FOLIAR FEEDING OF PLANT NUTRIENTS

New Ideas Through Atomic Energy

Extracts from THE CONTRIBUTION OF ATOMIC ENERGY TO AGRICULTURE
Congress of the United States, Research and Development Subcommittee of
the Joint Committee on Atomic Energy, Washington, D.C.
Present: Representatives Hinshaw (presiding), Van Zandt, Durham, and Price; and Senators Bricker and Pastore.

HINSHAW. The committee will come to order. Our meeting today and tomorrow will deal with the uses and applications of atomic energy and especially radioisotopes in the field of agriculture. These are open hearings and in this respect are a refreshing departure from the closed-door approach which we have had to take in so many atomic-energy matters.

Now we have Dr. H. B. Tukey, who will discuss the foliar application of plant nutrients and radioisotopes in horticultural research. Dr. Tukey is head of the department of horticulture at Michigan State College. He received his bachelor's philosophy at the University of Chicago. He has been the professor of pomology -- which I presume has something to do with fruit--at Cornell University from 1927 to 1945. He is a member of the Royal Horticultural Society in 1947, was a delegate to the 13th International Horticultural congress in London in 1952, has contributed much research and many publications on plant-growth regulators, fruit culture, and developmental morphology.

Dr. Tukey, we are very delighted to have you here today and expect to gain much from what you have to say. It is unfortunate that some of our Members have found it necessary to go back to their work on the floor of the House and Senate, but we are certain that the contribution you make will be found in the record for all time to come, and we greatly appreciate it.

Dr. TUKEY. Mr. Chairman and members of the committee, I, too, am honored to be asked to appear before you and I appreciate the opportunity to tell you something about what I think is one of the exciting new developments in agriculture, namely, that not only can plants absorb nutrients through the roots, but also through the foliage, the fruit, the twigs, the trunk, and even the flowers.

I would like to go back in history to King George III of England. Every child in elementary school knows about King George III. He made an award to his gardener, William Forsythe, upon recommendation of a commission from Parliament for revealing to the public a particular concoction of certain materials from the barnyard, soapsuds, lime from an old building, and so on, which put together and plastered onto trees, and then covered with a powder of burned bone and wood ashes, encouraged the recovery of wounded trees, and quite influenced the growth of the trees. All of this was viewed at that time with some misgivings.

A little later in California in 1914, scientists working on the control of insects and diseases found that if they applied certain fertilizers to dormant trees and to the foliage of trees, there was an improvement in growth the next year.

Again, in Oregon a few years later, some outstanding work in spraying dormant trees with fertilizers improved the growth of trees.

BRICKER. In spring and during the wintertime?

Dr. TUKEY. Yes, sir. In fact, after a severe winter in Michigan a few years ago, we also tried spraying dormant trees with fertilizers. Winter injury frequently appears in isolated areas of the tree the next year, in which the new leaves show symptoms of a deficiency of certain nutrients, as potassium. Our thinking was that if these areas could be maintained alive just as one might drop supplies to mountain climbers to keep them alive until communication can be established, perhaps the tree would regenerate more easily and recover. We feel that the treatments were helpful, but here again the result was looked at somewhat askance and with some doubt.

This is where radioisotopes have been a great help and have clarified the situation. We received from the Atomic Energy Commission radio phosphorus and radio potash. These in the wintertime were made into solutions, cotton gauze was dipped into them and wrapped around the branches of the tree, and then tested for radio activity by means of a counter such as you see in the case. Within 24 to 48 hours, even in midwinter and at below freezing temperatures, we could find these materials in vertical branches 18 inches to 2 feet above the pint of applications. Further they tended to accumulate near the bud, and so from these tests, the question of entry of nutrients into dormant branches has been established, and the practice that growers have adopted in California of spraying fruit trees in the dormant season with zinc is rationalized.

It might be mentioned in passing that the surface area of the twigs, branches, and trunk of a 25 year old apple tree -- we cut on down and measured it--is 800 square feet, which of course would be equivalent to a surface 100 feet long and 8 feet high. Furthermore, we were able to spray on this area the equivalent of 3 pound of fertilizer. You see, therefore, that the idea does have some basis in fact.

While all of this is interesting, I think the most exciting news is in the foliage feeding of plant--that plants can take up nutrients through the foliage. Here is a case where the farmer has really gotten ahead of the scientist as so often happens. He has learned that foliage feeding is helpful and he has adopted the practice. This has come about by virtue of the fact that a number of favorable factors have concentrated all at once to make this possible. For example, as you well know, spraying is a common procedure on the farm these days. Fungicides, insecticides, and herbicides, and fly and livestock spraying techniques are everyday occurrences. People understand the spraying technique. Second, we have machinery that is marvelously efficient. We can apply materials in great quantities very rapidly and with great exactness. Here is a picture of such an application being made to fruit trees in the field. Dr. Wittmer, who is changing the charts for us, is one of our research team. Research these days is done by teams and not by individuals. He is one of the very important members of our team.

