Technical Session IV :

K Nutrition Management of Perrenial Crops

Role of Potassium on Sustainable Citrus Production

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Introduction

Sustainable agriculture implies optimal production with minimum negative impacts on the natural resources. This philosophy is based on sound management to improve the efficiency of inputs. Nutrient management implies improved utilization of nutrients by minimizing the losses. Citrus is grown in several parts of the world, where minimum temperatures stay above -4 °C. This is the main reason why the major production areas are between 40 degree north and 40 degree south latitude. However, the greater proportion of the total world production and the fruits with best internal quality are produced in the subtropical region. Brazil and the United States combined account for up to 63% of total oranges produced, and the United States accounts for up to 67% of grapefruit production in the world. Citrus is grown in a wide range of soils, however, sandy to clay loam soils with pH range from 5.5 to 7.5 are best suited for production of high yields of high quality fruits.

Importance of Potassium

Potassium is important for formation of proteins, carbohydrates, and fats. Potassium also plays a role in chlorophyll synthesis and functions of several enzymes. Because of its high mobility in plants, it is found in high

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concentrations in growing parts including leaves, flowers, and fruits. Deficiency of K results in scorching of the leaf edge and sections between the veins. Older leaves may become bluish green eventually leading to leaf burns. Potassium deficient trees produce small fruits, often with poor color. Under severe deficiency, fruit drop could occur. Several rind disorders of orange and mandarins are associated with low K. Potassium nutrition influences the rind thickness and texture of fruits. A significant reduction in incidence of fruit splitting with an increase in K content in leaves of Hamlin orange trees was observed by Koo (1961). Incidence of creasing in fruits was reduced by increasing K levels in the trees. Among the juice quality parameters, only acid content is positively influenced by K application. Embleton, *et al.* (1964) and Koo (1963) have shown a 15% increase in acid content of lemon with application of high K as compared to that with low K fertilization. Potassium increases the fruit size, fruit weight, and peel thickness. In addition to this K fertilization increases vitamin C content in the juice (Sites and Deszyck,1952)

Potassium Requirement

Nutrient content in fruits represent the largest component of the nutrients removed from the soil. Nutrients removed by harvesting the fruits must be replenished. For 80 tonnes of fruits per hectare, the crop removal of K accounts up to 156.8 kg per hectare per year. The K removed in the fruits of Hamlin, Parson Brown, Valencia, and Sunburst cultivars were 121, 118, 129, and 124 kg K per hectare per year (Alva and Paramasivam, 1998b). In addition to the nutrients removed in the harvested fruits, the continued maintenance of the tree and annual new growth also require nutrients. However, for perennial trees, over the long term, a portion of nutrients stored in the tree contribute to the annual fruit production. Thus, the annual nutrient requirement should take into account that portion of the nutrients.

Guidelines for Potassium Fertilization

Nonbearing Trees: Studies to investigate the fertilizer requirement of non-bearing trees are very few. Likewise, the effects of different rootstocks and scion varieties have also not been adequately investigated. The fertilizer recommendations developed for orange trees are being used for grapefruit trees due to the lack of adequate research. Potassium rate recommended for non-bearing citrus trees during the first three years are 120 to 240, 240 to 480 and 370 to 740 g K $tree^{-1}$ yr^{-1} for first second and third year respectively (Tucker *et al.*, 1995). Criteria for selecting a rate within the recommended range includes N level of nursery trees, soil type, land history, and fertilizer placement. Increased frequency of fertilizer application and better timing of placement improve the nutrient uptake efficiency.

The fertilizer blend for young trees planted on previously uncropped soil should contain the following ratio of elements: N-1, P_2O_5-1, K_2O-1, Mg-1/5, Mn-1/20, Cu-1/40, and B-1/300, until such time when the soil and/or leaf analysis, and tree appearance indicate that one or more of nutrients may be omitted and/or applied at reduced rates. On previously cropped soils the proportion of P_2O_5 in the blend may be reduced or omitted if soil-test results indicate adequate P levels. Liquid and dry fertilizer sources are equally effective for young tree growth and have the same approximate formulations. Dry fertilizer may be applied in 4 to 6 doses during the annual growing period, while the liquid source could be split in 10 to 30 applications. Cost of injection of liquid fertilizer source during irrigation is relatively small for many systems if fertilizer injection can be automated. Due to the slow release characteristics of nutrients in controlled-release fertilizers, this source can be applied at reduced frequency, thus, decreases the labour cost of fertilizer application.

Bearing Trees : Potassium at the rates of 120 to 156 kg ha^{-1} yr^{-1} for grape fruit and 112 to 186 kg ha^{-1} yr^{-1} for orange and other varieties has been reported by Tucker *et al.* (1995). A minimum number of 3 dry application and 10 fertigation applications has been suggested. Managing fertilization for improved fruit quality is important for both processed and fresh fruit markets although increasing tree growth continues to be an objective for several years after fruit production begins. When trees reach containment size, further growth increase is not desired and nutrition levels may be stabilized and possibly reduced. Removal of elements by harvesting the crop becomes significant, but accounts for only part of the fertilizer requirements. Efficient management of irrigation continues to be critical.

Foliar Fertilization in Calcareous Soils: Soil application of K to calcareous soils is not quite effective to ensure adequate K availability to maintain the leaf K concentrations in the desirable range (Hunziker, 1960; Reitz and Koo, 1959, 1960). Foliar application provides a convenient and effective technique to overcome this problem. Calvert (1969) conducted four experiments using Valencia, Hamlin, Temple, and Murcott orange trees of different ages grown in calcareous soils (with pH range of 7.2 to 8.0). Potassium nitrate (KNO_3) was used as the source of K for foliar application at either zero (water spray-control), 9.07 or 18.14 kg KNO_3 in 380 liters of water. In the case of Valencia orange trees an additional rate of 27.21 kg per 380 liters of water was also included. The Valencia experiment included 1, 2, and 4 sprays at weekly intervals. **Figure 1** shows the leaf K concentration two weeks after the spray. Leaf K concentrations increased with increasing number of sprays, and also increased with increasing rate of KNO_3 from 9.07 to 18.14 kg. Further increase in KNO_3 rate to 27.21 kg had only marginal effects. In most cases, the concentrations of leaf K of the trees which received various foliar application of KNO_3 increased above 12 g kg^{-1} as compared to 10 g kg^{-1} in the unsprayed control trees.

