# Role of Fertigation in Horticultural Crops: Citrus

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## Abstract

Advances in micro-irrigation techniques, e.g., drip and under-tree sprinklers, have facilitated more widespread adoption of fertigation, especially for perennial crops, including citrus. It is generally believed that fertigation improves nutrient uptake efficiency and, therefore, is preferable to dry fertilizer broadcast application because it increases the yield, enhances crop quality, and minimizes loss of nutrients, i.e., leaching of $NO_3$-N below the root zone. The evaluation of tree response to changes in nutrient management requires long-term studies because of the large nutrient reserves in the woody portion of the tree. In this paper we have summarized recent evaluations of fertigation for citrus. Two-year studies on newly planted citrus trees revealed no significant difference between the fertigation and dry fertilizer broadcast treatments, partly because of the very low nutrient demand during at least 2 years after planting. Evaluation of 7- and 8-year-old trees that had grown under various nutrient management programs since planting revealed significantly greater yields of both fruit and total soluble solids from those under fertigation than from those under dry granular fertilizer broadcast management. The optimum N rate with continuous fertigation treatment was lower by 35 kg/ha than that in the dry fertilizer broadcast treatment. A 6-year study on over-20-year-old “Hamlin” orange trees on “Cleopatra mandarin” rootstock found no significant difference between the fertigation and dry fertilizer broadcast treatments. A 5-year study on over-35-year-old “Valencia” orange trees on “Rough Lemon” rootstock found a significantly lower surficial aquifer $NO_3$-N concentration under the trees that received total fertigation than under those that received dry granular broadcast applications three times per year at similar N rates. The groundwater $NO_3$-N concentrations in the former were below the maximum contaminant limit (MCL) of 10 mg/L whereas those of the latter were above it throughout the study.

## Introduction

"Fertigation" is a technique for application of fertilizers in the irrigation water. The advantages of fertigation include (Burt *et al*., 1998): (i) minimizing soil compaction by avoiding heavy equipment traffic through the field to apply fertilizers; (ii) reduced energy demand; (iii) reduced labor input; (iv) careful regulation and monitoring of nutrient supply; (v) even distribution of nutrients throughout the root zone; and (vi) application of nutrients matched in amounts and timing to the plant nutrient requirements. Fertigation can be applied through buried or surface drip-lines or through sprinklers. Recent technological developments in the drip and micro-irrigation methods have accelerated the adoption of fertigation for a wider range of crops, including fruit trees. Uniform distribution of water by a given injection system is important for maximizing the uniformity of distribution of nutrients delivered through fertigation. Managing irrigation to minimize the leaching of water below the crop rooting depth is critical to minimizing their leaching below the root zone. It is generally believed that carefully managed fertigation results in lower nutrient leaching losses than broadcast application of water-soluble granular fertilizers. However, this is dependent on the ability of the crop to take up a large amount of nutrients immediately following their application, and subsequently to redistribute them from the vegetative crop parts into those of economic importance, i.e., fruits, tubers, etc.

The major objective of this paper is to summarize the recent advances in fertigation of horticultural crops, with particular emphasis on irrigated citrus orchards. Evaluation of the response of citrus trees to changes in nutrient management requires long-term studies, because of the large nutrient storage capacity of the woody portion of the trees. The response of citrus trees to fertigation could vary depending on: the growth parameters of young non-bearing trees; fruit yield response; leaf nutritional status; or orange vs. grapefruit response. Unfortunately, despite the adoption of fertigation a number of years ago, there have been rather few long-term response evaluation studies. The available studies and unpublished data are summarized in this paper, despite their often conflicting findings. Since this is a review paper, no "Materials and Methods" section is necessary. Some background information on each of the reviewed studies is presented in the "Results and Discussion" section.

## Results and discussion

### Young tree growth

Willis and Davis (1991) conducted a study in Florida, using “Hamlin” orange trees on “Sour Orange” rootstock grown in a Kanapaha fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleaquults). They evaluated two N rates (0.06 and 0.11 kg/yr per tree), applied either as dry granular source broadcast, five times per year, or as fertigation at 5, 10, or 30 applications per year. Part of the results are shown in Fig. 1. The tree growth response was not significantly influenced by either the method of N application or the frequency of fertigations at either N rate. The authors concluded, despite the lack of demonstrated beneficial effects of fertigation based on one year’s tree growth data, that additional years of response measurements were needed to evaluate the difference between the effects of fertigation and broadcast application (at lower frequencies) of dry granular fertilizers.

