Correction of Potassium Deficiency of Citrus with KNO_3 Sprays

David V. Calvert* and Rodger C. Smith[1]

A brief review of recent development in spraying compounds of nitrogen and potassium (major fertilizer elements) to control plant deficiencies is presented, with special attention to a review of research on correction of potassium deficiency with KNO_3 sprays. On calcareous soils it is difficult to raise the K content of citrus leaves beyond very minimal amounts by extensive soil applications of K fertilizers. Citrus leaves analyzing 0.5 to 0.8% K are not uncommon in groves on calcareous soils, although maximum yield of citrus on these soils is associated with leaf K levels of over 1.0%. Accumulation of Ca in the citrus leaves apparently results in a physiological deficiency of K when grown on these soils. KNO_3 was compatible as a neutral constituent with both fungicides and pesticides commonly used in regular spray programs. Trees with adequate leaf K produced larger oranges, stronger peels, and greater yields, resulting in improved packing and keeping quality for fresh fruit markets. The ruptured albedo symptom known as creasing, particularly present in years of heavy fruit set and nutritional stress, was significantly reduced by foliar application of KNO_3.

In recent years considerable research has been focused on foliar applications of fertilizer nutrients to both horticultural and agronomic crops. Foliar application of fertilizers is an established practice in many areas of the world. The earlier advances in foliar spraying were with elements required in trace quantities, often referred to as micronutrients. The foliar spraying of the micronutrients boron, copper, manganese, and zinc to control deficiencies of these elements are common practices in both California and Florida for citrus and other crops. More recently, studies have been conducted on the foliar spraying of major elements required, primarily nitrogen and potassium. It is the purpose of this paper to review briefly the use of these fertilizer elements as sprays and to focus primary attention on the use of KNO_3 as a foliar spray for citrus.

SPRAYING MAJOR ELEMENTS

The use of foliar sprays of the major fertilizer elements is usually not a substitute for ground fertilization, but is a supplement to it. However, foliar spraying of fertilizer elements can increase the level of major fertilizer elements for short critical periods. Urea has been used as a common leaf spray for horticultural crops for several years. A thorough review of the use of urea sprays on citrus was made by Jones and Embleton (1965). Calcium has been sprayed extensively as a control for certain plant disorders (Middleton *et al.*, 1945; Evans and Troxler, 1953; Geraldson, 1957). Embleton and Jones (1959), Calvert and Reitz (1966), and Koo and Young (1969) reported foliar sprays of magnesium nitrate were effective in alleviating magnesium deficiency of citrus on California and Florida soils where uptake of magnesium was a problem. More recently, studies have shown promising results using potassium nitrate (KNO_3) as a foliar spray for both potassium and nitrogen deficiencies in citrus (Page *et al.*, 1963; Calvert, 1969).

There are a number of reasons for occasional and sometimes chronic short supply of major elements in plants which lead to the need for supplemental spraying of horticultural and agronomic crops with major elements. It may be practical to spray to overcome the interferences brought about by other fertilizer ions in the soil. For example, the absorption of potassium from the soil is strongly influenced by soil conditions where high concentrations of Ca or other cations reduce K uptake. Calvert (1969) found that foliar sprays of KNO_3 were more effective in raising the K content of leaves than were the equivalent amounts of K applied in ground applications. Also, in some fine textured soils the accumulation of available soil potassium is notably slow from fertilizer applications (Page *et al.*, 1969). Spraying KNO_3 would appear to be a practical method of maintaining an adequate level of K in citrus trees until an adequate level of soil potassium is attained. Furthermore, in dry land climates where subsurface seepage irrigation is practiced, applied potassium may not be available in the surface because of lack of adequate soil moisture to bring it into solution (Roberts, 1970). Lilleland (1971) reported foliar sprays of KNO_3 are highly effective in overcoming the stress of potassium deficiency of prunes when extremely heavy crops are set. Page *et al.* (1969) have pointed out that foliar applications of KNO_3 could be used as a means to correct K deficiency of citrus without introducing adverse effects associated with salinity when additional fertilizer salts are added to the soil.

Controlling potash deficiency in citrus is of great importance because potassium is found more frequently to influence fruit quality under the conditions which prevail in citrus groves than any other element. Koo (1968) has pointed out that foliar symptoms of potassium deficiency are seldom found in field grown citrus. He states this is because the effects of low K on fruit production, fruit size, and premature leaf drop precede any leaf symptoms. Smith *et al.* (1953) showed that young growing citrus begins to show leaf K deficiency at a K content of around 0.4%. Decreased yields and small thin-skinned fruit with high sugar content of the juice were characteristics of trees growing on calcareous soils whose leaves analyzed 0.56 to 0.84% K (Reitz and Koo, 1959). They presumed this was the broad range into which leaf K should not be allowed to fall. Reitz and Koo (1960) later reported high fruit yields of good quality were maintained on the calcareous soils of Florida when leaf samples averaged 1.21% K. Calvert (1969) found that spraying citrus trees with KNO_3 on calcareous soils resulted in higher percentage of leaf K, which was accompanied by larger fruit and reduced fruit rind disorders.

University of Florida, Agricultural Research Center, Citrus Section, P.O. Box 248, Fort Pierce, Florida 33450.
[1] Present address: AMAX Chemical Corp., 1270 Avenue of the Americas, New York, New York 10020.

ABSORPTION OF POTASSIUM

For foliage applied KNO_3 to be effective in supplying K to the trees, it must be absorbed. That KNO_3 is absorbed is indicated by leaf analysis before and after foliar application (Calvert, 1969; Page *et al.*, 1963). Page *et al.* (1963) also showed that the absorbed KNO_3 is translocated by measuring the K content of new leaves that arose after the initial spraying of old leaves. Both Page *et al.* (1963) and Calvert (1969) ruled out the possibility that KNO_3 was absorbed by the roots rather than the leaves by covering the ground to intercept the drippage from the sprayed trees.

Impey and Jones (1960) showed that the absorption of mineral elements occurs through both the lower and upper surfaces of the leaf. Therefore complete coverage of both upper and lower leaf surfaces is necessary to obtain maximum efficiency from spraying.

Absorption of potassium from KNO_3 into leaf tissue is rapid. Page *et al.* (1963) detected considerably higher leaf K content 1 week after spraying. Calvert (1969) found substantial increase in leaf K 2 weeks after spraying. However, the leaf K content increase was temporary since the K content returned to the initial potassium level at the end of 4 weeks after spraying. Since Calvert (1969) found both fruit quality and yield responses in plots sprayed with KNO_3, it appears reasonable to assume that KNO_3 was translocated and utilized in the overall metabolism of the citrus tree.

CONCENTRATION AND FREQUENCY OF SPRAYING KNO_3

The potassium content of citrus leaves is increased with KNO_3 sprays and the amount of increase is directly related to the spray concentration and frequency of application (Page *et al.*, 1963; Calvert, 1969). The increase of leaf K with increasing concentration above 9.07 kg KNO_3 per 0.38 kl of water (20 lb per 100 US gal of water) were small and usually inconsequential (Calvert, 1969).

Citrus leaves can be injured by potassium nitrate sprays (Page *et al.*, 1963; Calvert, 1969). The degree of injury depends on the salt concentration developed on the surface of the leaf, and this in turn depends on the concentration of the spray and its frequency of application. In old mature leaves the injury can be identified by burned leaf tips and defoliation, while on young immature leaves the injury is evident as necrotic areas at the leaf margin, and with continued expansion the leaves become deformed. Apparently, there are varietal differences in the susceptibility of citrus to leaf injury from KNO_3 sprays. Leaves on Temple orange trees were moderately injured while Hamlin orange trees in adjacent blocks in the same grove showed no injury from KNO_3 sprays at an 18.14 kg KNO_3 per 0.38 kl rate (Calvert, 1969). High air temperatures and low humidity increase the citrus leaves' susceptibility to injury from KNO_3 sprays. Caution should be exercised when spraying citrus trees under stress from low moisture.

Since both leaf K content and leaf injury are dependent on concentration of KNO_3 in the spray, it is desirable to use the highest safe concentration of KNO_3. This rate would be in the order of 4.54 to 9.07 kg KNO_3 per 0.38 kl water (10 to 20 lb of KNO_3 per 100 U.S. gal of water). Approximately 0.06 to 0.08 kl of spray solution is required to cover a mature citrus tree. In Florida some leaf injury may occur at the upper rate, depending on variety, temperature, and humidity conditions. The 4.54 kg KNO_3 spray rate currently is being tested by Calvert (1970). No burn symptoms are evident at this lower rate, but it is too early to make a statement on the effectiveness of this rate. Page *et al.* (1963) in California found that the burn experienced at the 9.07 kg (20 lb) rate was not greater than that usually experienced with regular nutritional sprays in grove programs.

