The Growers Program

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Foliar Nutrition

Since 1955 Growers Mineral Solutions (GMS) has helped farmers increase their profit by raising high quality crops with lower overall costs in a large part by using GMS to foliar feed nutrients to plants.

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Foliar Feeding of Nutrients

Foliar feeding constitutes one of the important milestones in the progress of agricultural crop production. As a natural phenomenon of nutrient uptake it has existed with all forms of plant life from their beginning. The marine algae and most other aquatic plants live in a one phase environment from which all the necessities of life, including minerals, are absorbed by the entire plant surface.

With land plants, adapted to a two-phase environment, there is the separation into top and root. The root is a specialized organ for absorption and anchorage. The aerial shoot, on the other hand, while adapted as an organ for photosynthesis will also function in the absorption of water and dilute solutions of both organic (usually pesticides) and inorganic (usually minerals) substances.

At first this is rather surprising since plant surfaces are covered by the cuticle which has been considered impenetrable in the past; however, during the last few decades it has become more and more evident that absorption can take place through the surfaces of aerial plant parts. Foliar feeding in the broad sense involves absorption of nutrients by all above-ground plant parts.

Historically, water soluble salts of various elements were first used as sprays in foliar feeding. Some of the very first soluble salts came from a manure and water mixture. The first published reports on foliar feeding appeared as early as 1844. Since this first report, numerous other studies have substantiated the success of foliar spraying of nutrients. A great boost to the studies of foliar absorption of mineral nutrients came with the availability of radioactive tracers in 1938. For the first time, accurate measurements of uptake and transport of elements were conducted, and a means of distinguishing between nutrients absorbed simultaneously by the foliage and the roots was available.

Early doubters suggested that the above ground portions of plants could not absorb fertility elements. However, research sponsored by the United States Atomic Energy Commission using radioactive isotopes conducted at Michigan State University and reported in scientific publications in the early to mid 1950's demonstrated that fertility elements applied as foliar sprays to plant leaves could be absorbed into and utilized by plants.

Dr. H. B. Tukey, who was the head of the Department of Horticulture at Michigan State University, stated to the Joint Committee on Atomic Energy, for the 83rd Congress of the United States that when "we apply fertilizer nutrient materials to the above ground growing portion of the plant 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 on the soil, we find about 10 percent of it to be used."

Growers Mineral Solutions and Foliar Nutrition

In the 1930's, Dr. V. A. Tiedjens participated in research that showed when dry fertilizer was dissolved in water it significantly improved the absorption of the fertilizer into the plant. Dr. Tiedjens then worked with the idea of using less quantities of fertility elements applied directly to plants. In the process he discovered he had to substitute higher grade raw materials for the materials normally found in dry fertilizers.

In 1935, Dr. Tiedjens invented soilless culture equipment. In the 1940's, he was employed by The Standard Oil Company of New Jersey to establish hydroponic vegetable gardens on the islands of Aruba and Curacao in the Dutch West Indies. Drawing on his hydroponics experience, Dr. Tiedjens formulated the best balance or ratios between the elements necessary for healthy plant growth.

Dr. Tiedjens experimented to determine how these elements could be supplied in the real world farm setting, in an economical, safe and easy to use format. He demonstrated that small amounts of balanced fertility, in the proper form, correctly sprayed on the plant showed results that were economically competitive with plants where larger amounts of dry fertility were spread on the soil. Thus he became one of the first practical advocates of foliar fertilization which is placing nutrients directly onto the above ground portions of plants by-passing or eliminating the soil's tendency to tie-up applied fertility.

As of today, foliar nutrition has established itself as a useful technique in the nutritional management of crops. Since 1955, Growers Chemical Corporation's experience with foliar nutrition has given this company expertise with the series of complex and interdependent events that comprise the foliar application of nutrients:

1. Formulation of the nutrients
2. Atomization of the spray solution

3. Transport of the spray droplets to the intended plant surface
4. Impaction of the spray droplet on the plant surface
5. Retention of the spray droplet on the plant surface
6. Residue formation of the spray droplet on the plant surface
7. Penetration of the spray solution nutrients into the plant

FORMULATION OF THE NUTRIENTS: Dr. Tiedjens' early research showed him that when foliar spraying nutrients, it is very important to use raw materials that have small concentrations of salts and heavy metal contamination and to have a specific ratio balance between all the elements being used in the solution. Also, his chemical background gave him great understanding about water quality and element solubility which are paramount to insure success with foliar nutrition.