The fruit yield increased significantly with two sprays per week as compared to that with only one spray per week at both 9.07 and 18.14 kg rates. The fruit yield increased by 70 kg per tree in the trees which received KNO_3 sprays as compared to those which were unsprayed. Leaf K

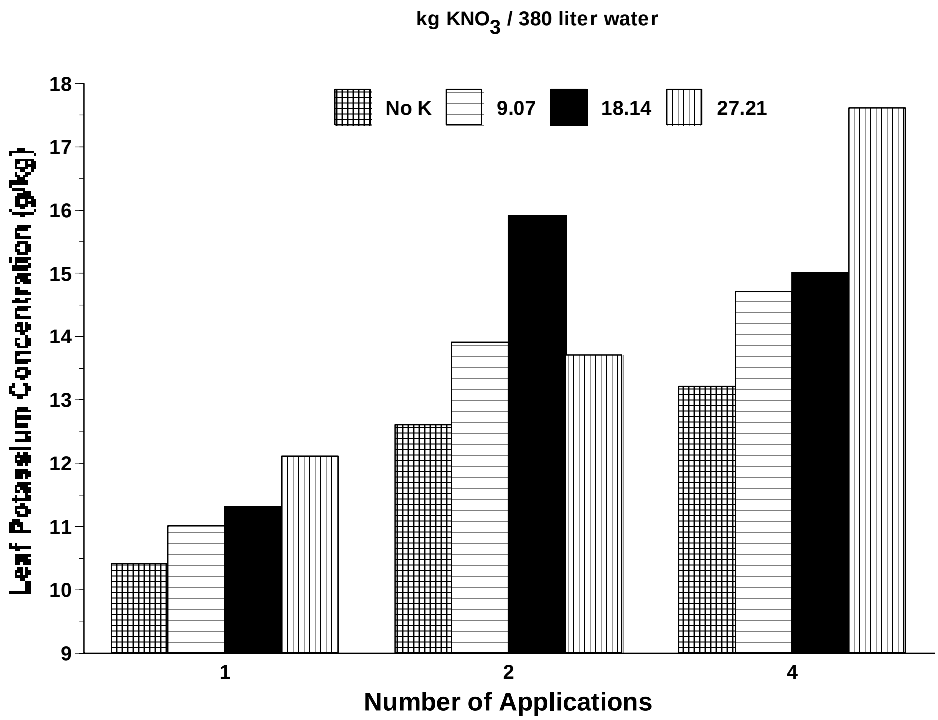

Figure 1. The concentration of potassium in the leaves of Valencia orange trees which received 1, 2, or 4 foliar applications of either no K or various rates of KNO_3.

concentrations increased to 12.3 g kg^{-1} in the trees which were sprayed with KNO_3 (18.14 kg per 380 liter water) as compared to 9.2 g kg^{-1} in the unsprayed trees. The foliar application of KNO_3 decreased the severity of creasing to 11 and 16% in Hamlin and Temple fruits, respectively, as compared to 24 to 30% severity in the respective cultivars in zero K treatment (**Fig. 2**).

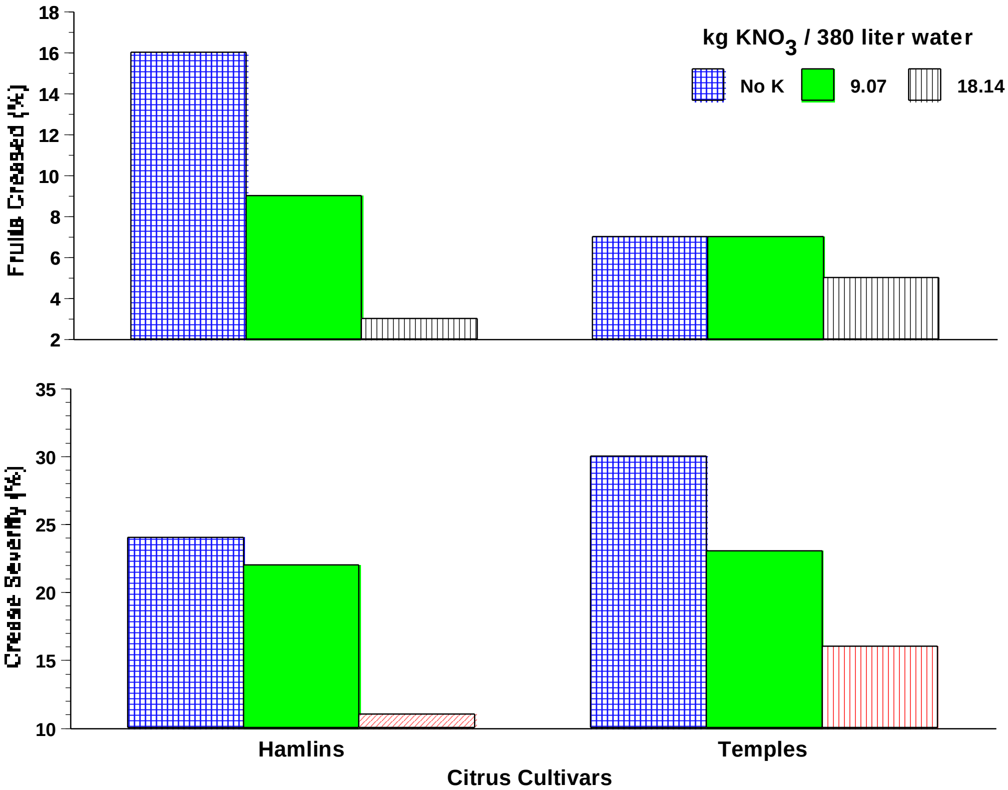

Figure 2. Effects of different rates of foliar K application on percentage of fruits creased and severity of crease in Hamlins and Temple fruits.

Effects of Potassium Source:

Very few studies has been conducted on the evaluation of different sources of K on fruit yield and quality. Koo and Reese (1972) conducted three experiments on the effects of K sources on young Hamlin orange trees, young bearing 'Marsh' grapefruit trees, and mature bearing 'Valencia' orange trees. The five year study on young Hamlin orange trees, showed generally non-significant effects of K sources, applied as either KCl or K_2SO_4, on either trunk diameter or leaf K concentrations (**Fig. 3**). Potassium rate, however, had significant effects on leaf K concentrations in all five years of the study. The rate variation for young trees was made possible by changing the percent of K_2O content in a 8-2-X (N-P-K) fertilizer blend as 1.7, 6.8, and 12 percent. The leaf K concentration varied from 12 to 26 g kg^{-1} with an increase in K content in the fertilizer blend. In a second experiment with 7 year old 'Marsh' grapefruit trees, four years mean fruit yields were 144 and 138 kg per tree for the trees which received K as KCl and K_2SO_4, respectively. The mean fruit yield increased from 124 to 147 kg per tree with an increase in K application from 78 to 156 kg K per hectare. Further increase in K rate to 234 kg K per hectare, had no significant positive effects on the fruit yield. Fruit weight response was non-significant to K sources, however, showed a significant increase with increasing rates of K. The mean fruit weights were 362, 397,

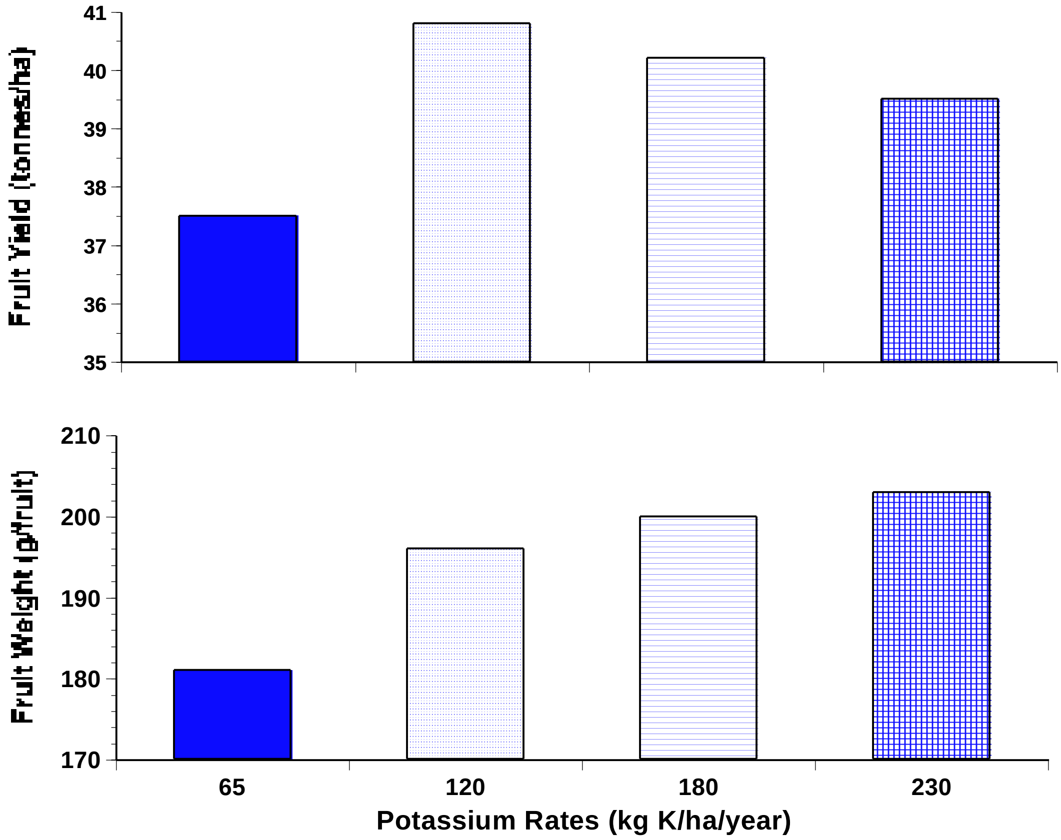

Figure 3. Fruit yield and fruit weight response of 11 year old orange trees to various rates of potassium. (The data shown are three years mean across 'Valencia', 'Hamlin', and 'Pineapple' cultivars, all on Rough lemon rootstock).

and 415 grams per fruit for the trees which received K rates of 78, 156, and 234 kg K per hectare per year, respectively.

Effects of Potassium on Fruit Yield, and Juice Quality

Orange Cultivars: A long term study with K applications at 65, 120, 180, and 230 kg K per hectare per year rates showed that the mean fruit yield increased from 37.5 to 40.8 tonnes per hectare with an increase in K rate from 65 to 120 kg K per hectare (**Fig. 3**). The corresponding increase in fruit weight was 181 to 196 grams per fruit. Further increase in K rates to 180 and 230 kg K per hectare had no effect on the fruit yield or fruit size. The fruit diameter increased significantly with an increase in K rate from 65 to 120 kg K per hectare. Further increases in K rates to 180 and 230 kg K per hectare showed only rather marginal increase in fruit size. The fruit juice acidity was 0.70, 0.73, 0.75 and 0.75 percent at 65, 120, 180, and 230 kg K per hectare rates, respectively (Reese and Koo, 1974, 1975).

To maintain a fixed ratio of N : P : K rather than varying single nutrients at a time the rates of NPK blend with ratio of 6.0 : 1.0 : 6.1 were varied (Alva and Paramasivam, 1998a; 1998b; Paramasivam *et al.*, 2001). Results in **Figure 4** show the fruit yield response to various rates of fertilizer for six years. The first two years yield data showed consistent increase in fruit yield with increased rates of fertilization within the range evaluated, another high rate was included in the subsequent years. The subsequent four years data show a quadratic response indicating that the range of rates used was adequate to elucidate the optimal production and also illustrates the luxury consumption indicated by slight negative response to increased fertilizer rate beyond the optimal rate. The fruit yield data also illustrates the typical "Alternate Bearing" response indicated by high production years followed by a low production year. This grove was under the best management programme including optimal irrigation as a part of the efforts to develop best management practices aimed to maximize production while minimizing leaching losses below the root zone. With the exception of 1994 and 1996, the fruit production was quite high. Therefore, the optimal nutrient rates developed by this experiment were widely applicable to a wide range of growing conditions.

