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Potassium Fertilization on Fruits Orchards: A Study Case from Brazil

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1. Introduction

What captures attention of those who are familiar with the production of fruits in Brazil is the diversity of species the country offers its people and foreign markets. From the temperate regions to the tropics and the equator line, only few varieties do not find their ideal climate and soil conditions across the country. It is common knowledge that Brazilian people are privileged when it comes to the question of supply. Domestic consumers have year round access to the types of fruit they prefer and, more recently, have even had the chance to select their product according to the different production systems. The planted area in 2010, it was 2.240 million hectares. The activity involves up wards of 5 million people throughout the country. In general, fruit growing is carried out on holdings of up to 10 hectares and provide enough income for the families to live life of quality.

2. The fig tree

The fig tree (*Ficus carica*, L.) originated from Asia Minor and Syria, in the Mediterranean region, and was first cultured and selected by Arabs and Jews in Southwest Asia. It is one of the oldest plants cultivated in the world – since prehistoric times – and is considered by ancient people as a symbol of honor and fertility. According to botanists from the American University Harvard, Middle Eastern fig trees were the first species cultivated by humans, 11,400 years ago. Researchers have found the remains of small figs and dry seeds buried at a village in the Jordan Valley located to the north of Jericho. The fruits were well conserved, which indicates they were dried for consumption [1].

The fig is one of the most popular food that has been sustaining humanity since the beginning of History. The fruit was used to feed advanced Olympic athletes and was offered to the winner as the first Olympic medal. The tree was described in many passages from the Bible as sacred and respected by man. During the period of the great discoveries, the fig was disseminated to the Americas. In Brazil, the fig tree was probably introduced by the first colonizing expedition in 1532 in São Paulo State.

In Brazil, economic exploration of the fig tree only started from 1910, when it was first commercially cultivated in Valinhos region, São Paulo State, where crops are restricted to only one cultivar – ‘Roxo de Valinhos’. This cultivar was from a region close to the Adriatic Sea in Italy and was introduced in Brazil, in the region of Valinhos, at the beginning of the 20th century by the Italian Lino Bussato.

‘Roxo de Valinhos’ fig plant is vigorous, productive and adapted to the drastic pruning system; this practice was adopted to help control pests and diseases. This is the only cultivar that has economic value due to its rusticity, vigor, and productivity; in addition, it is a product sensitive to handling and easily perishable. Production can be directed to industry for the fabrication of green fig compote, jam and crystallized fig, or for consumption of raw fruits.

The fig tree is commercially cultivated in the Brazilian states Rio Grande do Sul (39.42%), São Paulo (35.15%), and Minas Gerais (18.75%). In São Paulo State, the production is mainly destined for the market of raw fruits, whereas in the other states it is directed to industrial processing. According to data from the Brazilian Ministry of Agriculture (2008), Brazil produced 26,476 t figs in 2006, in a 3,020ha area, resulting in an average national productivity of 8.8 t/ha.

The culture is interesting for Brazil as it may lead Brazilian exportations to be incorporated between harvests in Turkey, which is the world’s main producer of figs. Brazil is a great furnisher of figs to the world; 20 to 30% of the total volume produced in the country is destined for exportation. Commercialization is done in boxes containing 1.6 Kg of the fruit [1].

2.1. Potassium fertilization in fig orchards

Little is known about the nutritional demands for the fig tree culture. The results available mostly discuss the use of organic fertilizers, where those appear as favorable practices, both in the development and the production of fig trees. Experiments with different sources and doses of nitrogen had also been widely performed, however, little is known about the demands of the other nutrients. According to [2], balanced and satisfactory mineral nutrition factors during the phase of formation of the plants assure good crops in the production phase of the plant.

Thus, in the absence of systematic studies for this purpose, the fertilizations of this fruit tree are performed mostly in an empiric way, mainly during implantation and formation of the trees. Likewise, nutritional diagnosis of plants through foliar analysis, although being a widely recognized valuable instrument for perennial plants, is incipient in the case of fig culture, often with conflicting values and absence in case of diagnosis with use of petioles.

Although the nutritional demands of the fig tree are of fairly knowledge, its measurement involves components of a very complex range, since the nutrient demands are closely related to the aspects of the species' physiology. During reproductive phase, the nutritional requirements have a component which is easily measurable and highly important in the evaluation of nutritional demands, the export of nutrients within fruit crops. However, during plant formation phase, the nutritional demands become difficult to determine since those are only for the growth and establishment of the plant, as well as the analyses of development the plants are rarely done in this period. In this phase excessive fertilization is performed according to visual diagnosis done by the producer, which is not uncommon.

2.2. Nutritional diagnosis and fertilization recommendations

According to [3], the knowledge of any needs or excesses of chemical elements responsible for the metabolism of plants and, due to the vegetation and productivity of fruit trees, it constitutes a necessary and indispensable step for corrective measures, since the fertilizing recommendations consist in the employment of fertilizer amounts, aiming to correct the element or limiting factor detected by the diagnosis.

The fertilizing recommendations during the formation period of the fig trees had been advocated exclusively from interpretations of soil analysis. In case of planting fertilizations, the recommendations are made by subjective criteria, not taking into consideration the content in the soil [4]. However, according to [3,5], soil analyses may be used to follow up the fertility of the soil and fertilizing recommendations during the development of the plants, because when used concomitantly with diagnosis methods may yield better results. The nutritional state of the plant can reveal the availability of nutrients of the soil and the ability the plant has to absorb them. Yet, fertilizing recommendations based on nutrient demands for fruit production, growth of branches, trunk and roots, during the phase of plant formation, cannot be considered a practice sufficiently broad, since such requirements are hard to measure. According to [6,7], the nutritional demands are better evaluated for plants at full production, where the crops of unripe and ripe fruits constitute the main sources of nutrient extracting sources.

2.3. Effect of potassium fertilizer on the fig tree

Due to scarce information on fertilization and nutrition of the fig tree, coupled to the evaluation of its effects on the nutritional state, a research was conducted using the levels of potassium fertilization, during the period of plant formation [8].

2.4. Methodology

The experiment was carried through in field conditions at the Orchard of Experimental Farm, of São Paulo State University, Faculty of Agronomic Sciences, Campus of Botucatu, São Paulo, Brazil, located at 22° 51' 55" South Latitude, 48° 26' 22" Western Longitude, with altitude of 830 meters. The predominant climatic type at the location, according to [9,10], based on the KOEPPEN international System, is included in the Cfb, namely the temperate

climate without dry winter, mean temperature of the coolest months below 18°C and the ones from the warmer months below 22°C, with annual mean precipitation of 1314 mm, reaching in the driest month (August), a 26 mm average. The climate conditions observed during the conduction of the experiment are in Figures 1 and 2.

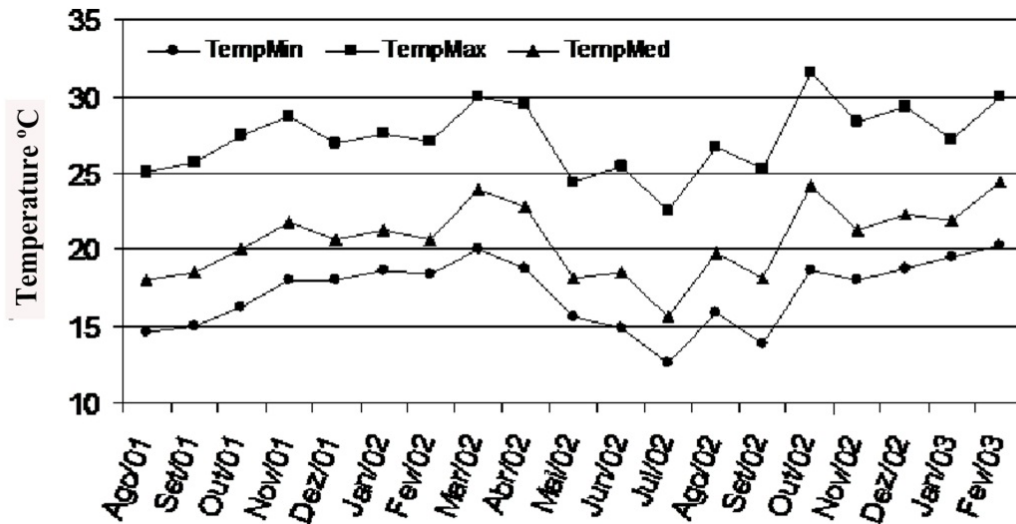


Figure 1. Maximum, mean and minimum temperatures observed during the conduction of the experiment. UNESP/ Botucatu - SP, Brazil, 2012.[8].

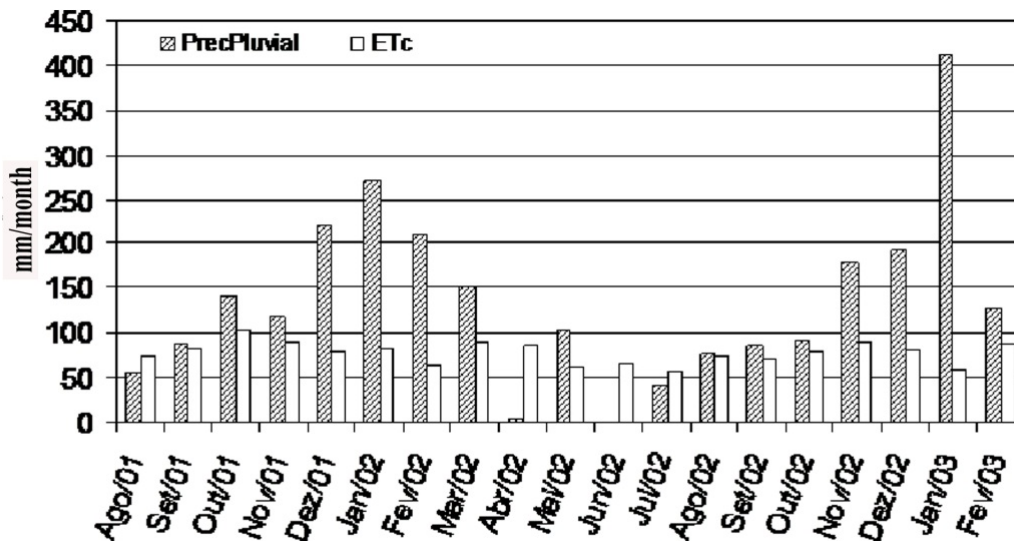


Figure 2. Pluviometric precipitations and evapotranspiration of the fig tree culture during the conduction of the experiment. UNESP/Botucatu - SP, Brazil, 2012.[8]. Source: Evapotranspiration of Class A Tank (ECA) - Area of Environmental Sciences (FCA). Evapotranspiration from the Culture (ETc) – Calculated by Culture Coefficient (Kc) data.

The soil is Rhodolic Haplo Udalf, according to the criteria established by [11]. The results of soil analysis of the 0-20 cm layer performed before and after saturation increasing by basic cations, according to the methodology in [12], are presented in Tables 1 and 2, respectively.

pH CaCl ₂	MO g dm ⁻³	P resin mg dm ⁻³	H + Al	K	Ca	Mg	SB	CTC	V %
			mmol _c dm ⁻³						
4.2	24.0	3.0	77.0	1.5	12.0	5.0	19.0	96.0	19.0

Source: Soil Fertility Laboratory – Department of Environmental Resources – Area of Soil Science.

Table 1. Chemical characteristics of the soil where the experiment was performed before saturation increasing by bases. UNESP/Botucatu-SP, Brazil, 2012. [8].

pH CaCl ₂	MO gdm ⁻³	P resin mgdm ⁻³	H + Al	K	Ca	Mg	SB	CTC	V %
			mmol _c dm ⁻³						
5.6	31.0	14.0	32.0	1.3	37.0	21.0	60.0	91.0	66.0

Source: Soil Fertility Laboratory – Department of Environmental Resources – Area of Soil Science.

Table 2. Chemical characteristics of the soil after saturation increasing by bases and planting fertilization. UNESP/Botucatu-SP, Brazil, 2012. BRIZOLA et al. (2005)[8].

The experiment was performed adopting the randomized block design, in an experimental scheme of subdivided parcels along the time, with four repetitions. The parcels were composed by potassium levels, sub-parcels by years and sub-parcels by harvesting months. The experimental unit was composed by three useful plants of the fig tree from cv 'Roxo de Valinhos', completely surrounded by border plants, in 3 x 2m spacings among plants and among lines, thus composing an useful area of 18m² for each experimental unit.

The main treatments, potassium fertilization levels (Table 3), were administered in the period from August to September of the agricultural cycles using increasing doses in arithmetic progression, in which the levels of the second cycle were equal to the first.

Treatments	Potassium Levels
K 0 (Witness)	Zero K ₂ O
K I	30g K ₂ O plant ⁻¹
K II	60g K ₂ O plant ⁻¹
K III	90g K ₂ O plant ⁻¹
K IV	120g K ₂ O plant ⁻¹
K V	150g K ₂ O plant ⁻¹

Table 3. K₂O levels applied in the experiment. UNESP/Botucatu-SP, Brazil, 2012. [8].

Potassium fertilizations began from seedling fixation, potassium chloride used as a nutrient supplier, the levels during the first year adopted according to the recommendation in [4], with two levels lower and three levels higher than the 60 g K₂O/plant recommendation. For levels higher than 60g K₂O plant⁻¹, the applications were divided in three occasions, with 20-day intervals. Nitrogenized fertilizations were also used using ammonium sulphate in four applications, placing 15g nitrogen plant⁻¹ at each occasion. The fertilizations were applied in the projection of the crown of the tree and superficially incorporated using a shovel in the two years of conduction of the experiment. The use of phosphorus was done only during the plantation, at the amount of 100g plant⁻¹ of P₂O₅, applying simple superphosphate.

The evaluation of the nutritional state of fig tree plants was performed through the diagnosis of the leaf and petiole, in three months within each evaluation year: October, December and February. The analyses of macronutrient content and branches and fruit accumulations were performed to evaluate the extraction of nutrients by the fig tree. The evaluations were obtained during the growth and plant production periods, the collections performed in three periods (October, December and February), evaluating: number of leaves, length of branches (cm), trunk diameter, dry matter of branches and production of fruits.

2.5. Results

The results obtained evidenced that the content of macronutrients in branches were not influenced by potassium fertilization in the crown. According to [13,14], the interactions between ions assume the existence of a certain relationship within those in soil solution (nutrient availability), this relationship being able to manifest itself in the form of nutritional imbalance, where the leaves are the first organs to manifest those changes, both at the level of contents and visual symptoms. Regarding the macronutrient content in branches, those were not influenced by potassium fertilizations. Thus, it can be accepted that such interactions in levels of content in branches are observed in more prolonged conditions of nutritional imbalance.

The growth of branches and the number of leaves by branch increased with fertilization and, accordingly, positive responses were obtained with potassium fertilization in the production of dry matter of branches and fruits (Figures 3 and 4).

According to [13], potassium deficiencies may reduce the photosynthetic activity and increase respiration, reducing the supply of carbohydrates and with consequent effects on the growth of the plants. For [15], the physiological functions played by potassium are directly involved in protein synthesis, in the use of water and in the translocation of carbohydrates, conditions which, when perfectly functional, may lead to plant growth.

The evaluation of structures of the plant showed that the leaves were the organs that presented the highest levels of nitrogen, phosphorus, calcium and magnesium, while the fruits were the organs that presented the lowest levels of macronutrients (Table 4).

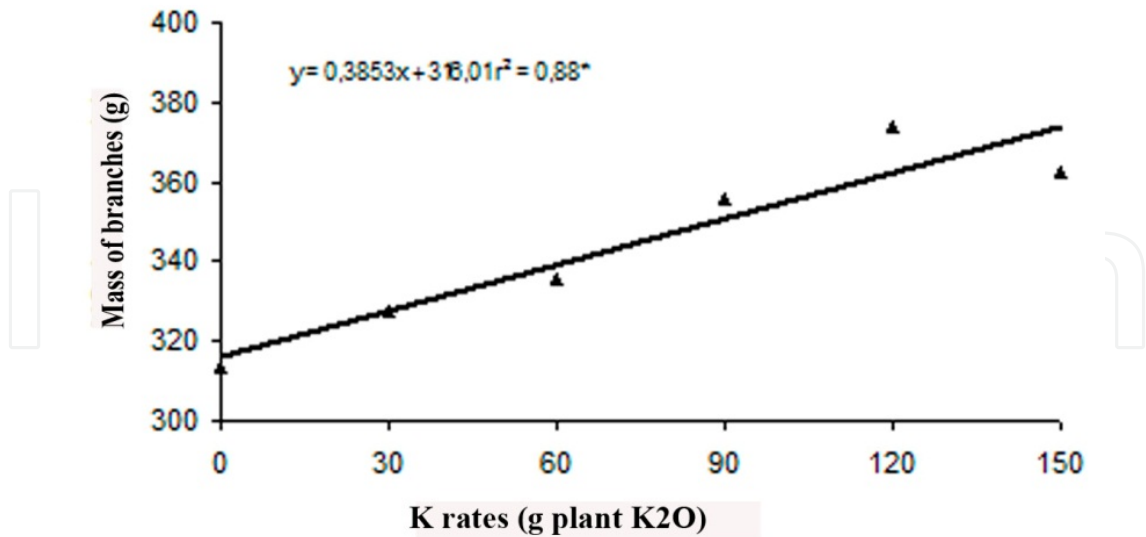


Figure 3. Effects of potassium fertilization in the dry matter of branches of the fig tree. FCA/UNESP/Botucatu, SP, Brazil. [8].

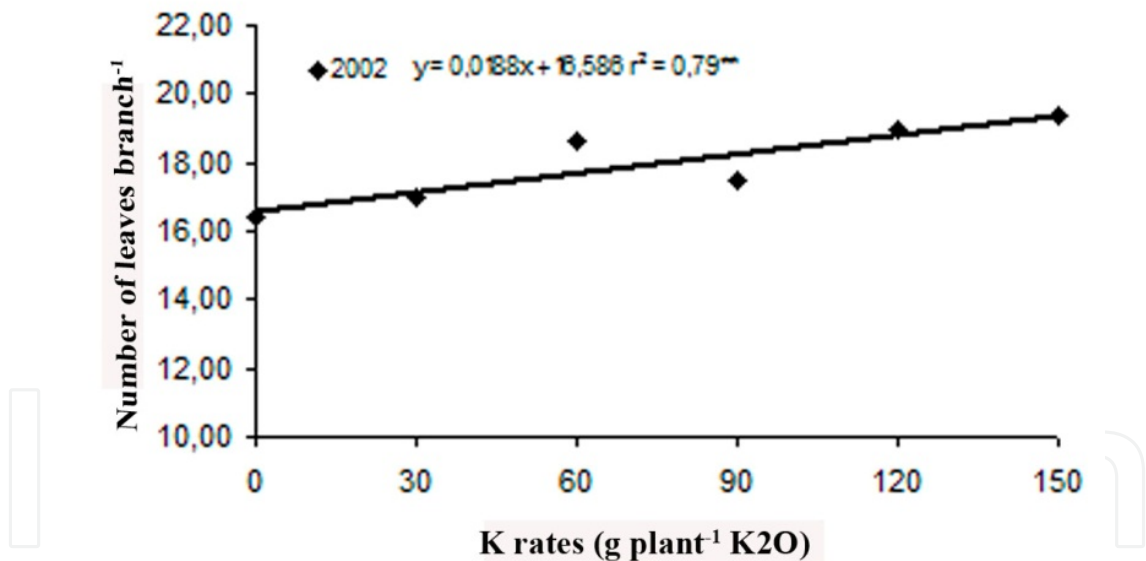


Figure 4. Effects of potassium fertilization in the number of leaves by fig tree branch. FCA/UNESP. Botucatu, SP, Brazil. 2012. [8].

Comparing the results found for foliar contents in the experiment to those suggested by [16] as optimal for well-nourished plants, it is observed that only nitrogen and potassium presented levels lower than those found by the authors, whereas in such concentrations, according to the same authors, those nutrients were already approaching deficiency zone. In [17], foliar contents indicated as satisfactory for fig tree culture are in ranges of 22-24

for N; 1.2-1.6 for P; 12-17 for K; 26-34 for Ca and 6-8 g Kg⁻¹ for Mg, whereas, in comparisons, only for Ca and Mg content lower than those indicated by the authors were detected. In comparison to the values indicated by [18] for foliar contents, calcium and magnesium presented values lower than those considered optimal for the culture, however, there was no perception of any manifestations of nutritional deficiency symptoms connected to those two nutrients, even in the treatment where the highest doses of potassium were applied.

Nutrient (g Kg ⁻¹)	Leaves	Petioles	Branches	Fruits
Nitrogen	25.57 A	11.14 B	10.36 B	7.995 C
Phosphorus	2.096 A	1.475 B	1.033 BC	0.777 C
Potassium	21.89 B	31.82 A	2.213 D	8.620 C
Calcium	19.25 A	10.75 B	6.982 C	1.863 D
Magnesium	5.675 A	4.262 A	1.981 B	0.727 B
Sulfur	1.707 B	3.064 A	0.960 B	0.766 B

Means followed by the same letter, in the same line, are not significantly different from the means by contrast, at the level of 5% of likelihood by F test.

Table 4. Mean content of macronutrients in leaves, petioles, branches and fruits of fig tree undergoing six levels of potassium in top-dressing fertilization. UNESP/Botucatu-SP. [8].

Regarding the contrasts of means between the content in leaves and petioles, it was noticed that the potassium and sulfur content were lower in leaves, whereas for magnesium, the contents were not different in leaves and petioles. For nitrogen, phosphorus and calcium the foliar contents were higher than those found in petioles, results in agreement with those found by [16], where contents of N of 33.9 and 15.1; P of 2.0 and 1.6; K of 26.8 and 45.9; Ca of 16.7 and 11.9; Mg of 6.3 and 8.4; and S of 2.0 and 4.4 g Kg⁻¹ were found in leaves petioles, respectively.

It was also observed that macronutrient content in leaves presented good correlations to those determined in petioles, and the petioles had better correlation coefficients with dry matter production and fruit production, making them preferential for the analysis of nutritional status of fig trees being formed (Table 5). Such results are in agreement with literature data, which indicate that the petiole is the most appropriate organ for evaluation of potassium in the plant [16,17,19].

Ratios Between Nutrients	Correlation Coefficient (r)		Significance test (F)	
	First crop cycle	Second crop cycle	2001/2002	2002/2003
N (leaf x petiole)	0.738	0.806	0.009**	0.000**
P (leaf x petiole)	0.591	0.634	0.040*	0.025*
K (leaf x petiole)	0.715	0.761	0.001**	0.002**
Ca (leaf x petiole)	0.771	0.829	0.003**	0.000**
Mg (leaf x petiole)	0.612	0.651	0.034*	0.018*
S (leaf x petiole)	0.658	0.660	0.018*	0.019*
K (leaf x soil)	0.386	0.773	0.215ns	0.003**
K (petiole x soil)	0.417	0.736	0.176ns	0.009**

ns = Non-significant a P>5% by F test; * Significant at 5% of likelihood; * * Significant at 1% of likelihood.

Table 5. Correlations of macronutrient content in leaves and petioles of fig tree undergoing six levels of potassium in top-dressing fertilization. UNESP/Botucatu-SP, Brazil, 2012. [8]

The results of fruit production (Figure 5) show that increases in potassium levels in top-dressing increased linearly with the production; however, the trend of the equation indicates an adjustment for a cubic equation when using higher levels of K₂O. Thus, the availabilities of potassium above 90 g K₂O plant⁻¹ could be considered as luxury consumption, since those would not be increasing the production values.

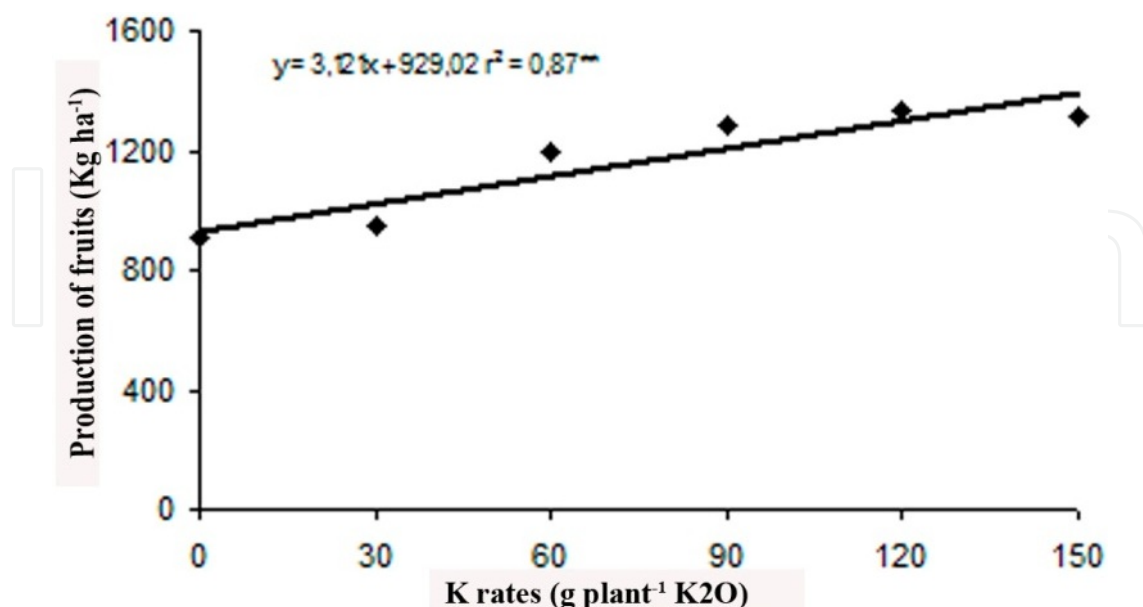


Figure 5. Effects of potassium fertilization in total production of fruits of developing fig tree. FCA/UNESP/Botucatu, SP, Brazil, 2012. [8].

In [20] no effects were obtained for the higher doses of potassium, although the employment of the dose of 60g K₂O plant⁻¹ had been about 40% higher than the dose of 30g K₂O plant⁻¹. The authors justified such results due to the high variation coefficient obtained for the analysis of harvesting of unripe fruits. For [3], the effects of potassium fertilizations on fruit trees are more conditioned to aspects of quality than quantity, since this element is not in limiting amounts for the development of the plant.

2.6. Conclusions

The results showed that potassium fertilizations provide increases of production of dry matter of branches and fruits, where better results were associated with levels of 90 g K₂O plant⁻¹, in a stand of 1600 plants per hectare and in soils under conditions of low and medium fertility in potassium.

3. The apple tree

The apple tree (*Malus domestica*) origin center is the Caucasus region, in the Asian mountains and in the East of China. It is supposed that the development of the casual species have been initiated 20.000 years ago. It seems that the Greeks in the classical ancient times had cultivated apple tree, in fact in the roman empire the apple tree culture was already widespread. In Brazil, the beginning of the apple tree culture occurred probably in Valinhos municipality, state of São Paulo in 1926 [21].

Apple is among the fourth most consumed fruits in the world. In Brazil it is commercialized during the twelve months of the year and distributed all over the country. Except its consumed *in natura* it is utilized in puree, jam, dry fruit, concentrated juice and fermented beverages. The apple tree fruit is rich in pectic substances and cellulose that together with lignin constitute fibers [21].

The apple orchards in Brazil initiated in the end of the 60's and beginning of the 70's. Since this date, Brazil depended on importation to supply the apple market. But through the government supporting, now a days, the evolution of the crops was fast, getting to 34 thousand of hectares and a production of about 850 thousand ton, concentrated in the Santa Catarina state. From 1988 Brazil started to export apples reaching self-sufficiency in 1998 when the exportations exceed the importations [21].

3.1. Potassium fertilization in apple orchards

Potassium (K) is the most extracted nutrients from the soil by apple fruits. Currently, with the use of new technologies, yield may reach values higher than 100 t ha⁻¹ [22]. Which increases the nutrients demanded by the apple.

The effective fruiting of apple trees is influenced by N, which plays an important effect in floral bud formation and increases the period when the ovule can be fertilized [23]. K in-

creases sugar translocation to sink tissues, promoting their growth [24]. Thus, fruits from K-deficient plants have reduced size [25,26,27,28]. Which can reduce overall yield [22].

According with [29,30], an excess of K can affect the calcium (Ca) nutrition, increasing the intensity of physiological disorders related this nutrient, including the bitter pit, cork spot and lenticel blotch pit, among others. Increasing K as well as N rates can decrease flesh firmness, reducing the storage life of apples.

Fertilizer recommendations for apple in Santa Catarina (SC) and Rio Grande do Sul (RS) states Brazil are based on soil and leaves chemical analysis, shoot growth and orchard productivity [31]. The amount recommended for each year varies from 0 to 100 kg ha⁻¹. These recomenadtion were obtained from results of research conducted in Fraiburgo/SC and Vacaria/RS, or adapted from other production regions around the world. Reginal fertilization test are quite important to São Joaquim/SC, considering that this region presents very stony and shallow Inceptisols and the mean temperatures are lower when in comparison to other production regions in Brazil.

3.2. Methodology

In [32] made an research with the objective to evaluate the effects of long-term annual additions of K to the soil on yield, fruit size, mineral composition and Ca-related disorders of 'Fuji' apples for São Joaquim, Santa Catarina state, Southern Brazil (28° 17' S, 49° 55' W). The experiment was conducted in the growing seasons from 1998 to 2006 in three commercial orchards of 12, 16 and 19 years old. Clay content and chemical characteristics of the soil from the experiment orchards, at the beginning of the experiment, are presented in Table 6.

The experimental plots comprised five plants, spaced 4.5 m between plants by 6.0 m between rows in one orchard and 3.0 by 6.0m in the other two, with the three central plants used as measurement plants. Trees were trained on a central leader system and received the same pruning and thinning practices as recommended for apple commercial orchards.

Attribute	Orchard 1	Orchard 2	Orchard 3
pH (H ₂ O)	6.8	6.4	6.6
P (mg dm ⁻³)	33.0	45.0	63.0
K (mg dm ⁻³)	141.0	240.0	258.0
Ca (mmolc dm ⁻³)	89.0	112.0	119.0
Mg (mmolc dm ⁻³)	60.0	62.0	64.0
Organic matter (g dm ⁻³)	50.0	49.0	65.0
Clay 9 g dm ⁻³)	300.0	380.0	300.0

Table 6. Soil testing results before experiment implementation (1998). [32].

3.3. Results

The results showed the apple yield was increased by K fertilization in four of eight evaluating growing seasons (Table 7), corroborating the results obtained in a long term experiments in south Brazil. The maximum increment in yield due to K fertilization ranged from 8.4 t ha⁻¹ to 17.5 t ha⁻¹, representing increases of 16,0% and 68,3% in fruit yield, respectively, as compared to trees not receiving K in these years.

In the first and third year no effect of K fertilization on yield was detected, because of the high exchangeable K content in the soil in all orchards prior to establishment of the experiment (Table 6).

Yield was more consistently increased by K fertilization after the 2002/2003 growing season, when exchangeable K contents were reduced in the plots without fertilization. The absence of response in the 2005/2006 growing season can be attributed to the increase in K levels of the plant, as a result of lower yields observed in the previous two growing seasons (Table 7).

K ₂ O	Growing Season								
	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	98-06
Kg ha ⁻¹	-----t ha ⁻¹ -----								
0	50.7*	52.5	38.7	41.0	35.3	28.3	25.6	46.6	318.7
50	50.5	56.8	38.9	43.3	40.6	31.1	38.8	55.3	355.3
100	50.8	60.9	40.7	47.5	46.4	36.2	42.4	54.7	379.6
200	48.7	56	44.1	45.6	47.7	39.7	43.1	49.2	374.1
Mean	50.2	56.5	40.6	44.3	42.5	33.8	37.5	51.4	
Coefficient Variation	34.5	21.1	35.9	29.7	17.8	24.6	20.5	31.3	

* Average values (n = 12)

Table 7. Average annual and cumulative fruit yield (1998-2006) for 'Fuji', as affected by annual surface addition of K. [32].

3.4. Conclusions

Yield size of apple were influenced, in a non interactive way, by K fertilization. Depending upon the growing season, yield and size of the fruit were often increased in response to annual addition K to soil, with fruit size more affected by K.

4. The pineapple in Brazil

The pineapple tree *Ananas comosus* (L.) Merrill belongs to the Bromeliaceae family, subclass of subclass of Monocotyledonous and gender *Ananas*. It is a plant native to South America,

covering latitude from 15° N to 30° S and longitude from 40° E to 60° W. About 50 genders and 2000 species of Bromeliaceae are known, some of them showing high ornamental value and others producing fibers excellent for cordage [33].

According to [34], the fruit of the pineapple tree is composite or multiple types called syncarp or sorosis formed by the coalescence of individual fruits, berry type, in a spiral on the central axis which is the continuation of the peduncle. The fruit is parthenocarpic, i.e., formed without the advent of fecundation. This fecundation may be possible but generally the varieties cultivated are self-sterile. According to [35], the skin of the fruit is composed of sepals and tissues of bracts and apices of the ovaries, while its edible portion consists mainly of the ovaries and bases of the sepals and bracts, as well as the cortex of the central axis.

The leaves of the pineapple tree, which can reach a maximum 70 to 80 per plant, are rigid and serous in the surface and protected by a layer of hair (trichomes) found in the lower surface, which reduces transpiration to a minimum [36]. The leaves are inserted in the stem and arranged in a rosette where older leaves are located on the outside of the plant and the newest in the center [37]. The "D Leaves" are the newest among the adults and the most physiologically active within all leaves, the reason why they are used in evaluations of nutritional status of the plant and in measures of growth [36].

The radicular system of a mature plant is of the fasciculated type and is located in the superficial part of soil surface. The majority of the roots are located in the first 15 to 20 cm of depth. The process of flowering begins with the reduction in vegetative growth velocity with a corresponding increase in collection of starch in leaves and stem [38].

The pineapple, native to Brazil, thrives under the Country's ideal soil and climate conditions, where it is grown from North to South, and its economic importance is acknowledged everywhere.

Pearl is the major variety in Brazil while in the world the Smooth Cayenne variety is the most popular. Although having an acid taste, this variety boasts the characteristics required by the consumers. To please consumers' eyes and palate, pineapples must have yellow pulp and skin, cylindrical shape, small crown and a taste similar to the Pearl variety, in addition to normal packaging and labeling requirements.

Brazil is one of the world greatest growers of pineapple producing around 2.5 million tons in 2008 [39]. Despite the importance of potassium fertilization for this crop, there is a lack of information about the effects of different sources of K on fruit yield.

The pineapple tree is considered the worldwide third most cultivated fruit tree and exhibits a market which annually moves about US\$ 1 billion dollars, being cultivated in more than 50 countries [39]. The Philippines followed by Thailand are the world biggest producers of pineapple with an annual production of two million tons, next in 6th place Brazil reaches around 1.47 billion fruits per year and, in the sequence, India, Nigeria and México [40].

In Brazil the pineapple is traditionally cultivated under rainfed conditions, in sandy, acid and low-fertility soils, with limitations for Ca, Mg and K and unbalances on the ratios among those cations [41]. In real values potassium and nitrogen are the most ab-

sorbed elements by the pineapple tree. The size and weight of the fruit are variables directly related to nitrogen, while potassium is linked to the physical-chemical quality of the fruits [42,43,44,45].

4.1. Potassium fertilization in pineapple

The nutrients required the most by the pineapple tree and which influence its growth are potassium and nitrogen [46]. Potassium is the nutrient which accumulates the most in the plant, markedly interferes in product quality and also in culture productivity; nitrogen mostly influences the fruit mass. The pineapple tree is not very demanding in phosphorus and its importance to the plant is mainly in floral differentiation and fruit development phase [47]. In [48] it is mentioned that an increase of N reduces the acidity of the fruits, but it can or cannot decrease soluble solids. According to [49,50], the extraction for macronutrients in decreasing order is expressed: K, N, Ca, Mg, S and P and for micronutrients: Mn, Fe, Zn, B, Cu, Mo.

Potassium is an important enzyme activator, responsible for opening and closing of stomata and carbohydrate transportation. It increases the content of soluble solids and acidity, improves the color and firmness of the skin and pulp and increases the mean weight and diameter of the fruit, and also decreases the emergence of internal darkening of the fruit [51].

According to [52] potassium fertilization can be supplied with potassium chloride, potassium sulphate, potassium and magnesium double sulphate and potassium nitrate, the two last ones being harder to find on the market and more expensive. The minimum guarantees and characteristics are presented in Table 8.

Source	Minimum guarantees/characteristics
Potassium chloride KCl	58% K ₂ O. Potassium in the form of chloride determined as K ₂ O soluble in water.
Potassium sulphate K ₂ SO ₄	48% K ₂ O and 15% de S. Potassium in the form of sulphate, determined as K ₂ O soluble in water.
Potassium nitrate KNO ₃	44% K ₂ O and 12% de N. Potassium determined as K ₂ O soluble in water. Nitrogen in the nitric form.
Potassium and magnesium double sulphate K ₂ SO ₄ · 2MgSO ₄	20% K ₂ O, 10% de Mg and 20% de S. Potassium and magnesium determined as K ₂ O and Mg soluble in water.

¹Source: Instrução normativa n° 5 do Ministério da Agricultura, Pecuária e Abastecimento [53].

Table 8. Sources of potassium used in pineapple trees¹.

The mostly used source by the producers is potassium chloride due to its low cost, but its composition has chloride which is a toxic element. The combination of chloride from the fertilizer with the one present in the irrigation water in the region, further increases the toxicity

of this element on the plant. Potassium sulphate is the most appropriate source, for being less harmful to the crop.

The presence of chlorine affects the starch and sugar contents in the plant. High concentrations may prevent fructification and potassium absorption, reducing the size of the fruit, the sugar and starch contents, increasing the acidity, symptoms similar to K deficiency [54].

When evaluating different combinations of potassium sulphate and chloride, supplied in pits of basal leaves, at 30, 90, 180 and 270 days after planting at the dose of $8 \text{ g plant}^{-1} \text{ K}_2\text{O}$, [55] no differences were observed in the production and quality of the fruits when cultivating Smooth Cayenne, although a trend of slight increase in acidity and decrease in total soluble solids/total titratable acidity ratio had occurred to the extent that the applications of sulphate were replaced by potassium chloride. In addition, no visible registered symptoms of foliar burning were registered by the use of KCl nor changes in fruit color.

In [56], the effect of fertilization (potassium sulphate, 0; 8 and $16 \text{ g plant}^{-1} \text{ K}_2\text{O}$) on the production and quality of the fruits from Smooth Cayenne cultivar, in Argissolo Vermelho dos Tabuleiros Costeiros de Pernambuco, containing $17 \text{ mg dm}^{-3} \text{ K}$ was evaluated. Significant effects of K on the content of soluble solids were seen, which reached maximum values at the dose of $15.6 \text{ g plant}^{-1} \text{ K}_2\text{O}$.

When evaluating the effect of four doses of K (0, 413, 722 and $1.031 \text{ kg ha}^{-1} \text{ K}_2\text{O}$), applied in the form of potassium chloride, in low fertility soil from Minas Gerais, [57] observed better use of K by the plants in the presence of liming and that the doses of K_2O which maximized the production were greater in more elevated doses of N (236 and $720 \text{ kg ha}^{-1} \text{ K}_2\text{O}$ to 10 and $15 \text{ g plant}^{-1} \text{ de N}$, respectively). The increase in doses of K increased the foliar content of K and reduced the Ca and Mg content. It also increased the content of total soluble solids and fruit acidity, granting good balance in the SST/ATT, *ratio*.

Overall, the doses of K to maximize the quality attributes of the fruits are greater than those to maximize the production. In this context, [44] when evaluating the doses of K (0, 175, 350 and $700 \text{ kg ha}^{-1} \text{ K}_2\text{O}$) necessary to obtain maximum physical and quality yield of pineapple fruits Smooth Cayenne cv. observed that the doses of K positively influenced the size of the fruits and a total production in addition to increase the content of vitamin C, soluble solids and total acidity. However, the dose of K to maximize the size of the fruits ($569 \text{ kg ha}^{-1} \text{ K}_2\text{O}$), was higher than the one to maximize the production ($498 \text{ kg ha}^{-1} \text{ K}_2\text{O}$).

Due to a long cycle culture and high K demand throughout the cycle, the application of potassium fertilizers in the pineapple tree should be divided to meet the demands of the culture, minimize losses, increase efficiency of fertilizations and improve fruit quality [43].

In Brazil, the main soil classes are Latosol and Argisol with elevated degree of intemperization and little presence of potassium minerals. In less intemperized soils, like Neosoils, Vertisoils, Luvisoils and Chernosoils, more rare in the Country, there are larger quantities of potassium minerals, like feldspates and mica, which may represent important sources of the nutrient [58]. Thus, soil contents maintenance appropriate to plants becomes extremely important in cultivation of the pineapple tree.

4.2. Sampling and chemical analysis of the soil

Some technical criteria should be adopted in soil sampling, since failure in the collection of soil samples generate errors that cannot be corrected later by soil analysis. All care should be taken in order to the samples being representative of the areas to be cultivated.

The sample collection should be performed before plantation, with enough time for the corrective to have time to react and to perform the fertilization step. The area to be sampled should be divided in homogeneous plots. For this division, observe the topography, vegetable covering, area history, drainage, soil texture, soil color and further related factors.

At the samples withdrawal the arable layer, which normally is more intensely changed by plowing, harrowing, correctives, fertilizers and culture residues, is considered. Therefore, sampling should be performed in this layer from 0 to 20 cm depth. For the analysis of sub superficial acidity and availability of sulfur the depth from 20 to 40 cm should be collected.

For larger representativeness, 15 to 20 single samples should be collected, using an instrument which provides equal volume between collections, at randomly distributed points in each area; the set of single samples will constitute the composite sample (500g homogenized fraction).

The composite sample from each area should be forwarded to a lab for soil chemical analysis for fertility purposes that present performance control of its results by IAC, easily identified by the seal. The requested analyses should be the basic (pH, MO, P, H+Al, K, Ca and Mg) and micronutrients (B, Cu, Fe, Mn and Zn) ones. Optionally, the analyses of Al, SO_4^{2-} and texture can be requested, as indicated.

4.3. Evaluation of nutritional availability

Foliar diagnosis was performed for plants status nutritional evaluation. Foliar analysis allow monitoring the of fertilizers used, however, is necessary caution for sample collection, working within sampling standards and criteria.

4.4. Foliar diagnosis

In leaf sampling, it is important to establish criteria to define the plots, grouping plots with similar characteristics regarding cultivated variety, age, phenology, handling, productivity and which ones belong to areas with homogeneous soils.

For the pineapple tree it is recommended to collect the Leaf "D" (Figure 6), considered metabolically more active, which is the last well-developed leaf, generally the longest one, forming, in general, a 45° angle relative to the soil (Figure 7). The sample collection should be performed by the period of floral induction [59]. However, the sampling time indicated for the pineapple tree does not allow corrections in the current crop. The suggestion is to collect at least 25 leaves of different plants, from each uniform plot, randomly taken, considering one leaf per plant [17].



Figure 6. Overview of a pineapple plant with indication of the leaf to be sampled for chemical analysis (Leaf "D").
Photo: REIS, L. L.

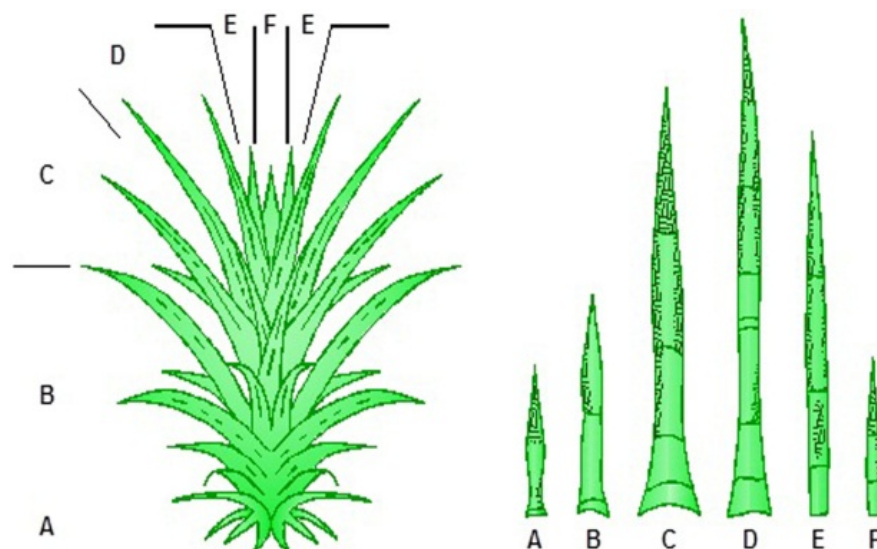


Figure 7. Morphological representation of pineapple tree leaves. Leaf A, the eldest, to F, the youngest. (Adapted from [60]).

As an evaluation parameter for the nutritional state, there are nutrient levels in leaves compared to optimal values, such as in sufficiency ranges or critical levels, presented in tables. Thus, when a nutrient concentration is different from the values presented in those tables, it is suggested that it will limit the plant growth, or productivity and even quality of the fruit.

According to the literature, there are indications of contents of nutrients considered appropriate for the pineapple tree (Table 9). It is observed that there are variations among the nutrients compared to the whole leaf, chlorophyllid and achlorophyllid portion. This fact shows the importance of standards when collecting leaf samples.

Authors								
Nutrients	A	B	C	D*	E**	F***	G	H
-----g kg ⁻¹ -----								
N	10.3	8.8	16.3	13.0-15.0	6.6-9.7	10.9	15.0-17.0	15.0-25.0
P	1.4	1.5	2.1	1.0-1.4	0.3-13.8	2.0	0.8-1.2	1.4-3.5
K	25.0	22.0	20.0	20.0-24.0	3.2-13.8	24.0	22.0-30.0	43.0-65.0
Ca	3.4	3.2	3.9	4.3-7.6	0.9-2.3	6.5	8.0-12.0	2.2-4.0
Mg	3.5	3.1	2.4	2.1-3.6	0.5-1.3	2.2	3.0-4.0	4.1-5.7
S	0.6	0.7	1.3	1.4-1.8	0.4-1.2	1.6	-	-
-----mg kg ⁻¹ -----								
Fe	73.0	65.0	77.0	-	-	118.0	100.0-200.0	80.0-150.0
Mn	149.0	132.0	67.4	-	-	127.0	50.0-200.0	150.0-400.0
Zn	13.6	14.0	14.3	-	-	12.5	5.0-15.0	15.0-70.0
Cu	-	-	4.5	-	-	4.5	5.0-10.0	10.0-50.0
B	-	-	26.0	18.0-30.0	5.5-8.5	22.0	20.0-40.0	-
Productivity (fruits ha⁻¹ x 1000)								
	40	20	-	-	-	-	-	-
Part of the plant analyzed								
-----Whole leaf ¹ -----						Chlorophylled Portion	Achlorophylled Portion	

Source: Adapted from [61]; A and B -[62]; C - [63,64]; D*-[65,66], Cultivation with full fertilization; E**- [65,66], Cultivation with nutrient deficiency; F*** -[67], Contents of nutrients in foliar dry matter from pineapple tree seedling at nine months after seed-plotting of sections from the stem; G-[68]; H- [69].

Table 9. Nutrient contents and ranges observed in foliar dry matter from the pineapple tree in different trials.

DRIS¹ is an alternative technique to evaluate the nutritional state. The critical levels of N, P, K, Ca and Mg were estimated by [70] from the DRIS rules for the "Smooth Cayenne" pineapple tree, in the Bauru – SP region: N (12.0 +/- 0.3⁽²⁾), P (0.92 +/- 0.02), K (21.4 +/- 0.6), Ca (4.0 +/- 0.1), Mg (2.8 +/- 0.1), where (2) is the confidence interval (95% CI) for foliar critical levels estimated by means of a multiple regression between the DRIS indexes and the levels of macronutrients in the leaves.

¹ Integrated System of Diagnosis and Recommendations

4.5. Visual diagnosis

The information on visual symptoms of nutritional deficiencies of the pineapple tree, described hereafter, are reported according to [71].

Potassium deficiency (Figure 8) is characterized by green to dark green foliage, more pronounced with nitrogenized fertilization. The leaves show small yellow dots that grow, multiply and may concentrate on the limb margins. Dryness on the apical extremity also occurs. The plant presents erect port and slightly resistant peduncle. The fruit is small, with low acidity and no aroma.



Figure 8. Symptoms of potassium deficiency in pineapple tree leaves. Photo: REINHARDT, D.H.

Potassium deficiency occurs frequently, except in plantings installed in soils rich in this nutrient. It is favored by unbalanced nitrogen rich fertilization, by strong solar radiation, by intense lixiviation and by soils with increased pH and rich in Ca and Mg. According to [72] potassium fertilization intensifies the color of the skin of ripe fruits, changes the color of the pulp from yellow-straw to golden yellow, increases the content of total soluble solids and acidity and improves the organoleptic characteristics of the fruits, providing a better commercial value.

In [47], fruits with lower levels of sugar, less acids, slightly colored, weaker aroma and little resistant peduncle were observed under potassium deficiency, turning those fruits more susceptible to tipping and sun burning. According to [73], it was described that the visual symptoms of K deficiency are characterized by presenting the apex of the older leaves browned and necrotic. Fruits deficient in K presented a pulp with interior darkening.

As general information, it can be stated that the pineapple tree fertilization should be performed in the vegetative phase of the plant cycle, period in which there is a more efficient use of the nutrients applied. Anyway, caution should be exercised regarding the decision making on applying fertilizers in the reproductive phase of the plant cycle, considering the likelihood of increasing the production costs.

4.6. Effect of potassium fertilizer on pineapple

Potassium is the nutrient required in the largest amount by the pineapple tree and its lack represents not only the decrease in plant growth and production, but also affects the quality of the fruits. Facing the importance of this nutrient for the culture, a research was performed where the main focus was to exploit the effects of potassium fertilization in aspects concerning the production and quality of the fruits.

4.7. Methodology

The experiment was conducted in the period from April 2007 to November 2008, in the sector of agricultural production in the State University of Mato Grosso do Sul, located in Cassilândia, MS, with approximately 471m altitude, 19° 05' S latitude and 51° 56' W longitude. The climate of the region, according to the classification of [74] is considered rainy tropical (Aw), with a rainy summer and dry winter. Considering the tropical climate in the city of Cassilândia which holds minimal temperatures of 11.19 °C to 22.66 °C and maximum temperatures of 28.35 °C to 36.16 °C with annual precipitation of 2000 mm.

The monthly variations of temperature and precipitation occurring during the conduction of the experiment are represented in Figure 9.

For its execution, the experiment was installed in a medium texture soil, with chemical composition during the implantation period of implantation and conduction of the experiment as presented in Table 10.

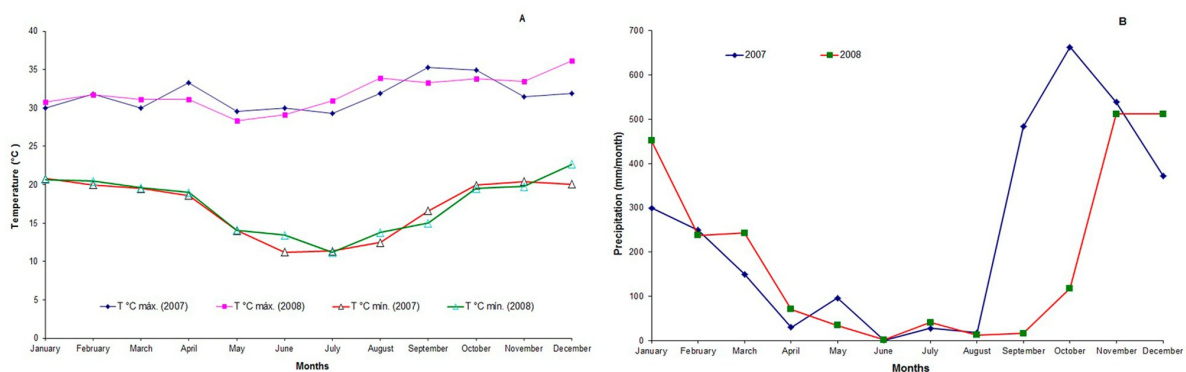


Figure 9. Maximum and minimum temperatures (A) and monthly precipitation (B), during the period of conduction of the experiment. Data provided by Agrometeorological Station from INPE/CPTEC (Instituto Nacional de Pesquisas Espaciais/Centro de Previsão de tempo e Estudos Climáticos).UEMS. Cassilândia, MS, Brazil. 2009.

pH	MO	P	K	Ca	Mg
CaCl ₂	g dm ⁻³	mg dm ⁻³	-----mmol _c dm ⁻³ -----		
5.0	9.0	5.0	1.0	9.0	3.0
S	H+Al	Al	SB	CTC	V
(mg dm ⁻³)	-----mmol _c dm ