Effect of Different Rates of Sulphur Fertilization on Fruit Yield and Leaf Mineral Composition of 'Valencia' Oranges in the Subtropical Environment of South Africa

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Abstract

Although sulphur is one of the essential nutrients for plant growth with a crop requirement similar to phosphorus (P), this nutrient element has received little attention because it is supplied in insecticides, fungicides, manure and from the atmosphere. With the relaxation of this requirement, and restrictions on sulphur dioxide emissions by industries it has become apparent that sulphur deficiency is widespread throughout the world. The majority of farmers submitting samples for soil and leaf nutrient analysis do not request a sulphur (S) test. This is due to the fact that farmers are still under the impression that there is enough sulphur in the soil. This study was carried out at Nelspruit, South Africa, to determine the influence of sulphur fertilizers on fruit yield and leaf mineral composition of a 13-year-old 'Valencia' (*Citrus sinensis*) orchard. Forty five plants, in as good physiological condition as possible were selected. Brimstone 90 fertilizer was used as the source of sulphur and the following five rates were applied (0, 60, 120, 180 and 240 g S tree^{-1} season^{-1}). A randomized complete block design with three replications was used in the experiment. Data revealed that soil pH, potassium (K), sodium (Na) and zinc (Zn) decreased with increasing levels of sulphur while P and Al increased. Increasing the rate of sulphur at 240 g tree^{-1} increased the leaf sulphur content from 0.29 to 0.36% which is considered as a critical level for optimum fruit production in orange trees. Leaf Mg content increased with increasing levels of sulphur while nitrogen (N), iron (Fe) and boron (B) contents of the leaves significantly decreased. The application of sulphur at 240 g S tree^{-1} significantly ($P<0.05$) increased fruit yield as well as the number of fruit tree^{-1}. The results emphasized the importance of applying sulphur to facilitate an increase in fruit yield of 'Valencia' orange trees.

INTRODUCTION

Effects of individual mineral nutrient including nitrogen, phosphorus, potassium and calcium on fruit yield and quality have been well established (Embelton et al., 1973). Much less has been done on the effect of sulphur in relation to citrus fruit yield and quality because it is supplied in insecticides, fungicides, manure and from the atmosphere (Kamprath et al., 1957). With the relaxation of this requirement, and restrictions on sulphur dioxide emissions by industries it has become apparent that sulphur deficiency is widespread throughout the world. The sulphur deficiency in soil is also aggravated by using fertilizers which are either lower in sulphur or even sulphur-free. At the same time continuous cropping and higher yielding cultivars removed more sulphur in cultivated soils which is recognized as a potential threat to arable crops (Kamprath et al., 1957). As a result, the sulphur content of soils in many countries has dropped severely and yield and quality of many crops have suffered (Morris et al., 1984). The majority of farmers submitting samples for soil and leaf nutrient analysis do not request a sulphur test. This is due to the fact that farmers are still under the impression that there is enough sulphur in

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the soil. The potential for the occurrence of sulphur deficiency in soils has thus increased greatly and it has become necessary to warn farmers about the reduction of sulphur in the soil and its consequences on fruit crop production. Investigation on the effects of mineral elements of various crops demonstrates that sulphur play a central role on the yield and quality maintenance (Terman, 1978). However, such investigation has lagged behind research fruit trees in many parts of the world including South Africa. As a constituent of the amino acids cysteine and methionine, sulphur plays an important role in the synthesis of vitamins and chlorophyll in the cell (Marschner, 1995). Without adequate sulphur, crops cannot reach their full potential in terms of yield, quality or protein content; nor can they make efficient use of applied nitrogen. Therefore, for sustainable crop yields and quality, sulphur fertilization should be incorporated in the fertilization program.

An analysis of leaf samples from selected citrus orchards around Nelspruit, Malelane and Burgershall by the Agricultural Research Council's Institute for Tropical and Sub-tropical Crops (ARC-ITSC) revealed a low level of sulphur in the leaves of citrus trees which was below the optimum ranges. As a result, there was a need to conduct a trial in order to investigate if sulphur deficiency that was observed in these fruit trees had an effect on the yield and quality of the fruits. The point of departure was to apply different rates of sulphur fertilizers on the affected orchards for a certain period of time. The objective of this study was therefore to: (i) determine the effect of sulphur fertilizer on the chemical properties of soil and plant tissues and, (ii) determine the effect of sulphur fertilizer on the yield of 'Valencia' orange trees grown under the sub-tropical climate.