Water soluble granular forms and fertigation were equally effective with respect to fruit yield responses. Fruit yields were lower with the use of 50/50 mix of water soluble granular forms and fertigation or use of polymer

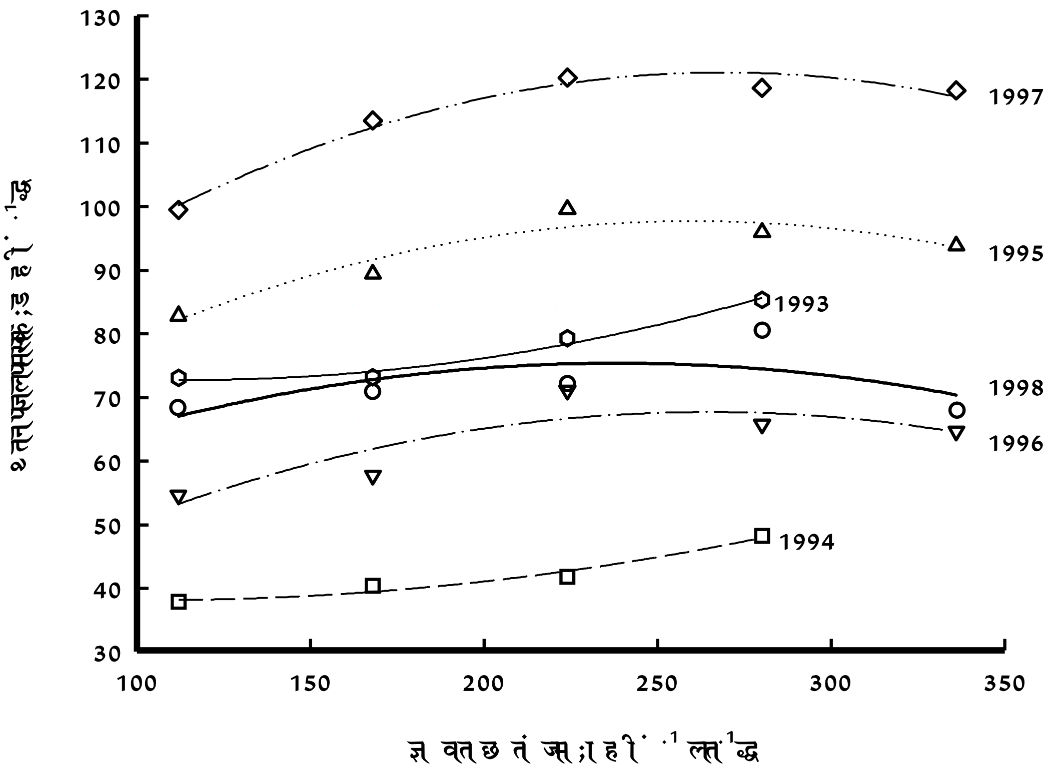

Figure 4. Fruit yield of Hamlin orange trees on Cleopatra mandarin rootstock as a function of various fertilizer rates (N:P:K blend at 6.0:1.0:6.1 ratio) in an Entisol in Florida.

coated N and K sources as compared to that with 100% fertigation or use of water soluble granular forms (data not presented). Using five years mean fruit yield response data for the water soluble granular form treatment, the optimal K rate appeared to be 250 kg ha^{-1} year^{-1} (**Fig. 5**).

The K concentrations in six-month old spring flush showed responses to only second or third incremental rates (**Fig. 6**). Further increases in fertilization rate showed no increase in leaf K concentration. The spring flush K concentrations, in general, were within the optimal range of 12 to 17 mg g^{-1} most of the years.

Grapefruit: A 20 year long field experiment was conducted by Calvert (1973) using 'Marsh' grapefruit trees grown in a Sunniland fine sand as well as Parkwood loamy fine sand. The trees were 23 years old when the study

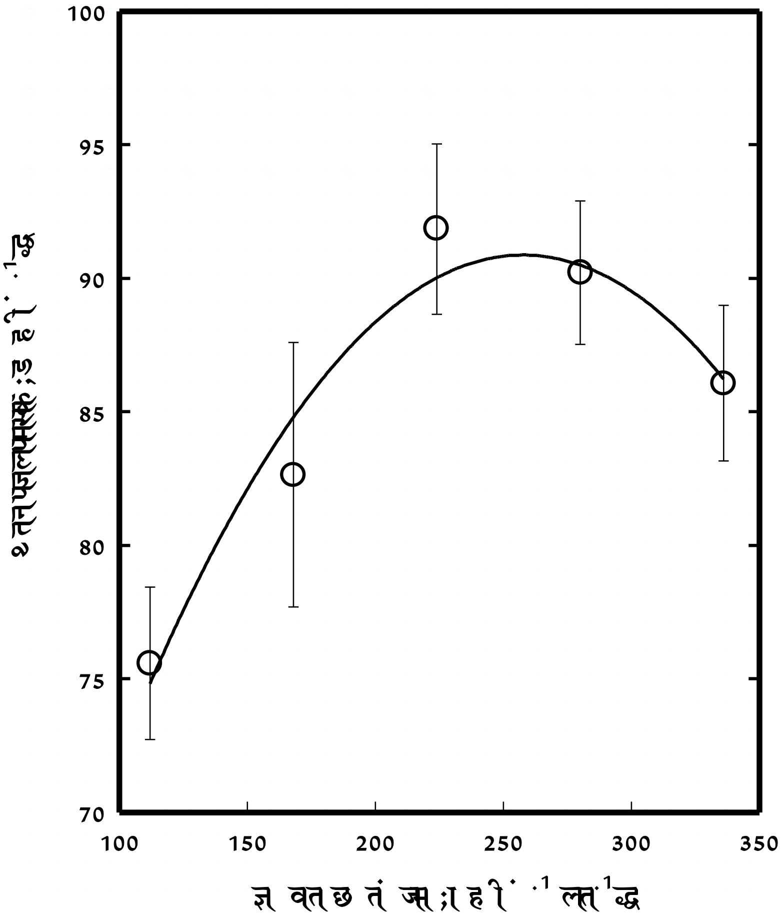

Figure 5. Potassium concentrations in six months old spring flush of Hamlin orange trees on Cleopatra mandarin rootstock as a function of various fertilizer rates (N:P:K blend at 6.0:1.0:6.1 ratio) in an Entisol in Florida.