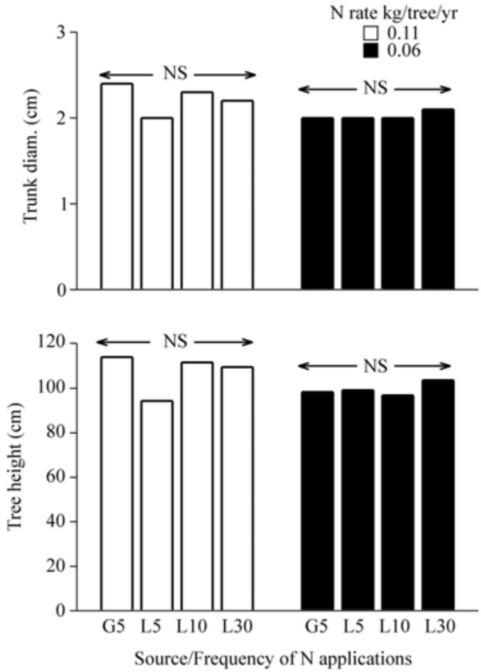


**Fig. 1.** Growth responses of “Hamlin” orange trees on “Sour orange” rootstock at two N rates, as broadcast application of dry granular fertilizer and via fertigation (extracted from Willis and Davis, 1991).

**Young bearing trees**

Thompson *et al*. (2002) conducted field studies on 5-year old “Newhall” navel orange trees on “Carrizo” citrange rootstock growing on a Gilman loam soil in Maricopa County, Arizona. The trees were planted in 1997 and the second year treatments included a factorial combination of three N rates (68, 136, and 204 g/yr per tree) and three application frequencies; either weekly (27 appl.), monthly (7 appl.) or three applications during the growing season. Increasing N rates increased the leaf N concentration significantly, particularly at the N rates of 136 and 204 g/tree, compared with that of the unfertilized trees. The weekly application of N at either 68 or 136 g/yr per tree significantly increased the fruit yield compared with that of the unfertilized trees. The responses of the trunk diameter, leaf N and fruit yield of 2-yr-old trees were non-significant across a wide range of N application frequencies (3 to 27/yr) (Fig. 2). In a parallel study (Weinert *et al*., 2002) reported that only 25% of fertilizer N was taken up by the trees, therefore, the lack of response to N rates and/or frequency of application was not unexpected.

Stored N in the nursery trees plays a major role in providing N nutrition of the trees during 1-2 years after planting. Accordingly, even for young trees, the evaluation of the effects of N rate/frequency should be carried out for several years to enable valid conclusions.

On the basis of the two studies described above and that of Rasmussen and Smith (1961), it appears that neither the choice of fertilizer delivery method (fertigation vs. dry granular-broadcast) nor the frequency of fertigation had any significant effects on the tree growth and leaf N concentrations during 1- to 2-year evaluations following planting. This lack of response was related to redistribution of stored nutrients in the trees, which leads to a very small portion of the applied nutrients being taken up by the young trees.

Schumann *et al*. (2003) presented the response data from 2 years of observation of 7- and 8-year-old trees, during the comparative evaluation of water-soluble granular (WSG; four equal applications per year), fertigation (FRT; 15 applications per year), and controlled-release fertilizer (CRF; single application per year) on over-7-year-old trees. These treatments were established at the time of planting, and the ranges of N rates were adjusted to match tree growth. Therefore, the trees were exposed to several different N sources and rates during the entire growth period prior to the yield evaluations, which were done during the 7$^{th}$ and 8$^{th}$ years. The N rates evaluated were 78, 134, 190, and 246 kg$^{/}$ha/yr. The results showed quadratic responses to N rates for canopy volume, fruit yield, fruit numbers, juice yield, and soluble solids yield (Fig. 3). At the optimal N rates, the peak fruit yield was 20 Mg/ha for the WSG source, whereas it was close to 25 Mg/ha for the FRT source. The net return to the growers is based on the yield of soluble solids, and by this criterion the optimal N rates were 145 and 180 kg/ha for the fertigation and dry granular broadcast treatments, respectively. Thus, there was an N saving of about 35 kg/ha in the fertigation treatment, which resulted in about 0.35 Mg/ha increased yield of soluble solids compared with that from the trees that received dry granular broadcast application of fertilizer. This study demonstrated for the first time the distinct benefits (increased yield at lower optimal N rate) of fertigation, by conditioning the trees to different sources of fertilization over a long period of time.