MATERIALS AND METHODS

The study was carried out on 13-year-old 'Valencia' orange trees budded on sour orange rootstock in the experimental site of the ARC-ITSC located in Nelspruit (25°26'S; 30°59'E; 637 m a.s.l.) South Africa. The climate in the study area is sub-tropical with a long term rainfall average of 674 mm. The soil is sandy loam developed from Nelspruit granite. Forty-five trees, uniform in growth and in good physiological conditions as possible were selected. Five rates of elemental sulphur (0, 60, 120, 180, and 240 g S tree^{-1} season^{-1}) were applied. Other nutrients were applied as follows: N (700), P (105) and K (1250) g tree^{-1} season^{-1}. The experiment was considered as a randomized complete block design with five treatments. Each treatment was replicated three times with three trees for each replicate. At harvest time (October) the mature fruits were harvested and the yield per tree was expressed by weight and number of fruit tree^{-1} (kg). Leaf samples were collected from the non-fruiting terminals of each selected tree, washed with distilled water, dried at 70°C and ground for chemical analysis. Soil samples were collected from each selected tree at 0-30 cm depth using an auger, air dried and sieved for chemical analysis.

Analysis of Leaf and Soil Samples

1. Leaf Analysis. Total nitrogen was determined by the micro-Kjeldahl procedure followed by distillation and titration (Okalebo et al., 1993). P, K, calcium (Ca), magnesium (Mg), Zn and manganese (Mn) were determined by the perchloric acid digestion procedure of Karla and Maynard (1991). P was determined using a spectrophotometer whereas K, Ca, Mg, Zn, and Mn were determined on an Atomic Absorption Spectrometer. The total sulphur in plant tissue was determined using a wet ashing procedure outlined by Novozamsky and van Eck (1977).

2. Soil Analysis. Soil pH was measured in a supernatant of 1:2.5 (soil:water) ratio using a glass-calomel electrode. Electrical conductivity (EC) was measured in 1:1 soil water extract using electrical conductivity-method. Available P was determined using Bray-1 method (Bray and Kurtz, 1945). Extractable cations (Ca, Mg and K) were extracted with 1 mol dm^{-3} ammonium acetate (NH_4OAc, pH 7.0). Ca and Mg were measured by atomic absorption spectrophotometry, while K was determined by flame photometry. Zn, Fe and Mn were extracted with EDTA solution and determined directly on an undiluted extract with atomic absorption spectrophotometer.

Analysis of Data

Data were exposed to the analysis of variance in order to test the significant effects of sulphur application rates on the leaf and soil nutrient content and yield of 'Valencia' oranges using General Linear Model procedure of SAS. Differences between means were tested for significance using Duncan's Multiple Range Test at 5% level. Pearson correlations coefficients (r) and regression analysis were calculated to establish the relationship between sulphur and fruit yields.

RESULTS

Soil Chemical Properties

Except for Cu, all other nutrient elements and pH were significantly ($P<0.05$) influenced by the application of sulphur fertilizer (Table 1). Soil pH, K, Ca, Mg, and Na decreased while the levels of P and aluminium (Al) increased with increasing levels of sulphur fertilizer. The highest value of pH (7.18) was obtained with 0 g S $tree^{-1}$ $season^{-1}$ (control) while the highest EC value (1298 ohms) was observed with 120 g S $tree^{-1}$.

The Nutrient Content of *Citrus* as Influenced by Sulphur Application

Increasing the sulphur levels increased leaf S, Zn and Cu while N, Mn, and Fe tended to decrease significantly ($P<0.05$) with increasing sulphur levels (Table 2). Increasing sulphur rates from 60 to 240 g S $tree^{-1}$ gave the highest leaf S content compared to control (no sulphur). Leaf sulphur content ranged from 0.28 to 0.38%, being suggested as optimum level for fruit yield production in orange trees. In general, sulphur concentration in the leaf was significantly increased with increasing sulphur (Fig. 1). On the other hand, increasing the rate of sulphur fertilizer significantly decreased the nitrogen concentration in the tree leaves. Maximum concentrations of sulphur (0.38%) in leaves were achieved with an input of 240 g S/tree, while maximum concentration of nitrogen (2.30%) was observed at 60 g S $tree^{-1}$. A negative correlation of leaf sulphur was observed with P ($r=-0.540$), K ($r=-0.581$), Mn ($r=-0.919$), Fe ($r=-0.910$) and B ($r=-0.608$), whereas Mg ($r=0.593$) had positive relationship with leaf sulphur (Table 3).

Influence of Sulphur Fertilizer on the Fruit Yield of *Citrus*

The application of sulphur at 240 g S $tree^{-1}$ significantly ($P<0.05$) increased both yield and number of fruits per tree, while the size of the fruit on the other hand, decreased (Table 4). Figure 2 shows that there was a very strong correlation between sulphur rates and number of fruit ($R^2=0.9905$) and fruit yield ($R^2=0.9845$). A weak relationship was observed between sulphur rates and fruit weight ($R^2=0.6273$), while the relationship between sulphur rates and peel thickness was not significant. The highest values of fruit yields, number of fruit per tree, weight of the fruits as well as peel thickness were observed when the leaf sulphur was at 0.38% (Fig. 3).

DISCUSSION

Application of sulphur fertilizer had an effect on the chemical properties of the soil in the study area. Increasing the levels of sulphur fertilizer reduced the pH of the soil from 7.18 to 6.27, probably due to the ability of sulphur element to acidify the soil. Although increasing the rates of sulphur fertilizer reduced the pH of the soil during the study period, the soil pH was within the optimal ranges (6.0 to 7.2) for the normal growth and development of Valencia orange trees. An increase in the concentration of P, Mg, Al and Zn in the soil was attributed to the oxidation of sulphur element. During oxidation of sulphur, soil pH is decreased and thus, the unavailable form of most nutrients can be changed to an available form for plant uptake. Based on these results, it is therefore necessary to monitor the pH of the soil and leaf sulphur concentration regularly before application of sulphur fertilizers.

The fact that an increase in the rate of sulphur fertilizer increased the sulphur concentration in the leaves of 'Valencia' orange tree confirmed that there was a deficiency of sulphur in the citrus orchard at Nelspruit which might have had a negative effect on the yield and quality of the fruits. Similar findings have been reported by Anderson (1968) who found an increase in the content of sulphur from 0.27 to 0.70% after the application of gypsum. On the basis of this study, about 240 g S is needed to maintain the concentration of sulphur in the leaves of 'Valencia' orange trees within the optimal range of 0.29 and 0.39% as suggested by Du Plessis et al. (1992). There was a clear tendency towards decreasing N concentrations in the leaves after the application of higher rates of sulphur. Similar results have been reported by Anderson (1968) who found a decrease in leaf nitrogen from 2.86 to 2.61% after applying gypsum. High rates of sulphur resulted not only in an increase in leaf sulphur content, but also in higher fruit yields, suggesting that the increase in the yield of 'Valencia' oranges with increasing fertilizer rates is a response to additional sulphur.

CONCLUSIONS

The addition of sulphur, just like nitrogen, is capable of acidifying the soil. The application of sulphur fertilizer has increased the S, Ca and copper (Cu) concentrations of 'Valencia' leaves and decreased the N concentration. From this study, it can be concluded that yield and number of fruits per tree of 'Valencia' orange trees were increased with the application of sulphur fertilizers. In general, applying sulphur fertilizer at the rate of 240 g S $tree^{-1}$ was the most promising rate that resulted in the highest yield in our trial and was probably due to improved soil chemical properties. For sustainable citrus yields, sulphur application should therefore form an integral part of the fertilizer program. These results, along with the fact that many soils in the study area are low in sulphur, emphasized that additional application of sulphur in the standard fertilizer program is needed.

ACKNOWLEDGEMENTS

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Tables

Table 1. Effect of sulphur fertilization on soil chemical under the 'Valencia' orange tree.

Rates	pH	Ec (ohms)	P	K	Ca	Mg	Na	Al	Zn	Mn	Cu
			(mg/kg)								
0	7.18a[1]	933b	44b	81a	649a	141a	12a	6.33b	12.12a	110.9a	22.4a
60	6.88ab	870b	73ab	75a	621a	102ab	10a	7.33ab	12.45a	92.0a	18.9a
120	6.55ab	1298a	72ab	66ab	549ab	96ab	9a	7.67ab	9.61b	110.5a	23.3a
180	6.40ab	720bc	92a	66ab	559ab	82b	3b	8.67a	11.45ab	75.7b	28.8a
240	6.27ab	757bc	83a	52b	571ab	77b	2b	9.33a	10.63ab	85.4ab	25.2a
p-values	0.047	0.028	0.038	0.034	0.031	0.029	0.047	0.039	0.033	0.044	0.063

[1] Mean values with the same letter in the column are not significantly different from one another by the Duncan's Multiple Range Test at P<0.05.

Table 2. Leaf nutrient content of 'Valencia' orange trees as influenced by different levels of sulphur fertilizer.

Rates	N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B
	(%)						(mg/kg)				
0	2.30a[1]	0.16a	2.11a	2.77a	0.29a	0.28ab	16.7b	65.3a	114.7a	5.33b	59.3a
60	2.18b	0.17a	2.11a	2.94a	0.31a	0.35a	17.0ab	50.0ab	93.3ab	5.67ab	58.8a
120	2.19b	0.14a	1.93ab	2.99a	0.33a	0.36a	15.7b	48.3ab	87.7b	5.33b	57.7a
180	2.15b	0.15a	1.87ab	2.96a	0.37a	0.36a	18.3a	47.0ab	85.0b	5.33b	53.0a
240	2.07bc	0.15a	2.01ab	2.80a	0.33a	0.38a	18.3a	46.0b	80.7b	6.00a	50.2a
p-values	0.022	0.071	0.048	0.069	0.077	0.043	0.040	0.038	0.036	0.033	0.063

[1] Mean values with the same letter in the column are not significantly different from one another by the Duncan's Multiple Range Test at P<0.05.

Table 3. Correlation coefficient (r) between sulphur and other nutrient concentration in the leaf of a ‘Valencia’ orange tree.

	P	K	Mg	Mn	Fe	B
Leaf S content	-0.540	-0.581	0.593	-0.919	-0.910	-0.608
p-values	0.03*	0.02*	0.02*	<.0001*	<.0001*	0.02*

* = significant at 5% level.

Table 4. Effect of sulphur fertilizer on the yield of ‘Valencia’ orange.

Rates	Number of fruit tree^{-1}	Yield tree^{-1} (kg)	Fruit weight (g)	Peel thickness (mm)
0	124b[1]	29.89b	260a	6.84a
60	123b	28.59b	230ab	6.31ab
120	137b	32.41b	240a	5.91ab
180	161ab	36.98ab	240a	7.16a
240	221a	42.50a	200b	6.46ab
p-values	0.033	0.037	0.041	0.039

[1] Mean values with the same letter in the column are not significantly different from one another by the Duncan’s Multiple Range Test at P<0.05.

Figures

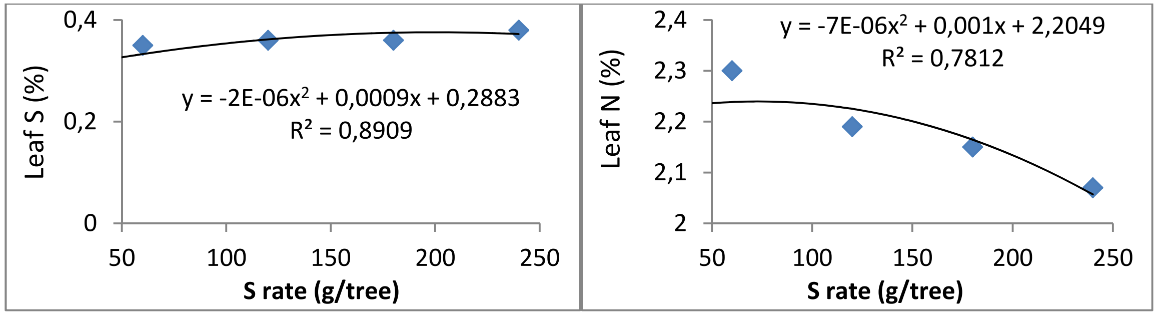

Fig. 1. Effect of sulphur application on the leaf sulphur and nitrogen concentration.