began. The K treatments included 1.5 and 3.0 kg K per tree per year (equivalent to 215 and 430 kg K per hectare per year) in Sunniland soil and only the high rate in the Parkwood sand along with zero K control. The fruit yield response to K rate were non-significant in both soils during the first 10 years of the study. The mean fruit yields per tree during the first 10 years of the study were 350 and 346 kg for the trees which received 1.5 and 3.0 kg K per tree, respectively, as compared to 323 kg fruits per tree for those which received no K in the Sunniland fine sand site. In the Parkwood sand site, the mean fruit yields were 290 and 327 kg per tree for the zero K and 3.0 kg K per tree treatments. Significant response to K fertilization was obtained in the

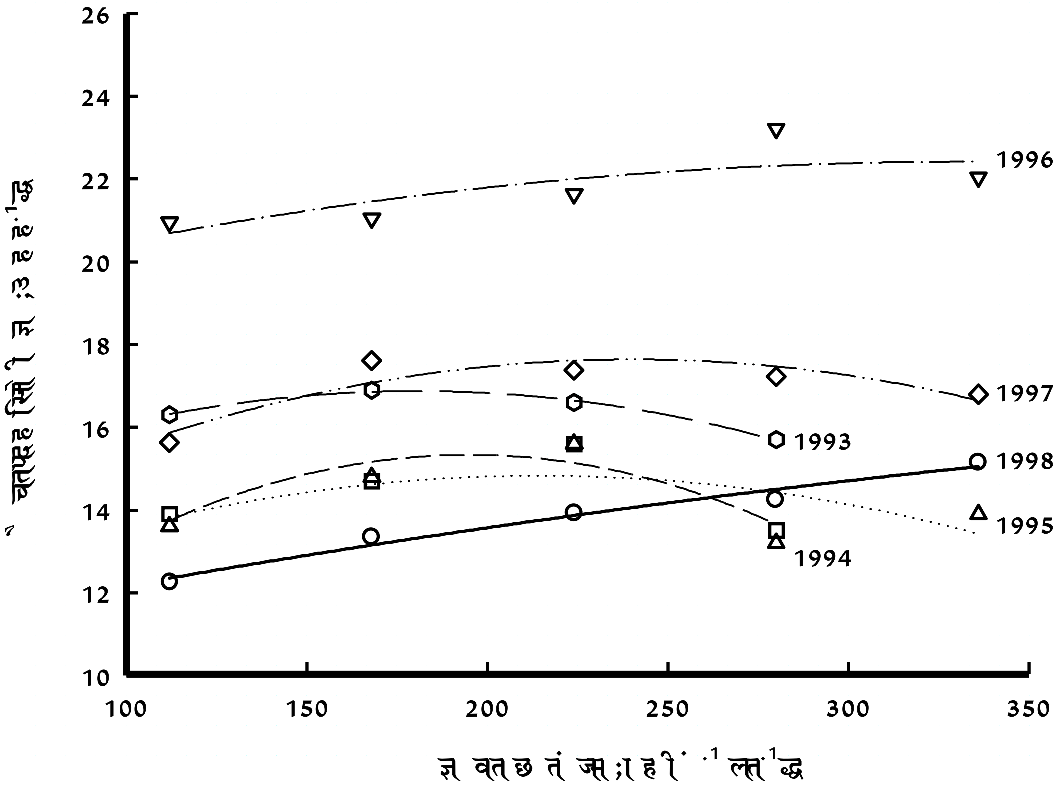

Figure 6. Mean fruit yield response 1995 through 1998 of Hamlin orange trees on Cleopatra mandarin rootstock as a function of various fertilizer rates (N:P:K blend at 6.0:1.0:6.1 ratio) in an Entisol in Florida.

subsequent 10 year duration of the study. The mean fruit yield increased to 340 kg per tree with application of 1.5 kg K per tree per year, as compared to 230 kg per tree for those which received no K in the Sunniland fine sand (**Fig. 7**). Further increase in K rate to 3.0 kg K per tree had no significant effects on the mean fruit yield as compared to that of the trees which received 1.5 kg K per tree. In the Parkwood fine sand also, the mean fruit yield increased to 334 kg per tree with application of 3.0 kg K per tree as compared to 170 kg per tree with no K application for 20 years during the course of the study.

The most noticeable response to K fertilization was an increase in juice acidity (significant during the 7^{th} and 9^{th} years out of a 20 years study in two sites), and fruit weight (12 out of a 20 years study in one site). The fruit weight increased from 414 to 460 and 377 to 466 grams per fruit with an increase in K rate from 0 to 3.0 K per trees in two soils (**Fig. 7**).