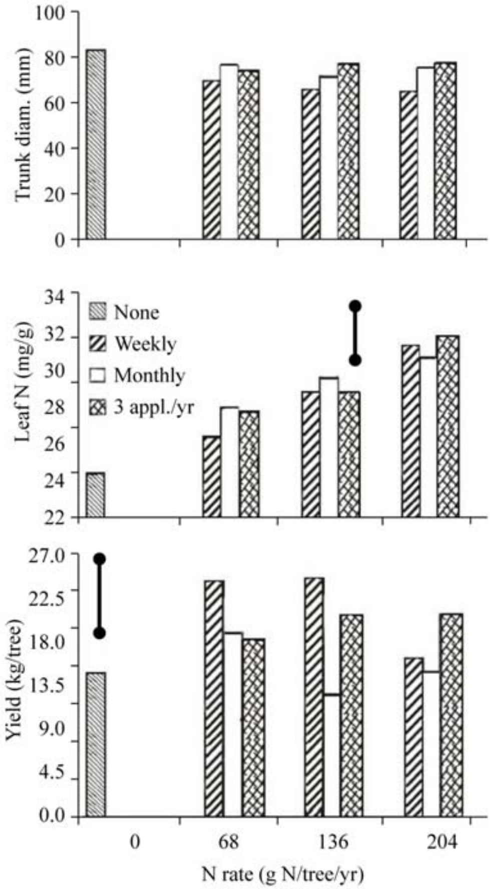


**Fig. 2.** Trunk diameter, leaf N and fruit yield of 2-year-old "Newhall" navel orange trees on "Carrizo" citrange rootstock, as influenced by different N application rates and fertigation frequencies (extracted from Thompson *et al.*, 2002).

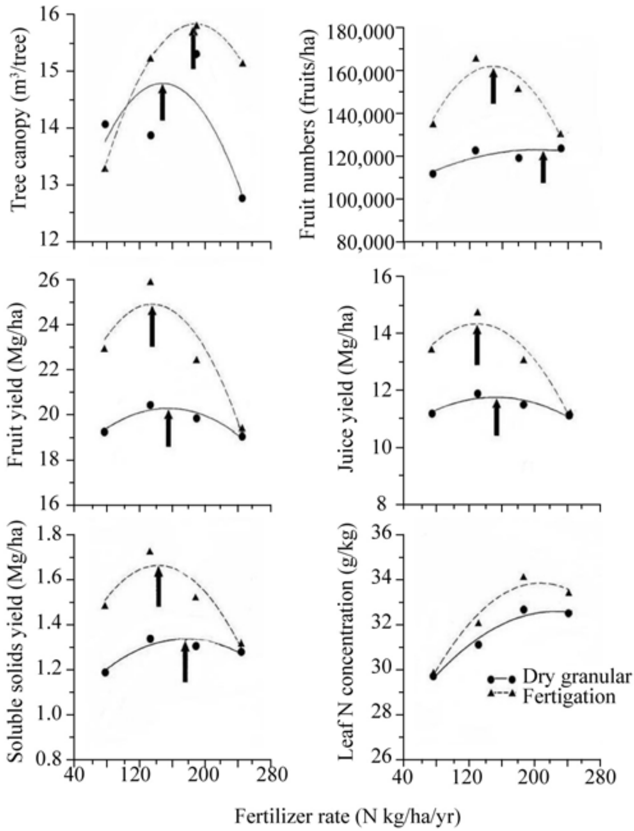


**Fig.3.** Effects of fertilizer sources and rates on tree growth, yield and leaf N concentration responses of 7- and 8-year-old “Hamlin” orange trees on “Swingle” citrumelo rootstock grown on a Candler find sand in Florida (extracted from Schumann *et al.*, 2003). Yield response data are cumulative for the years 7 and 8.