Also, it is very important to understand chemical reactions when mixing nutrient solutions for foliar feeding. Even if only water is added to a nutrient formulation the quality of that water can affect the final result of the foliar spray.

ATOMIZATION OF THE SPRAY SOLUTION: Dr. Tiedjens realized early with foliar nutrition that it was important to cover as much as possible of the entire plant with nutrient solution in order to get the most efficient utilization of foliar applied nutrition. Also, early research demonstrated a crop sensitivity to droplet size. Coarse sprays from certain nozzles allow the solution to migrate to the edges of the leaves where a burning can occur. This can happen at times when very coarse nozzles, such as a flood jet, are used when applying large amounts of spray volume.

Much burning of leaf margins could be avoided by applying low volume sprays as a fine mist where there is no coalescing of the droplets on the leaf surfaces or run off to the tips and margins. Flat fan or cone jet nozzles used at over 40 psi tends to give this fine type of spray pattern. Once the solution is atomized fine enough, leaf burning tends to subside.

TRANSPORT OF THE SPRAY DROPLETS TO THE INTENDED PLANT SURFACE: Once the best drop size has been discovered, the producer must use the methods necessary to force the spray drops onto the entire plant surface. As the plant changes size, the best way to cover the plant's surface may change the method of application.

Historically, vegetable and orchard producers have used air blast sprayers to foliar spray, while other producers have used the traditional boom type sprayer. Some producers have adapted the mist blower which is a lower cost machine than the traditional air blast sprayer. As the producer applies the smaller size particles, it is important to consider environmental conditions such as wind speed and relative humidity.

Growers Chemical Corporation's experience with foliar spraying suggests that the best environmental conditions for foliar spraying usually occur in late evening, early morning, or during night time.

IMPACTION OF THE SPRAY DROPLET ON THE PLANT SURFACE: The impaction of spray droplets on plant surfaces results in either reflection from or retention by the surface. Droplets that are initially reflected, if not lost to the environment, may again impact one or more times and eventually be retained.

GMS has organic molecules that influence the physical properties of water and the chemical properties of the solution so that the spray droplets tend to be retained and not reflected by the plant surface. Also, environmental conditions such as high humidity and low wind speed cause fewer reflected spray droplets to be lost.

RETENTION OF THE SPRAY DROPLET ON THE PLANT SURFACE: Again, spray droplet size, spray volume, environmental conditions, and the organic molecules in GMS create excellent success in retention of foliar sprayed nutrition.

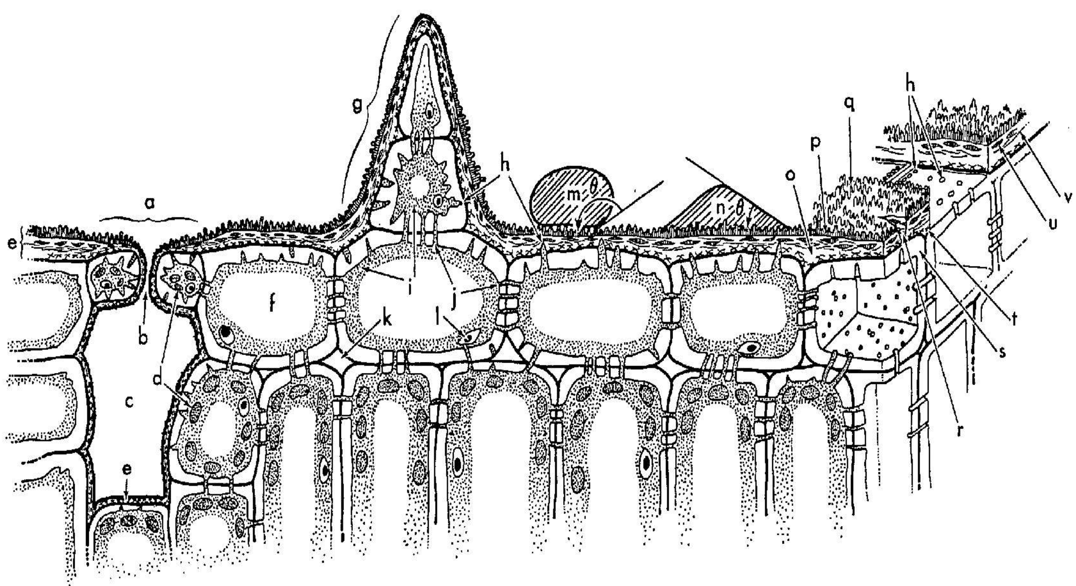
RESIDUE FORMATION OF THE SPRAY DROPLET ON THE PLANT SURFACE: If the foliar applied nutrient is not absorbed and the carrier phase of the spray droplet evaporates, a residue of the nutrient will deposit on the plant surface. Research has shown that absorption of the nutrient is better from the solution phase; however, absorption of the dry phase of the nutrient will occur. Also, the dry phase of the nutrient will resolublize when the relative humidity reaches the critical level. Usually 62 percent is the humidity level that solubilizes nutrients that are in the dry phase. To avert residue formation, some experts suggest not to spray when the air temperature added with the relative humidity yields a value that exceeds 135.

Growers Chemical Corporation's experience shows that the higher the humidity, the better success will be when foliar spraying nutrients. However, bright sun light and an air temperature over 70^{o}F to 75^{o}F can lower the effectiveness of foliar spraying nutrients.

PENETRATION OF THE SPRAY SOLUTION NUTRIENTS INTO THE PLANT: Early research showed that roots and root hairs are absorbing organs which are characterized by cell walls that are easily penetrable. In contrast to the roots and root hairs, the above ground portion of the plant is covered with a protective cuticular layer. The cuticle is composed of cutin, a mixture of long-chain fatty acids. In some cases, waxes which are a mixture of alcohol, ketones, and esters of long chain fatty acids, protrude from the surface of the cuticle. These two structures give the plant protection from the environment by regulating water or nutrient loss.

The pathways for plant penetration must occur at three sites: the cuticle, the cell wall, and the plasma membrane. Attention will be focused on the cuticle since the cell wall proper is relatively permeable to water and ions. The plasma membrane or plasma lemma selectively transports ions and molecules into the cell and a nutrient reaching this membrane would be assumed to be available to the cell.

The cells or conductive tissue of the leaves are bounded by the secondary and primary cell wall. Outside of the primary wall is the cuticular layer followed by the cuticle proper. A schematic representation of these regions of plant cells is shown below.



Diagrammatic representation of leaf epidermal cells and cuticle.

Modified after van Overbeek (1956), Orgell (1954, 1957), Franke (1962), and Wittwer, Bukovac and Tukey (1962) (Drawing not to scale).

LEGEND:

a: Stoma
b: Stomatal Opening
c: Stomatal Cavity
d: Chloroplasts
e: Cuticle
f: Vacuole
g: Hair
h: Ectodesma
i: Protoplasm
j: Plasmodesma
k: Intercellular Space
l: Nucleus
m: Non-wetting Droplet
n: Wetting Droplet
o: Cutin
p: "Wax" Layer
q: "Wax" Rodlet
r: Crack in Cuticle
s: Cellulose Cell Wall
t: Pectic Lamella
u: "Wax" Lamella
v: Cellulose Lamella
θ: Contact Angle

In past times, many researchers believed that the cuticle presented such a barrier to the penetration of nutrient solutions that uptake would not occur and that the only possible means of penetration would be only through stomatal pores. It is now thoroughly established that this is not the case. The stomatal opening may well be of relatively minor importance as an opening for foliar nutrients due to the fact that the stomatal pores have a cuticle lining also. There has been, of course, a search for pores in the cuticle of leaves by electron microscopy, but there is no indication of a general occurrence of these pores except for a few species.

A better explanation for foliar penetration centers around cuticle structure. The cuticular layer is viewed as an aggregation of organic platelets cemented together by pectin type materials. The chemical structure of cutin in the cuticular layer is assumed to be a condensation product of fatty acids. It is believed that intermolecular spaces or holes exist between the fatty acid chains within the cutin units as well as between the large molecules themselves. These holes allow the movement of solution from leaf surface to the cell wall. Cutin also contains water loving chemical radicals; thus, in a microstructural sense, cutin is more water loving than once believed.

This combination of intermolecular holes and water loving radicals assures that intercuticular penetration by the nutrient solution occurs through a continuous pathway from the outside of the plant to the plant's conductive cell tissue. Recent work has shown pointlike areas exist in the cuticle indicating still other pathways through the cuticle which have even higher permeability.

Extremely fine structures called ectodesmata which may exist in the outer tissue of plant cells and extend into the cuticle from the cell wall were once thought to be pathways facilitating the entry of nutrients into the cell. Recently researchers showed that ectodesmata appear only at sites of penetration in the cuticle and, in fact, demonstrated similar structures in an artificial medium resulting from the penetration of material through an isolated cuticle. Ectodesmata, therefore, appear to be a result of penetration into the plant rather than a pre-existing pathway. In summary, movement of nutrient solutions through the plant cuticle appears to occur through the intermolecular spaces that exist in that cuticle.

Finally, other conditions such as leaf age, light concentration, nutritional status of plant, and moisture conditions influence the plant's absorption of foliar applied nutrients. For example, hydration of the cuticle causes swelling, the wax platelets which are interspersed throughout the cuticle are spread further apart and penetration is facilitated. When the cuticle is dry either from lack of moisture in the plant or from the absence of moisture on the leaf surface, the framework constricts and impedes entry. It is well known that foliar absorption is most rapid in the presence of leaf surface moisture.

Foliar Nutrition Results and Discussions

According to researchers the practical importance of foliar application of mineral nutrients are many.

Foliar feeding is often effective when roots are unable to absorb sufficient nutrients from the soil. Such a condition could arise from an infertile soil, a high degree of soil fixation, losses from leaching, cold soil temperatures, a lack of soil moisture, or a restricted, injured, or diseased root system.

During its many years of existence, Growers Chemical Corporation has told producers to use foliar nutrition to help plants overcome root problems. Once the root undergoes stress, nutritional options for the plant became limited to the above ground growing portion of the plant.

As a preventive step to root or plant stress, Growers Chemical Corporation has always advocated a continuous regiment of foliar spraying during the growing season to try and minimize plant stress. The customers of GMS normally apply a weekly spray schedule of GMS for high valued crops or a regular, lower cost spray regiment for lower valued crops.

Some of these customers have suggested that the best way to foliar apply nutrients is to "read the crop". However, Growers Chemical Corporation believes it is unwise to wait for the appearance of a deficiency symptom before using foliar nutrition. The foliar spray should be used with the objective of maintaining crops at an optimal productivity status.

Another defined benefit of foliar feeding comes from what is termed the "photon pump priming effect" mechanism. By this we mean that after foliar nutrition is applied to the plant, increased chlorophyll production and syntheses occur. From this extra chlorophyll, an increase in cellular activity and respiration occurs that increases uptake by the plant vascular system in response to the increased water needs of the plant. This increase in uptake automatically brings more nutritional elements into the plant. The need for more moisture and greater gaseous exchange stimulates additional root mass to provide it. Excess sugars produced by the plant from the additional chlorophyll are excreted by the root hairs and stimulate microbial colonies on the roots by providing additional energy sources. The bacterial and fungal colonies in turn provide auxins, root stimulation compounds, and mineral nutrients to the plant. More root hairs and root tissue further increase the plant's ability to uptake water and mineral elements. A chain reaction can be set off by foliar nutrition to set up this loop. Great efficiencies are to be obtained with foliar nutrition when we stimulate this pumping mechanism.

Growers Chemical Corporation has for many years advised producers to use foliar nutrition as close to plant reproduction stages as possible. Researchers now have shown that at flowering, many plants, having achieved their largest leaf surface, show a marked depression in general overall metabolic activity including nutrient uptake by the roots. Therefore, these researchers state foliar applications of nutrients should be especially beneficial under such conditions.

Some of foliar nutrition's success does not always lie entirely in achieving growth and yield responses. Quality of crop resulting from foliar spraying is another area that has been reported by researchers and GMS customers. Some of the reported quality factor improvements are plant color transition; finished product firmness, flavor, and color; sugar content; and improved disease resistance.

Conclusions

With our experience since 1955, Growers Chemical Corporation believes the application of foliar nutrients is not a "quick fix" to poor management. However, if GMS is foliar applied consistently to plants whose roots are anchored in a healthy soil media, an economically competitive plant can be produced.

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