we have found the neutralized sprays successful for copper, zinc, manganese, and boron but unsatisfactory for iron, which will be discussed later. Molybdenum, on the other hand, is applied as sodium molybdate in a spray solution, in this case a soluble material, but the amount of molybdenum needed for normal functioning of the citrus tree is extremely minute. All of these materials have in their favor the fact that very small amounts of the elements involved are needed and absorption is sufficient to take care of the plant needs. Whether they should be applied as sprays or not depends upon a variety of other factors.

The two most important reasons for applying minor elements in spray form are lack of response to soil applications and economy. If soil applications are not satisfactory, sprays should be tried. Where soil applications must be of large magnitude and over prolonged periods, sprays may give quicker and comparable results from smaller quantities of rather expensive salts. Quick response may also be needed for some crops which grow rapidly and for this, sprays generally work better than for soil applications.

In many areas, the limiting factor in spray applications is the cost of spraying, if spraying is not already being done for other reasons. In Florida, minor elements are simply added to applications of spray that will be put on anyway, but in many areas where spray equipment is not readily available, to attempt to use minor element sprays on crops would require the purchase of equipment and the instituting of expensive procedures. Likewise, in many areas spraying would be extremely difficult. In Costa Rica, for example, extensive zinc deficiency has been found in coffee in the highlands but no results have been obtained from soil applications. Coffee is planted thickly on very steep slopes and the problem of spraying would be extremely diffi-





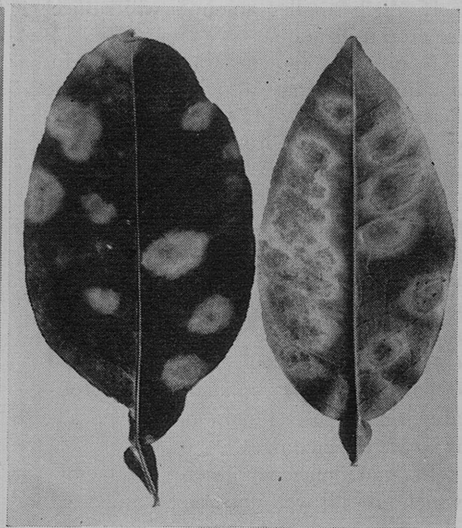


Figure 4. Fruit from zinc deficient trees (right) is small and usually borne in an upright position. The fruit and leaves shown at the left were borne on a tree which had been extremely deficient in zinc but had been treated one year previously. Figure 5 (right). Yellow spot of citrus leaves. This is now known to be the symptom of molybdenum deficiency

cult, if not impossible. The emphasis must be placed on finding some form of zinc which can be applied to the soil.

Insect Increase after Nutritional Spraying

In the Florida citrus industry another problem, of interest mostly to growers of fruit crops, has entered the picture. We have found notable increases in insect population following the application of many nutritional sprays and the insects have become almost as great a problem as the deficiency. This may be related, to a limited extent, to the mechanical conditions resulting. The finely divided residue on the leaves acts like sand on an icy sidewalk, thus giving the young insects protection. Probably more important is the fact that copper, zinc, and manganese tend to reduce the incidence of the fungus and bacterial diseases which tend to keep down insect pests. The result is increased populations that are difficult to control. Scales and some types of mites tend to build up rapidly following applications of zinc and copper.

This problem has also led to the development of a number of very concentrated spray materials, which tend to reduce the amount of residue on the leaves and thus relieve the mechanical factor which appears to be very important in the establishment of young scales, for instance. Increased insect infestation following spraying is of paramount importance to Florida growers and we believe that similar results will be found in other orchard crops. On truck and row crops, it may never be important and our anxiety to get away from sprays should not be taken as applicable to those crops.

As a result of the emphasis on scale build-up following applications of Bordeaux and similar nutritional sprays made of zinc sulfate or manganese sulfate neutralized with lime, we turned to the use of such materials as monobasic and tribasic copper sulfate and cuprous oxide, which contain much higher percentages of copper. These materials leave much less residue on the plant than Bordeaux, while applying the same amount of copper, and the result is a much smaller build-up of scales. More recently, neutralized compounds of zinc have been developed which are being used successfully, and a small amount of neutral manganese is being used. These materials are no more efficient as far as correcting copper, zinc, or manganese deficiency is concerned than are the lime neutralized sulfates of the elements, but do have the advantage of leaving less residue on the leaves to favor scale build-up. The development of a satisfactory material for this is not easy, because some materials will be too soluble and produce burn, and some of them will be too insoluble and give poor results. A good deal of experimental work remains to be done.

The original minor element program for citrus in Florida included magnesium, manganese, copper and zinc, but more recently molybdenum has entered the picture as an important deficiency. "Yellow Spot" had been known in this state for perhaps 50 years, as a serious trouble of citrus which showed up periodically and caused extensive defoliation, sometimes as high as 80%. An illustration of Yellow Spot will be seen in Figure 5. Until recently, this trouble had defied identification and many people felt it might be a toxicity of some kind. However, Drs. Stewart and Leonard of the Citrus Experiment Station proved that the yellow spotting was due to a deficiency of molybdenum and could be corrected by the application of molybdenum sprays, using sodium molybdate at the rate of 1 to 2 ounces per 100 gallons, depending upon the severity of the symptoms. Recoveries are almost miraculous, following the application, and an examination of our soils shows that we have a tremendous acreage of soil extremely low in molybdenum. This is the latest spray that has been introduced in the minor element picture.

Soil Application Problems connected with soil applications are more complicated than those connected with sprays, because the soil composition is a very large factor in their success or failure. Such things as pH, residual calcium carbonate, phosphate content, and the like are controlling factors on the usability of soil applications and there are also some factors which have not yet been unraveled but which operate very strongly in the case of zinc and iron. It is well known that high alkalinity may hinder the availability of such materials as copper, manganese, zinc, and iron and bring on deficiencies; at the same time a high pH may prevent satisfactory results from soil applications.

This fixing power as related to pH is readily understandable, but there are also other factors. Copper, for instance, which should be highly soluble on acid soils, is strongly absorbed by organic matter, as pointed out by Jamison of the Citrus Station a good many years ago, and by Wander more recently. In using soil applications of copper, it is necessary to use enough to satisfy the fixing power of the soil before a surplus is left over for utilization by the plant. When this fixing power becomes saturated, then probably much smaller amounts will suffice for crop utilization.

Iron, while known as a deficiency in alkaline soils, may also be sharply deficient at very low pH's, possibly because of precipitation of iron phosphate, while molybdenum may be deficient because of the insolubility of molybdic acid. Manganese sulfate applications on acid soils generally correct a deficiency of this element, but there is a tendency for manganese sulfate gradually to become insoluble manganese oxide and applications need to be repeated. In the case of boron deficiency on acid soils, it probably is not a case of fixation so much as it is a case of leaching.

In zinc deficiency, there are factors which are not well understood and need elucidation. Zinc sulfate applied to the soil proved to be a satisfactory corrective for zinc deficiency in tung trees in north Florida, Alabama, and Mississippi, and for zinc deficiency in citrus in the sandy soils around Gainesville, Fla. Further south in the citrus belt, however, and on very similar soils, zinc has not been very satisfactory as a soil application and very commonly must be used as a spray. The same is true in the case of coffee in Costa Rica, where on an acid soil, zinc applications have been complete failures, whereas zinc sprays have given almost miraculous results. Similar results were found in Argentina, Brazil, and in many other places in the world. This does not seem to be related to organic matter, as is the case with copper, but certainly some factor involved in many soils and under a great variety of conditions seems to tend to prevent the intake of zinc by plants when zinc sulfate is applied to the soil. This does not necessarily extend to all plants in the area.

Until recently, the common soil applications for the correction of deficiencies of copper, zinc, and manganese were the low grade sulfates of these materials. On acid soils, they have worked quite satisfactorily and constitute usually the cheapest soluble form of the element. A great deal of interest, however, has been aroused in another line of research, and that is the application of these elements in slowly available forms. This is essentially what the old "Cracker" citrus grower used when he applied coarse granular copper sulfate, frequently using crystals as big as the end of a man's thumb. The crystals broke down very slowly and often were present in the soil a year after application. Attempts to do the same thing with an artificial lump of zinc sulfate did not succeed. This sort of research is continuing with much interest in the possible utilization of crude minerals but very little in the way of satisfactory results. All of us are looking for something that we can apply once every 20 years, thus getting rid of the problem of repeated applications. Cuprous oxide has shown itself to be a quite satisfactory source of copper on sandy soils in Florida, though it is a relatively insoluble material, whereas somewhat similar compounds of manganese and zinc have been failures.

Chelates A major contribution to the use of minor elements has recently been made by Drs. Stewart and Leonard of the citrus experiment station, who found that iron chelates would remain soluble in the soil until iron could be absorbed by citrus trees. This makes possible the correction of iron deficiency on acid soils, which up to this time has defied correction. I will not discuss the chemistry of these chelates at this time, because it is a rather complicated picture, but suffice it to say that iron is held in a soluble but not ionized form by the organic compounds known as chelating agents. These organic acids will hold iron strongly against the action of phosphate or other materials which would tend to react with the iron and for the first time we are able to keep iron in an available form long enough for it to be absorbed by the plant on these acid soils. Extensive fields for research have been opened up by this finding and it seems reasonable to expect that the same principles may become applicable to zinc, copper, manganese, and other metals.

As already mentioned, the complex organic chelating compounds combine with iron in such a way that iron remains soluble but not ionized and does not react readily with fixing materials such as phosphate. Two materials of this type are available, made with two different chelating compounds. One contains 8% soluble iron and the other, 12%. These are dry materials and can be applied to the soil around the tree and in the case of iron deficiency on acid soils, the response is extremely rapid. Figure 6 will show the recovery obtained in approximately six months after treating an acutely deficient tree. The products developed to date have proved satisfactory only for acid soils and excessive applications have been required to get results on highly alkaline soils. Extensive research is under way to develop a compound that remains soluble in alkaline soils and thus correct the wide-spread iron deficiency on such soils.

Figure 6. Iron-deficient orange tree on left and comparable tree 6 months after treatment with iron chelate

Work with chelating compounds has been extending rapidly not only in Florida, but in many other states, and also on many other crops and with different chelating compounds. Iron deficiency is widespread in many crops on acid soils and excellent results have been obtained on many crops besides citrus. Parallel work is also under way, looking to the development of a chelated zinc. Such a compound might be a life saver for many tropical areas where zinc deficiency is becoming increasingly important. Just what the future in research on chelated compounds may be is difficult to say, but certainly it is opening a startling new avenue of research on minor elements and may be expected to contribute greatly to the future in this field—a future which is of vital importance to every farmer, food producer, or other individual or company connected with agricultural production.

Based on a paper presented before the spring meeting of the National Agricultural Chemicals Association, New Orleans, March 11-13, 1953.