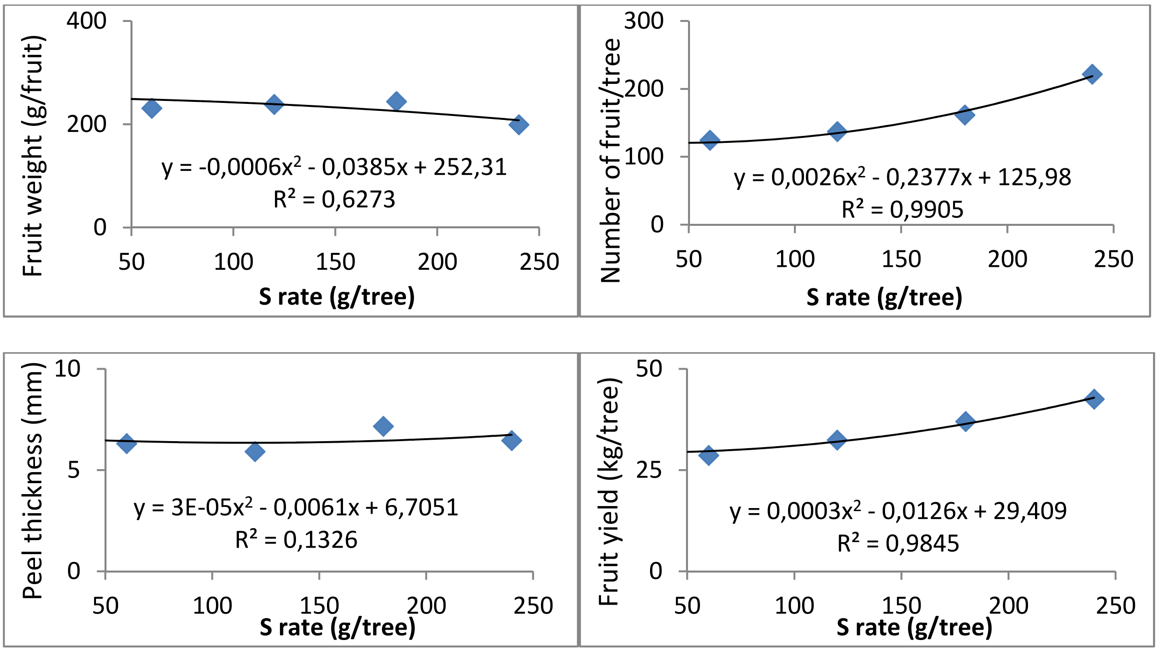

Fig. 2. Effect of sulphur application on the yields of ‘Valencia’ orange trees.

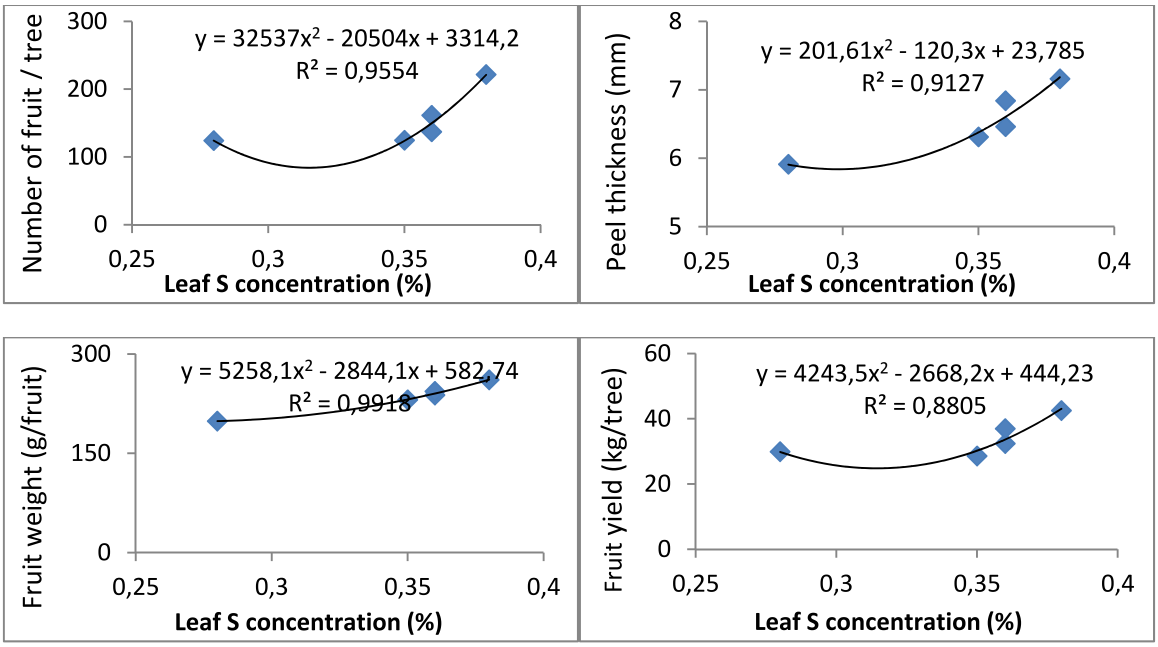

Fig. 3. Effect of leaf sulphur on the yields of ‘Valencia’ orange trees.