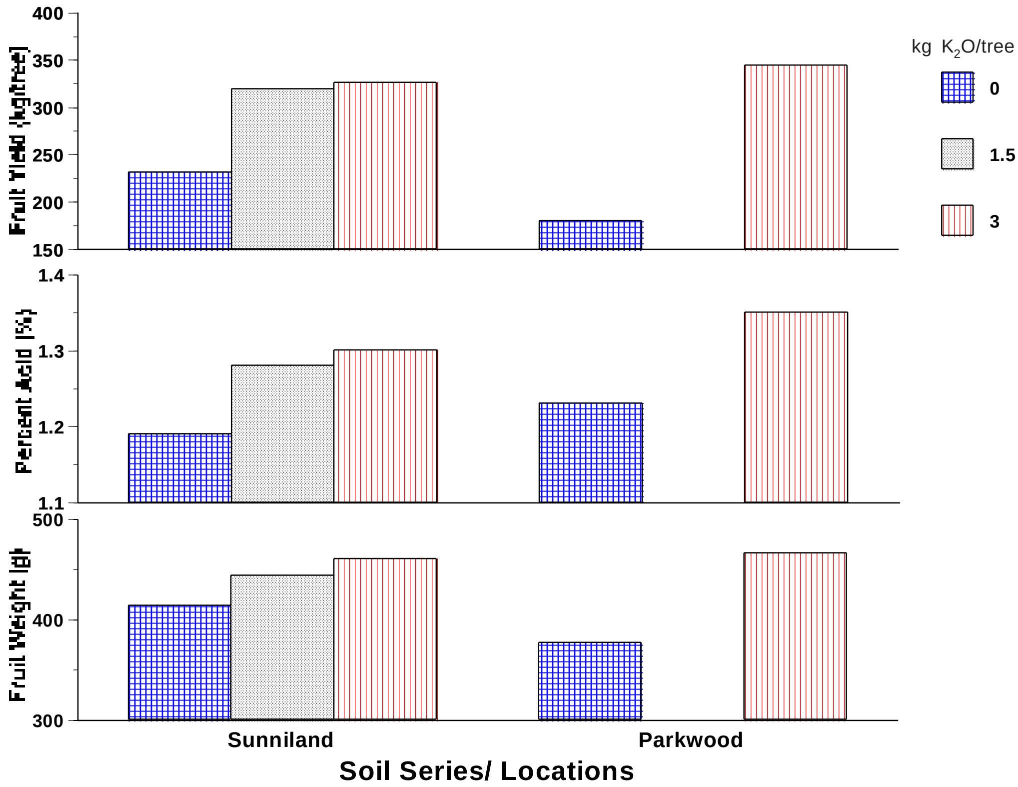

Figure 7. Effects of potassium rates on fruit yield, fruit weight and juice acid content of white "Marsh" grapefruit trees in two soils.

Effect of Potassium on Functional Components

Grapefruit (*Citrus paradisi* Macf.) contain various functional components including flavonones (naringin, narirutin), carotenoids, limonoids (limonin, nomilin, limonoid glucosides), folic acid, aurapatene, and vitamin C. The bitter compounds in grapefruit are naringin (7_-neohesperidoside of naringenin), limonin and nomilin. However, narirutin (naringenin 7-_-rutinoside) and limonoid glucosides are tasteless .

Certain functional components may not be considered essential by conventional measures, but are increasingly recognized for their beneficial effects on health promotion and disease prevention. Market research data from many sources showed that consumers in the United States, Japan, and Western Europe have already accepted the concept of biogenic diets containing biologically active functional components and are willing to try diets to prevent chronic diseases (Shukla, 1992). In recent years many epidemiological and case control studies have shown that citrus flavonoids have potential biological activities which include antioxidant, anticancer, antiviral, antiinflammatory activities, effects on capillarity, cholesterol lowering ability, and an ability to inhibit human platelet aggregation (Benavente-Garcia *et al.*, 1997; Guthrie *et al.*, 2000; Middleton and Kandaswami, 1994). Bronner and Beecher (1995) reported that average intake of flavonones from citrus juices by Americans is estimated to be about 23 mg per day while the average daily intake of flavonoids is 1 g per day.

The limonoids exist in citrus fruit primarily in the form of glucosides and are not bitter. Recent studies have shown that limonoids and their corresponding glucosides are inhibitors of chemical carcinogenesis in laboratory animals (Lam *et al.*, 1994; Miller, *et al.*, 2000) and in human breast cancer cells (Guthrie *et al.*, 2000; Tian *et al.*, 2001) as well as reduce cholesterol (Kurowska *et al.*, 2000).

Vitamin C is an essential nutrient for humans and citrus fruit as well as their processed products are the most commonly consumed sources (Kefford, 1993). Investigators have postulated a role of vitamin C in the prevention of cancer, heart disease, and in the augmentation of immune function such as in the prevention of common cold (Hemila, 1992). It is clearly established that the pigment lycopene is most sensitive to low levels of K. Evidence has shown that lycopene concentration increases with increasing K concentration in tomato (Trudel and Ozbun, 1971), and higher levels of carotene in cucumber leaves supplied with higher K (Lamarani *et al.*, 1996).

There is considerable interest in understanding the relationship between the management of production, inputs and the product quality including the components that contribute to human health benefits. These relationships are extremely important in an effort to cater to the needs of rapidly increasing health conscience consumers. Studies have begun to evaluate the effects of different fertilization rates on the quality production of grapefruits. Fruits were sampled from red grapefruit trees on Carrizo citrange rootstock from an experimental block in Polk County, Florida. The treatments included: 0, 112, 168, 224, and 280 kg N ha^{-1}. The fertilizer was applied using water soluble granular product broadcast in 3 applications per year. The N : K_2O ratio in the fertilizer was 1 : 1. Therefore, with the above rates of N, potassium rates also varied at 93, 140, 186, and 233 kg ha^{-1}. Potassium applications at different levels (0-233 kg ha^{-1} yr^{-1}) to soil did not significantly influence lycopene and beta carotenoids. However, concentratations of total carotenoids in control fruits were significantly greater compared to that of the fruits collected from trees which received 186 kg ha^{-1} yr^{-1} K (**Fig. 8**). Lycopene concentrations increased with increasing supply of K concentration in Tomato (Trudel and Ozbun, 1971), and cucumber leaves (Lamarani *et al.*, 1996).

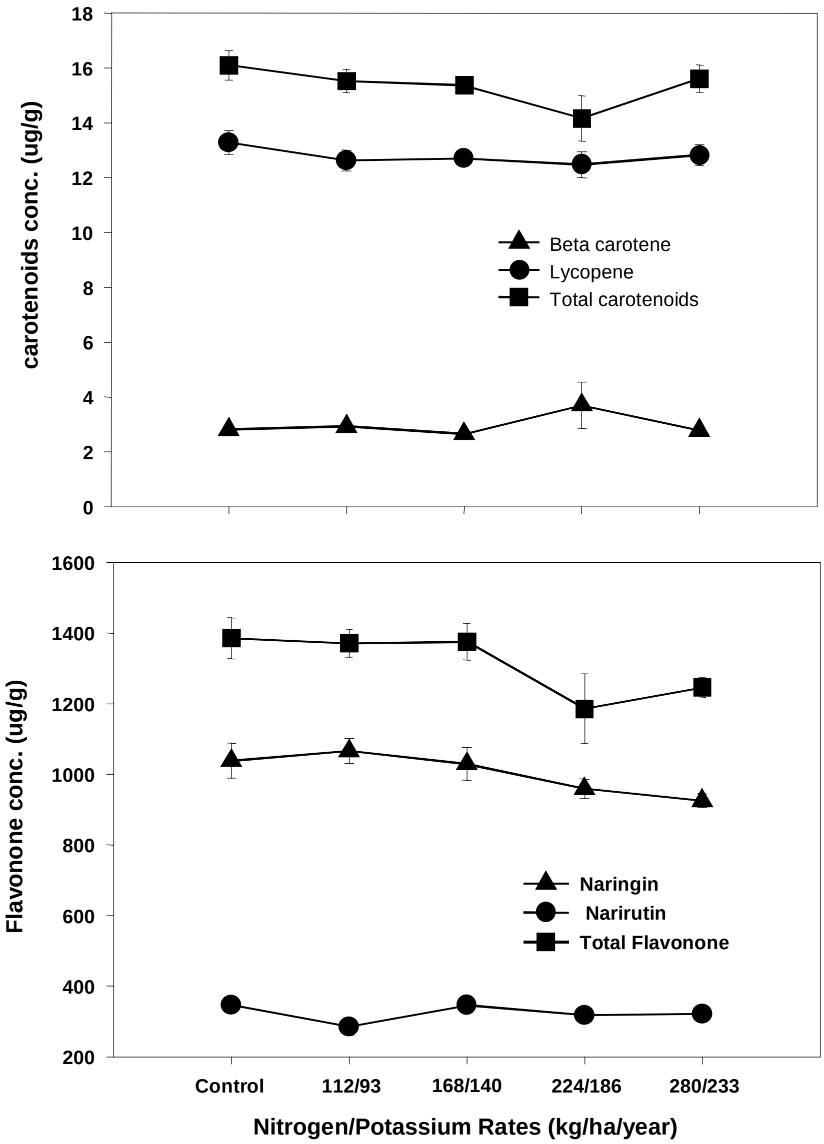

Figure 8. Concentrations of Carotenoids and Flavonone in grapefruit as influenced by different fertilizer rates.

In general naringin levels decreased due to increase in K concentrations. **Figure 8** clearly showed that the fruits with the highest levels of potassium applied (233 kg ha^{-1} yr^{-1}) had the lowest concentration of naringin. Indeed the fruits of the trees which received no fertilization had the higher levels of naringin, narirutin and total flavonone concentrations.

The total vitamin C concentrations were not significantly affected by K treatments, potassium applied at 83 kg ha^{-1} yr^{-1} treatment significantly increased dehydroascrobic acid and decreased ascorbic acid and limonin 17-beta glucopyranoside concentrations compared to those in the fruits from unfertilized trees (**Fig. 9**). This supports the previous conclusion that optimum

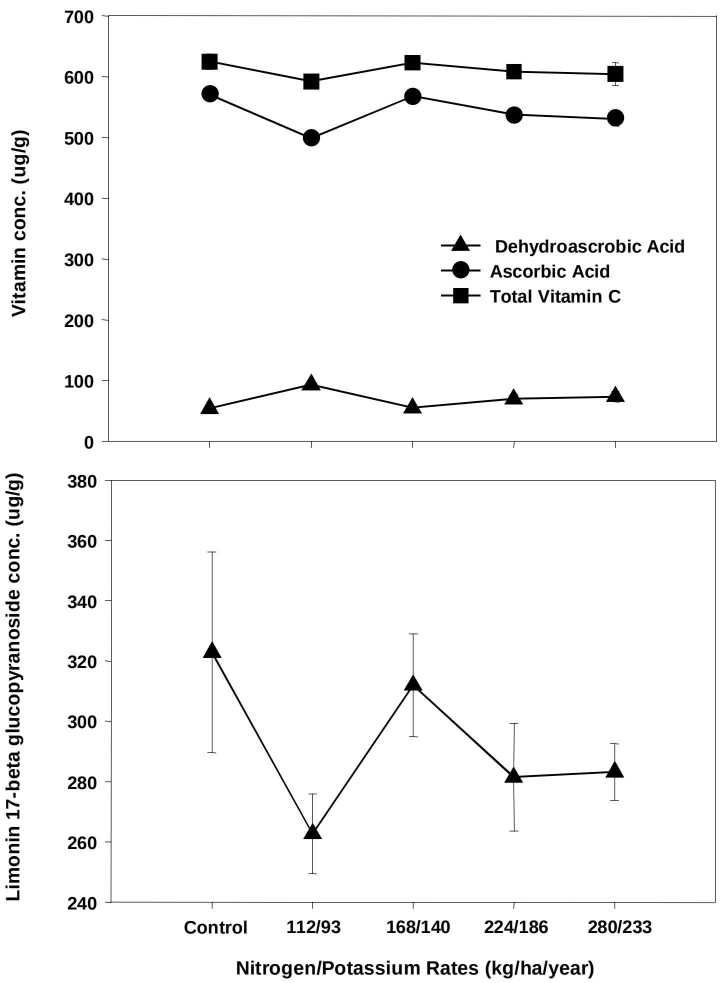

Figure 9. Concentrations of Vitamin C and Limonin 17-beta glucopyranoside in grapefruit as influence by different fertilizer rates.

supplies of K increases the vitamin C content of citrus fruit (Hearn, 1993; Smith, 1966; Jones *et al.*, 1973; Nagy, 1980). Because carbohydrate metabolism is strongly influenced by potassium supplies, K nutrition of citrus trees has a beneficial effect on the vitamin C content of citrus fruit (Embleton and Jones, 1966; Smith and Rasmussen, 1960).

Effects of Potassium on Post-harvest Quality

Peel Thickness: Increased application of K decreased the peel thickness and increased the juice content (Embleton and Jones, 1969). It increased the leaf K concentrations from 13.7 to 18.7, 6.2 to 12.3, and 4.4 to 6.6 g kg^{-1} in three sites, respectively, for the trees which received K fertilization as compared to those which did not. The peel thickness for the corresponding experiments decreased from 6.04 to 5.77, 6.72 to 5.94, and 4.13 to 3.88 mm, while the juice content increased from 29.6 to 30.9%, 29.5 to 34.3%, and 41.6 to 44.2%, respectively (**Fig. 10**).

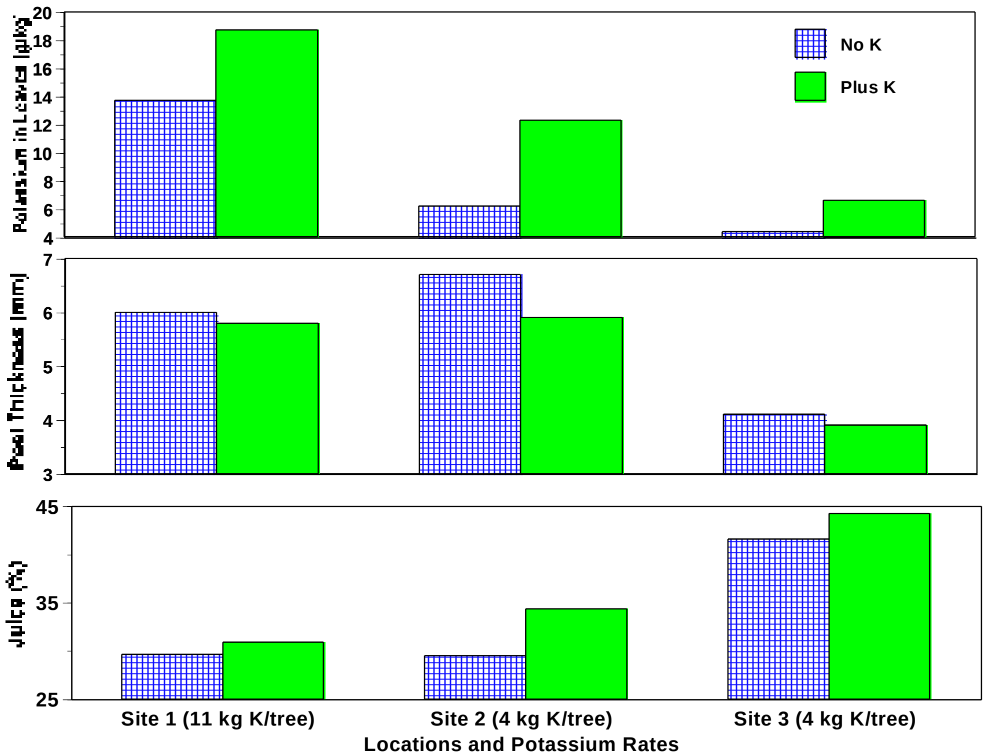

Figure 10. Effects of potassium on the concentration of potassium in the leaves as well as peel thickness of Valencia orange fruits and percent juice in three location trials.

Postharvest pitting is a newly defined physiological peel disorder caused by high temperature storage of waxed fruit (Petracek *et al.*, 1998; Petracek and Dou, 1998). This disorder is of considerable importance which can cause substantial losses during storage of waxed fruits (Dou *et al.*, 1999). Pitting is visually characterized by the collapse of oil glands and may develop within the first week of storage at higher temperatures (Petracek *et al.*, 1998).

Management of trees, particularly with regard to irrigation and fertilization, appears to play a role in predisposition of the fruits for varying degrees of postharvest pitting incidence as well as severity. The effects of K and irrigation on pitting incidence of white Marsh grapefruit have been evaluated in a three year field study. High N and K decreased the incidence of pitting (**Fig. 11**). In the fruits sampled in November, the incidence of pitting increased with increased duration of storage across all nutrition treatments. The storage duration effect was negligible on January harvested fruits. In a parallel factoral experiment with N and K on white Marsh grapefruit trees, increasing K levels in the range of 70 to 420 kg ha^{-1}, decreased the pitting at both 168 and 336

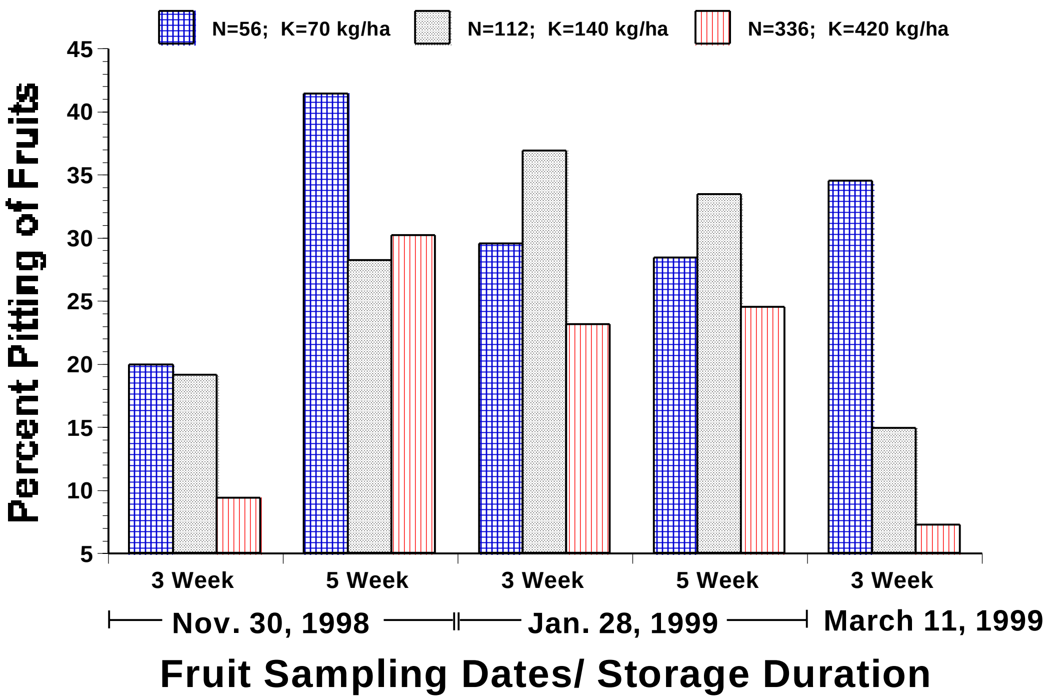

Figure 11. Effects of nitrogen and potassium rates on percent pitting of white "Marsh" grapefruits sampled at different times. Pitting evaluations were done either three or five weeks after storage of waxed fruits in commercial storage conditions.

kg N ha^{-1} rates. Increasing the duration of storage from 3 to 5 weeks increased the percent pitting.

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