Generally the initial effects of potassium sprays are more rapid, greater, and of shorter duration than are comparable soil treatments. In a grove where potassium supplying power of the soil was low, Calvert (1969) found that the three spray applications made in May, July, and October at the 18.14 and 9.07 kg per 0.38 kl rates were sufficient to maintain significantly higher leaf K in one citrus growing season. Equivalent rates of KNO_3 applied to the ground gave no response. Since KNO_3 sprays are rapidly effective, it may be possible to delay spraying until there is clear evidence that additional K is needed to control citrus rind disorders. Jones *et al.* (1967) found that creasing of the orange rind was significantly reduced by KNO_3 foliage sprays, even though some creasing was evident at the time of spray application.

EFFECTS OF KNO_3 SPRAYS ON FRUIT YIELD AND QUALITY

Foliar applications of KNO_3 produced larger oranges, thicker peels, and slightly greater yields (Calvert, 1969). Both Calvert (1969) and Page *et al.* (1963) found that increasing rate and frequency of KNO_3 sprays increased yields slightly over the check treatments. Presumably, the increase in yield was due to K not N because leaf K levels were in the 0.8 to 1.1% range where yield responses to K fertilization would be expected. Also, the level of N in the fertilization programs used in the groves was sufficiently high to give no yield response to N. Larger, slightly greener fruit with slightly more acid in the juice resulted from trees in KNO_3-sprayed plots (Calvert, 1969). Sugar content of the juice decreased in one season and the sugar-to-acid ratio was slightly to considerably decreased in two seasons by increasing rate and frequency of KNO_3 foliar applications.

Probably the most important factors affected by increasing the K content of the leaves were the incidence and severity of orange creasing. Creasing is a defect of the orange fruit characterized by narrow sunken furrows in the surface of the orange peel which are indicative of a break in the underlying albedo. This abnormality causes the fruit to be more susceptible to cracking and splitting, resulting in unmarketable fruit. It appears most often in thin-skinned fruit and is often present on fruit which is potassium deficient. Calvert (1969) found in a year of moderate creasing that foliar applications of KNO_3 at the 9.07 and 18.14 kg per 0.38 kl water rates reduced the incidence of creasing on Hamlin oranges. Jones *et al.* (1967) also found that creasing was markedly reduced under California conditions by foliar applications of KNO_3.

COMPATIBILITY

Foliage sprays combining KNO_3 with zinc, manganese, copper, and a wide range of insecticides and fungicides were used successfully by Calvert (1970) in field spray trials with citrus in 1969 and 1970. Beavers (1971) reports commercial use of KNO_3 with pesticides and nutritional sprays commonly used on citrus with no evidence of physical incompatibility of the sprays. Sprays containing nutritionals are usually applied to citrus during the spring or early summer. This does not always appear to be the time of maximum potassium need for citrus. For this reason KNO_3 may be sprayed singly or in combination with fungicidal or insecticidal applications later in the year when potassium stress is more of a problem. The nitrogen applied in the spray appears to be equally available as that applied in regular ground fertilizer applications. Therefore, the amount of nitrogen applied in the KNO_3 spray should be considered when preparing the yearly nitrogen budget of the citrus grove. If this is not done, excessive nitrogen may adversely affect the fruit quality of oranges and grapefruit.

LITERATURE CITED

Beavers, A., AMAX Chemical Corp., New York, N.Y., private communications (1971).
Calvert, D. V., *Proc. First Int. Citrus Symp.* **3**, 1587 (1969).
Calvert, D. V., unpublished data (1970).
Calvert, D. V., Reitz, H. J., *Proc. Fla. State Hort. Soc.* **79**, 1 (1966).
Embleton, T. W., Jones, W. W., *Proc. Amer. Soc. Hort. Sci.* **74**, 280 (1959).
Evans, H. J., Troxler, R. V., *Proc. Amer. Soc. Hort. Sci.* **61**, 346 (1953).
Geraldson, C. M., *Proc. Amer. Soc. Hort. Sci.* **69**, 309 (1957).
Impey, R. L., Jones, W. W., *Proc. Amer. Soc. Hort. Sci.* **76**, 191 (1960).
Jones, W. W., Embleton, T. W., Garber, M. J., Cree, C. B., *Hilgardia* **38**(6), 231 (1967).
Jones, W. W., Embleton, T. W., *Calif. Citrogr.* **50**(8), 334, 355 (1965).
Koo, R. C. J., "The Role of Potassium in Agriculture," American Society of Agronomy, Madison, Wisc., 1968, p 469.
Koo, R. C. J., Young, T. W., *Proc. Fla. State Hort. Soc.* **82**, 274 (1969).
Lilleland, O., University of California, Davis, private communications (1971).
Middleton, G. K., Colwell, W. E., Brady, N. C., Schultz, F. F., Jr., *J. Amer. Soc. Agron.* **37**, 443 (1945).
Page, A. L., Martin, J. P., Ganje, T. J., *Proc. Amer. Soc. Hort. Sci.* **82**, 165 (1963).
Page, A. L., Ganje, T. J., Embleton, T. W., Jones, W. W., *Proc. First Int. Citrus Symp.* **3**, 1605 (1969).
Reitz, H. J., Koo, R. C. J., *Proc. Amer. Soc. Hort. Sci.* **75**, 244 (1960).
Reitz, H. J., Koo, R. C. J., *Proc. Fla. State Hort. Soc.* **72**, 12 (1959).
Roberts, K., Sonoma County Fruit Findings, Univ. of Calif. Agri. Extension Service, April 1970.
Smith, P. F., Reuther, W., Scudder, G. T., Jr., *Amer. Hort. Sci. Proc.* **61**, 38 (1953).

Received for review October 21, 1971. Accepted January 18, 1972. Presented at the Division of Fertilizers; 162nd Meeting; ACS, Washington, D.C., September 1971. Florida Agricultural Experiment Station Journal Series No. 4104.

Alachlor Effects on Plant Nitrogen Metabolism and Hill Reaction

James M. Chandler,[1] Lavoy I. Croy, and Paul W. Santelmann*

Intact wheat (*Triticum aestivum* L.) plants were utilized to study the effect of alachlor [2-chloro-2′,-6′-diethyl-*N*-(methoxymethyl) acetanilide] on nitrate reductase, nitrate, amino acid, and water-soluble protein. Alachlor may stimulate or inhibit both nitrate ion uptake or nitrate reductase activity, depending on the rate used, order of exposure, or the total time of exposure. The nitrate reductase activity was affected more than the nitrate content. Alachlor addition after nitrate caused a greater reduction in nitrate content and nitrate reductase activity than if added before the nitrate was. Nitrate reductase activity was inversely proportional to alachlor exposure time. The amino acid content was decreased with an increase in total exposure time to alachlor. High concentrations of alachlor depressed the amino acid content and protein level, while the lower concentration did not. Alachlor did not inhibit the Hill reaction in isolated wheat chloroplasts.

Since a substituted urea has been shown to inhibit protein synthesis and some other herbicides affect nitrate reductase, the effect of alachlor [2-chloro-2′,6′-diethyl-*N*-(methoxymethyl) acetanilide] on nitrate reductase, the enzyme substrate, nitrate, and two products, the amino acids and water-soluble protein were determined. The action of alachlor on the Hill reaction of isolated wheat chloroplasts was also investigated.

Nitrate is the primary form of nitrogen available to higher plants for protein synthesis and the enzyme nitrate reductase initiates the reduction process. Nitrate reductase is the rate-limiting step in this reduction process (Beevers and Hageman, 1969). Nitrate reductase is substrate inducible and thus its level of activity should be an index of the reduced nitrogen available to the plant for protein synthesis.

α-Chloroacetimide herbicides have been shown to inhibit protein synthesis. Protein synthesis in root tips has been inhibited and growth of cucumber roots reduced by propachlor (Duke, 1967). ATP formation or respiration was not affected. The inhibition of nascent protein formation was believed to result from the failure to transfer the amino-acyl-S-RNA to the polypeptide chain. Alachlor has been shown to stimulate growth and ^{14}C-leucine incorporation into root protein in excised cucumber tissue (Edmondson, 1969). Polyribosome formation was not affected by alachlor, while the amount of RNA and DNA increased in root tissue of treated cucumbers. Alachlor reduced proteinase activity 69% in cucumber cotyledons with very little effect on ribonuclease activity in pregerminated embryos.

Other families of herbicides such as 2,4-D and simazine have been shown to affect the enzyme nitrate reductase. The nitrate reductase level was increased in corn and reduced in cucumber in cell-free extracts from corn and cucumber plants sprayed with varying levels of 2,4-D (Beevers *et al.*, 1963). Nontoxic levels of simazine added to the root zone of corn plants, grown under both suboptimal temperatures and low nitrate levels, increased the nitrogen content and dry weight of plants by 20–25% (Tweedy and Ries, 1967). These increases were associated with increased nitrate reductase and were attributed to increased nitrate absorption, nitrate assimilation, or both.

The Hill reaction is inhibited by some herbicides. In the Hill reaction, when illuminated, chloroplasts perform oxygen evolution using water as an electron donor (Bonner and Varner, 1965). Monuron, a substituted phenylurea herbicide,

Department of Agronomy, Oklahoma State University, Stillwater, Oklahoma 74074.

[1] Southern Weed Science Laboratory, U.S. Department of Agriculture, Stoneville, Mississippi 38776.