BRICKER. Is that a fertilizer, insecticide, or a combination?

Dr. TUKEY. This is a combination of fertilizer with insecticide. This is a common way of applying them. And here is a picture of application to vegetable crops. Furthermore, we now have new materials available which are ideally suited to spray applications that we apply these days. Instead of limestone, bonemeal, raw rock phosphate, and that sort of thing, we now have fertilizers which are completely soluble in water, such as urea, which carries up to 40 percent of nitrogen, othophophoric acid, and so on.

Also horticulturists perhaps more so than some other groups, because of the nature of their crops, find critical times in the development of a plant when nutrients should be applied. At other times they should be withheld. A cherry fruit, for example, does not just swell up as it grows. The cherry grows for a certain period of time and then stops for several weeks. In the period of time when the cherry is apparently not growing, the pit is hardening. Inside the pit the embryo is growing a still a different time. And so at one time one part needs magnesium, another needs phosphorus, and so on. We are developing a more critical evaluation and control of crops.

Through all of this, the isotope technique is very effective. In this technique, of course, we take such a plant as Dr. Hendricks showed you over there, which we have treated with a radioactive material. After a period of time the plant takes up the material. The plant is destroyed and dried, a piece of x-ray film is placed against it, and the two are put into a dark box for a matter of days. The result is these beautiful radioautograms that I show here, and showing the distribution of these materials in the plant. Or we use a Geiger counter or some other measuring device.

This picture illustrates the movement of some of these materials. The first pint I should like to make is that the materials do enter the leaves rather easily. Here is a tomato plant, and you can see that the materials have entered the plant and have moved outward from the leaf in all directions. Here is a corn plant. We have worked with a number of plants, showing that the phenomenon is not restricted to just these few crops.

In final analysis we find that a leaf is a very efficient organ of absorption. We find that the materials move into the upper surface of the leaf as well as the lower surface. We find that it enters at night and during the daytime. Further, we find the leaf surface of a 12-year-old apple tree in Washington State to be equivalent to one-tenth of an acre, even though that tree only occupies about one-hundredth of an acre. So there is a large feeding area.

HINSHAW. Is that when the leaves are fully out?

Dr. TUKEY. Yes, sir; that is when the leaves are fully out. Representative

HINSHAW. It has 10 times the area that the tree actually covers in the area of absorption.

Dr. TUKEY. Exactly. So it really is a substantial area for coverage. Not only do these materials enter rather easily--and this is interesting, too, because all the textbooks used to tell how the plant was covered by an impervious cuticle--now we find the textbooks are re-written and the leaf is reported as a beautiful mechanism for absorption--if we apply some of this material to the leaf of a bean plant, the material moves very quickly into all parts of the plant. You notice in this photograph how it concentrates in the growing tips of the roots even way down in the soil. Commonly it accumulates in the most actively growing regions. This is of come importance, too, to plant breeders, and I am sure that you will hear about this from Dr. Singleton tomorrow in terms of plant breeding. Some of the research workers in Sweden and some in this country as well are now utilizing this technique, whereby using a higher concentrations of phosphorus than has been used commonly in fertilizer treatments, the radioactive material accumulates in the buds and other susceptible parts where it may induce genetic change, and produce a new form of plant--a mutation.

If we compare leaf feeding with soil feeding, as in these photographs, this is the root application and this is the leaf application--if we apply it to the root, we see it moves upward in the plant. If we apply it to the leaf, we find it moves downward through the plant--at the rate of a foot an hour. It is very interesting that it moves so freely. If we apply it to a middle leaf, it moves both ways very effectively.

I mentioned the fact that there are certain parts of the plants that need certain nutrients at certain times. We find, for example, that when a seed is forming in the strawberry, the phosphorus concentrates immediately in the seed. We find in the case of the apple that both phosphorus and magnesium concentrate in the seed when it is developing. This is a very interesting point to fruit growers, because they have noticed the magnesium deficiency appears in the foliage in the summer. This is when the seed is drawing magnesium from the leaves, when the supply is short, and so magnesium deficiency shows up in the foliage.

We have seen that materials are absorbed by the plant and move rather freely in the plant. The amounts may at first seem relatively small, but to offset this handicap, the efficiency is high. In fact, this is the most efficient method of applying fertilizer to plants that we have yet discovered. If we apply these materials to the leaves in soluble forms, as much as 95 percent of what is applied may be used by the plant. If we apply a similar amount to the soil, we find about 10 percent of it to be used.

This chart helps to clarify this matter of efficiency. We apply the material here to the leaves and of course the fruit is quite near the leaves, which may be a point. Now if we follow this curve to the total phosphorus in the fruit derived from foliar application, we find a substantial amount at 14, 15, 16 perhaps 30 to 40 hours after application. Contrast this with the soil application where the rate is much slower. This is very important in certain critical times of the year.

For example, the soil may be cool and low in phosphorus at just the time it is needed by a transparent vegetable or strawberry plant. Or there are cases where the soil locks up certain materials that are applied, like potash and magnesium. Under such conditions we find leaf application very significant and very effective.

Now let us take a long look at calcium. Calcium behaves quite differently. If we apply calcium to the foliage of the plant, it moves into the plant, to be sure, but it does not move down to the roots with any great degree of freedom. Applied to the soil it moves upward through the entire plant. Applied to the leaves, it does not appear in the roots. This is of considerable importance to us when it comes to growing strawberries. Here is a radioautogram of a mother plant that was treated with radio calcium. You will notice how the material has moved through the plant and moved over here to adjacent plants and into the foliage of that plant. But you will also notice that it has not moved into the roots of the daughter plants. In other words, the daughter plants might starve to death for lack of calcium if the material is available only through the leaves. So here it must be applied to the soil if we wish the calcium to reach the entire plant, including the roots.

HINSHAW. Let us stay on strawberries for a second. It so happens that I just bought a few strawberry plants, and this is very interesting to me. Is it possible to feed those strawberry plants in a dormant state so that plant will consider itself fed for enough time to travel across the United States, and perhaps wait around awhile, and then be planted?

Dr. TUKEY. I think maybe that is less likely than if you plant the plant out, and then make a foliar application. After all, there is not much leaf surface to a dormant strawberry plant. Nevertheless, you have raised a most interesting point. It might be possible to do just what you suggest.

HINSHAW. I think it would, because the shipment of plants over the country is a very considerable industry, that is, the shipment during the dormant state. If they could be fed by some means so that they would not starve to death, or have some other casualty befall them and they would not have to have very much root surface to feed from if they were fed from the other parts of the plant.

Dr. TUKEY. That is a very worthwhile thing to follow up. This might also be carried through to some other perennial plants and to nursery stock in general.

HINSHAW. Yes.

Dr. TUKEY. Just a word about urea, because urea is being used very freely by orchardists and vegetable crop specialists, applying the material to the foliage. It is of considerable importance. Urea is a material which has two groups of nitrogen here and carbon and oxygen as shown in this diagram. We make the molecule radioactive not by making the nitrogen radioactive, but by making the carbon radioactive. When this material is applied to a plant, there is an enzyme urease, which acts on the molecule and splits it at this point, so that NH2 groups combine with hydrogen in the water to five us NH3, which moves into the plant.

Then the radioactive carbon and the oxygen from he water molecule combine with the hydrogen to five us radioactive caron dioxide. Now by using a Geiger counter and counting the radioactive carbon dioxide that is given off from the urea, we have an absolute measurement of the use of nitrogen from the urea applied to the plant.

This has been a very interesting story. When we do this to a number of plant species, we find that they differ in their ability to utilize urea. Here again is the sort of thing the farmer has found out to some degree. In the case of the cucumber, for example, we find that it can use urea very rapidly. In fact, in a matter of a few hours the small amount which we put on a cucumber leaf in our test is entirely used up.

By contrast, a peach, a cherry, and a potato plant utilize material very slowly. You see in this chart that the amount used is way down here, below “1" on the scales compared to the above “4" for the cucumber plant. In between is the apple. Between the apple and the cucumber are the tomato and corn. Low in the scale is the peach, which does not respond ver well, and the plum which also does not respond ver well. And so we can take into the laboratory certain plants, measure them by this technique, and secure an index of response that might be expected from urea application using this radioactive technique.

That is not all. We find that certain plants will tolerate higher concentrations of urea than others. We find that the cucumber, which utilizes urea so rapidly, will tolerate only a concentration of 3 to 4 pounds per hundred gallons. On the other hand, the crops that utilize it the least will tolerate the most, some up to 20 pounds of urea per a hundred gallons. This rationalizes and makes sense out of a number of experiences that have been confusing in various parts of the country. We feel that this technique is a significant help.

The whole field, as I have said, is a field of considerable promise. The thing that impresses, I think, is not how much we know but how really little we know. You will recognize that this afternoon I have talked about phosphorus and calcium--I did not mention potash, though I might have. I could also have mentioned strontium, which follows somewhat the pattern of calcium. I could mention magnesium and how in celery deficiency is cured rapidly by Epsom salts (magnesium sulfate), making a whole crop that was formerly thought unmarketable, marketable. But, though we know of a few things, we are impressed, as I have said, with how little we know. Because, we have great number of elements that must be taken into consideration. Also, we have numerous formulations that have not been critically studied. We have not touched insecticides and fungicides and herbicides. It is entirely likely, and it seems possible, fruit growers have noticed it, that when we use certain fungicides on a plant, the plant grows better. It is strongly suggestive of the fact that some of these materials are used as nutrients by the plants, and I could name some of them.

Still further, since materials move into the leaf, we are highly suspicious that they move out of the leaf as well. We would like to carry on a project in which we leach materials from the leaf. In some locations where certain fruits do not set well, we make the explanation on the basis of adverse temperatures and perhaps sunlight. But now we are highly suspicious that here may be a case where materials are actually being leached out of the leaves, maybe by overhead irrigation, maybe by rain, and having a profound effect upon the crop. Here is a whole additional new field that needs exploration.

To summarize, I have shown that the value of leaf feeding is established. Entry is certain. Movement occurs within the plant. We have materials that are available, suitable, and effective. We have apparatus that is well suited to our needs. The limiting factor is knowledge and this is where the radioactive isotope technique promises a great deal for the future.

Finally, Mr. Chairman, may I comment, and I will end as I began, that King George III of England, regardless of how we may feel about his judgement on other matters, is vindicated in the matter of giving a reward to his gardener, William Forsythe, for plastering fruit trees with peculiar barnyard concoctions that were said to improve the growth of the trees. Thank you very much.

HINSHAW. Doctor, you have explained a couple of techniques that I will not describe that were engaged in by my grandfather. I will not describe them here, because they are not particularly beautiful. But on the other hand, they were very effective. I always wondered why. Now I see that my grandfather should have received a medal along with Mr. Forsythe.

Dr. TUKEY. There apparently was some relation between evil smells, weirdness, and black magic, and the efficacy of the compound.

HINSHAW. He made a poultice out of familiar elements and applied them to some trees that were injured, and it seemed to be very satisfactory.

I am particularly interested in this. It is a very interesting subject. I presume that you have discovered by what process the leaf of the plant takes in this material--whether it is just straight through the pores of the plant in an absorption way, or whether it combines with some element in the leaf at once, that is, the leaf element on the exterior of the leaf or some other method. How do you figure that?

Dr. TUKEY. I am sorry to say that there is much left to be desired in our knowledge on this topic. But I can add this: Whereas at one time we felt the leaf was covered with a cuticle impervious to water, now we find that certain tissues come right to the leaf surface, making a connection link right from the leaf surface, so that when the material touches there it is absorbed and moves through the cell walls and into the leaf.

HINSHAW. Does it move fast?

Dr. TUKEY.It moves surprisingly fast. We used to think that the materials must move through the openings on the underside of the leaf, and sometimes on the upper side. This is no longer true. It is now thoroughly established that there are regions on the leaf where materials may enter and are actually almost like a blotter, drawing them right down into the leaf.

HINSHAW.That must have some dark and deep history back in early times, that is, a million years ago or so, when it was found to be a efficacious means of receiving food into the plant. Otherwise, the plant would not do that; is that correct?

Dr. TUKEY.That would seem proper. Gardeners years ago have maintained some of these things, but they were denied by many.

HINSHAW. We generally find that these processes that take place unbeknownst to us have some foundation in primordial times. For example, somebody probably some day will find a good reason why man has tonsils. We must have used them at one time in history. So perhaps we can say in earlier days we might have had mudstorms or we might have had some other things that would account for this absorption principle, or else that plant life, having submerged at some time--that perhaps it learned how to absorb food at that stage in early history, I do not know, 10 million years ago or so, or a hundred million years ago, or a billion years ago.

Dr. TUKEY. At least we now know we have a mechanism in the leaf for absorption that we did not realize we had a number of years ago. That makes a lot of things rational, as you say, that we doubted before.

HINSHAW. I take it that these water weeds that grow wholly submerged in water must absorb practically all of their food through the leaf and stem, is that not true?

Dr. TUKEY. It would depend on the supply of nutrients in the water. It could be that they could do this. If you think in terms of a lake or stream where the water has a very small amount of nutrient, I would be inclined to doubt whether they would derive enough from water. Perhaps if we could increase the amount, then I think this could be done. I know, for example, that with tomato plants you can cut off the roots and take the leaves and put them in beakers of sugar and other nutrients and you can grow them very nicely without any roots. For that matter, certain of the giant algae that grow in seawater attach themselves to a rock, and evidently absorb needed nutrients directly from the water.

HINSHAW. It has been a very interesting discussion. I am sorry that all of the members of the committee could not have been here to hear it. We thank you very much indeed for coming this far from the great State Of Michigan, although I understand that in the course of it you doubtless escaped a little weather.

Dr. TUKEY. We did. Thank you very much. Representative

HINSHAW. Thank you, sir.