Schumann *et al.* (2003) conducted a parallel study to compare three sprinkler coverage areas, comprising circles of 1.5, 3.0 or 4.5 m diameter around each tree. All sprinklers delivered water at 37.8 L/h, regardless of the coverage area, and two N rates – 134 and 190 kg/ha delivered as fertigation (15 applications/yr), were evaluated. At the higher N rate, the yields of soluble solids and juice increased with increasing area of sprinkler coverage, over the full range. At the lower N rate, the responses followed a quadratic curve, with decreases in both soluble solids and juice yields at the largest sprinkler coverage area. This study demonstrated that by conditioning the root distribution to different sprinkler coverage areas over the entire 8-year growth period of the trees, the response of the soluble solids yield to sprinkler coverage area differed with different N rates.

**Mature Bearing Trees**

A 6-year field experiment was conducted in central Florida, with over-25-year-old “Hamlin” orange trees on “Cleopatra mandarin” rootstock, planted at 286 trees/ha in a Tavares fine sand (hyperthermic, uncoated Typic Quartzipsamments), to evaluate the effects of various rates and sources of fertilizers on fruit yield and quality, and on the fate and “transport” of N in the soil (Alva and Paramasivam, 1998; Alva *et al*., 2005). Fig. 4 shows responses of the 3-year mean fruit yield to applications of N and K at rates of 112 to 336 kg/ha/yr as a water-soluble granular source (four applications/yr) or of 112 to 280 kg/ha as fertigation (18 applications/yr). Across the full range of N rates – 112 to 336 kg/ha – the fruit yield response was quadratic with the optimal N rate at about 260 kg/ha. At a given N rate, fruit yield was not significantly different between the treatments which received either dry granular or fertigation sources. According to the findings of this study regarding the fruit yield response, fertigation failed to demonstrate a significant advantage over the WSG broadcast application.

Alva *et al*. (1998; 2003) conducted a demonstration project in two identical 32 ha blocks of over-34-year-old “Valencia” orange trees on “Rough lemon” rootstock, planted at 286 trees/ha in an Astatula fine sand in Highlands County, Florida. Both blocks were irrigated via-under-the tree, low-volume sprinklers, with one emitter per tree delivering 96 L/hr into a wetting area of 28 $m^2$ per tree. During 1993 and 1994, both blocks were under similar management regimes, including fertilizer application at N rates of 197 and 209 kg/ha, respectively. Dry granular sources of N, P, and K were used with the annual rates split among three broadcast applications: Jan./Feb., May/June, and Sept./Oct. Subsequently, for 4 years the two blocks received differing fertilizer treatments, whereas all other management practices, including irrigation, were the same in the two blocks. The nitrogen rate was about 180 kg/ha for both blocks, but one block received a dry granular product that included P and K sources, in a 1.0:0.5:1.0 NPK blend, which was broadcast three times/yr (Jan/Feb, May, and Sep), whereas the second block received the same annual N rate except that the NPK blend was applied in 18 fertigations per year, in Jan.-May and Sept.-Oct. Because of heavy rainfall (60% of the total annual precipitation), no fertilizer was applied during June through August. The results showed that over a 4-year period the cumulative fruit yield was 11% greater and the total soluble solids

(TSS) yield was 16% greater with fertigation than with dry granular fertilizer application (Fig. 5). This was a demonstration project that used large commercial-size blocks to facilitate application of commercial industrial-scale management practices. Therefore, there were no replications, which limited the statistical analysis of the data.

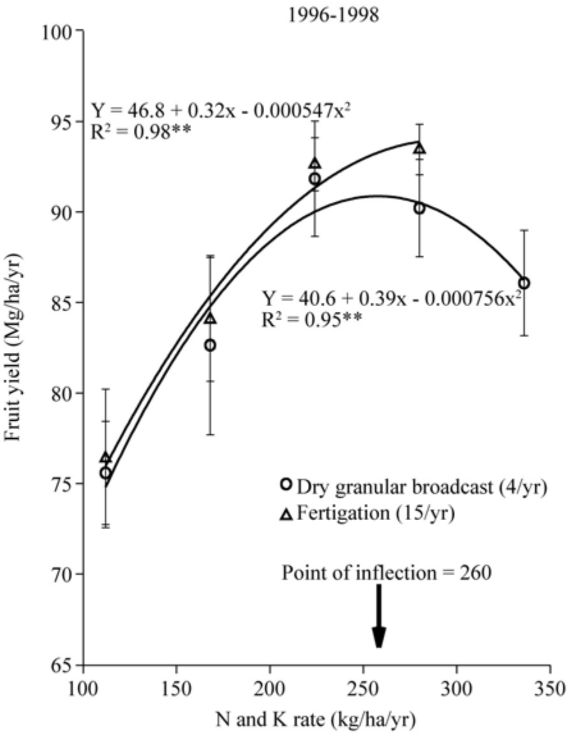


**Fig. 4.** Fruit yield responses of over-25-year-old "Hamlin" orange trees on "Cleopatra mandarin" rootstock, grown on a Tavares fine sand in Florida, to various rates of fertilizer, applied via broadcast application of water soluble granular (WSG) four times/yr or via fertigation (FRT) 18 times/yr. The data shown are mean values for years 4 through 6 of the study (extracted from Alva *et al*., 2005). Vertical line through each data point represents value of standard error of the mean.

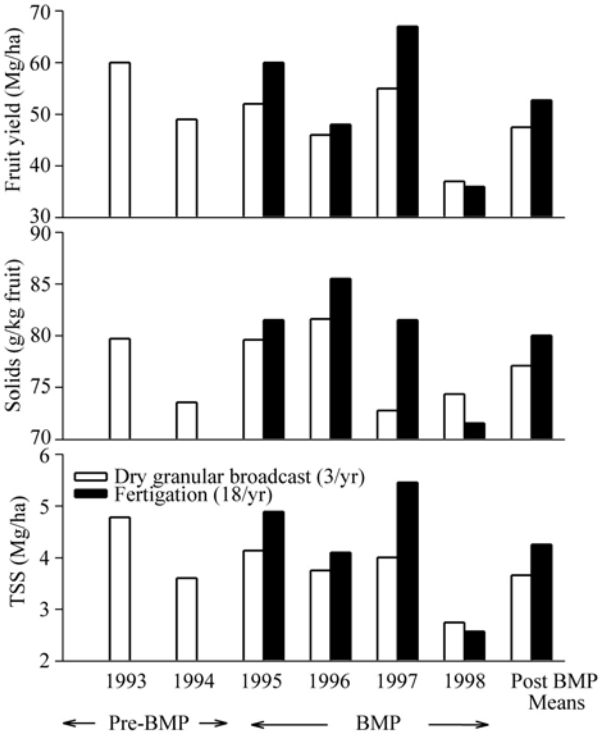


**Fig. 5.** Fruit yield and total soluble solids (TSS) responses of "Valencia" orange trees on "Rough lemon" rootstock subjected to dry granular broadcast or fertigation at similar N rates (extracted from Alva *et al*., 2003).

The $NO_3$-N concentration in the surficial aquifer was monitored during the study by sampling four monitoring wells in each block (Fig. 6). When the study began, the surficial aquifer $NO_3$-N concentration was above the maximum contaminant limit (MCL) of 10 mg/L in both the citrus orchards. As the study progressed, the $NO_3$-N concentration in the groundwater beneath the orchard that was under fertigation decreased to levels that were well below the 10 mg/L MCL, and also significantly lower than those in the groundwater underneath the orchard that received broadcast application of dry granular fertilizer. In the latter, the $NO_3$-N concentrations in the surficial aquifer generally remained above the 10 mg/L MCL. This long-term study demonstrated for the first time, the beneficial effects of fertigation in decreasing the $NO_3$-N leaching into the surficial aquifer underneath citrus groves in sandy soils exposed to high summer rainfall.

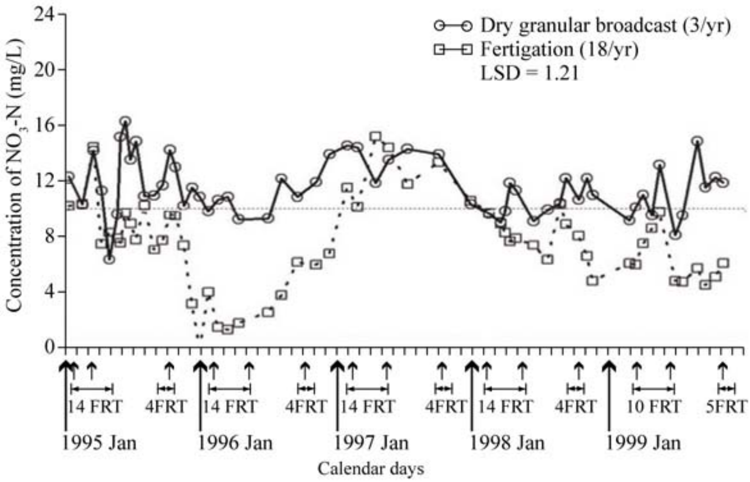


**Fig. 6.** Concentration of $NO_3$-N in the surficial aquifer underneath citrus groves with over-34-year-old "Valencia" orange trees on "Rough lemon" rootstock grown in Astatula fine sand in central Florida. Each data point is the mean of the data from four monitoring well samples (A.K. Alva 2005, unpublished data).

Dasberg *et al*. (1988) conducted a 5-year study with over-17-year-old "Shamouti" orange trees on "Sweet lime" rootstock. Fertigation was evaluated at N application rates of 80, 160, and 280 kg/ha, with no P or K. Fertilization at N rates of 160 and 280 kg/ha, by means of soil application of granular fertilizer (in March) or fertigation (in March-August) was also evaluated. The 5-year average fruit yield was greater by 29% with fertigation than with soil application of granular fertilizer only with N at 160 kg/ha. With N at 280 kg/ha the method of N delivery had no significant effect on the fruit yield (Fig. 7).

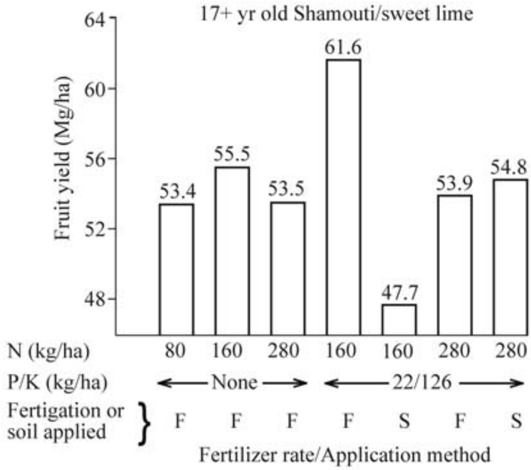


**Fig. 7.** Five-year mean fruit yields of over-17-year-old "Shamouti" orange trees on "Sweet lime" rootstock, with various rates of N, applied as fertigation (F) without P and K, or at two rates with P and K as a single soil application of granular fertilizer (S) or as fertigation (F) during March through August (extracted from Dasberg *et al*., 1988).

## Fruit quality

Morinaga (2004) conducted studies on "Satsuma" mandarin in southwestern Japan. The premium quality fruit that attract high net returns require the maintenance of sugar and acid contents of 12-14% and about 1%, respectively. To achieve this, Morinaga (2004) developed a new system of drip fertigation combined with year-round plastic mulch. The results presented in Fig. 8 show that under the conventional practice the Brix rating usually was in the range of 9.0-10.9%, whereas under the alternative system of drip fertigation with year-round plastic mulch, the Brix value usually remained within the range of 10-12.9%. The beneficial effects of the latter system included: (i) elimination of the labor cost of annual plastic mulch removal; (ii) improved fruit quality and vigor; (iii) drip fertigation facilitated application of fertilizers underneath the plastic mulch. Morinaga (2004) also concluded that the alternative system improved fruit color, and enhanced the contents of vitamin A, B-carotene, and B-cryptoxanthine; he did not discuss the mechanisms responsible for the enhancement of fruit quality.

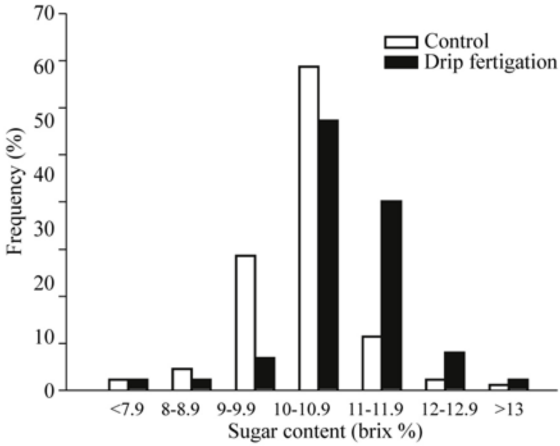


**Fig. 8.** Comparison of the effects of fertigation vs. broadcast application of dry fertilizer on sugar content of "Satsuma" mandarin (extracted from Morinaga, 2004).

### Grapefruit Yield Response

Boman (1996) conducted a 4-year field experiment with mature "Ruby Red" grapefruit trees on "Sour Orange" rootstock planted in St. Lucie County, Florida. Two methods of fertilizer applications were compared, both with N and K applied at approximately 180 and 150 kg/ha, respectively: (i) broadcast application of dry granular sources (annual rates of N and K applied in three equal amounts during Feb./Mar., May/June, and Oct./Nov.); and (ii) one-third of the annual amounts of N and K applied as granular material broadcast in February, with the remainder of the N and K sources applied as fertigation at 2-week intervals during April through early November (i.e. 17-18 fertigations per year). Across the four years, the leaf nutrient concentrations were not significantly influenced by the methods of fertilizer applications. However, as shown in Fig. 9, the yields of fruit (in three out of the four years) and of total soluble solids (in one out of the four years) were significantly greater from the trees that received dry fertilizer broadcast + fertigation treatment than from those that received the full-rate application of N and K as dry broadcast.

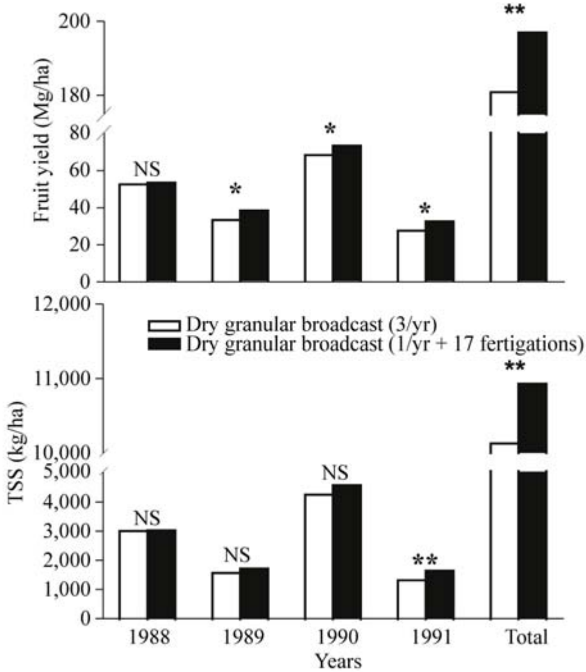


**Fig. 9.** Fruit yield and soluble solid response of "Ruby Red" grapefruit trees on "Sour orange" rootstock (extracted from Boman, 1996).

A 6-year study by Alva *et al*. (2005; unpublished data) on over-25-year-old "White Marsh" grapefruit trees on "Sour orange" rootstock, planted at 268 trees/ha, showed that mean fruit yield response (47 to 60 Mg/ha) over the N rate range of 56 to 224 kg/ha was quadratic when fertilization was with dry granular fertilizer broadcast three times per year (Fig. 10). With fertigation, the fruit yield response (47-67 Mg/ha) over the same range of N rates was almost linear. Thus, at the high N rate, the mean fruit yield was 26% greater with fertigation than with dry granular broadcast.

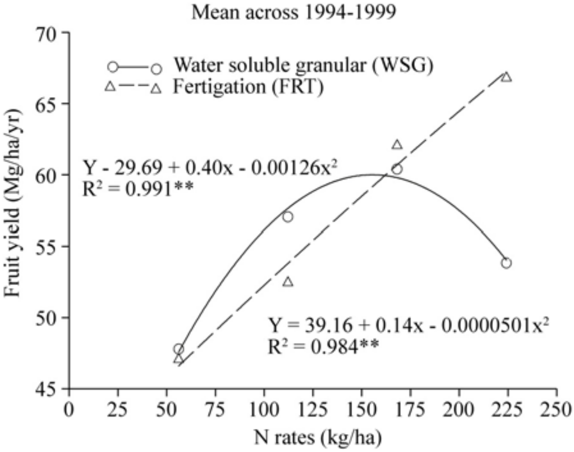


**Fig. 10.** Fruit yield responses (6-year mean) of over-25-year-old "White Marsh" grapefruit trees on "Sour orange" rootstock to different rates of N, applied as three water-soluble granular broadcast applications per year, or as 15 applications per year via fertigation (Alva *et al.*, 2005, unpublished data).

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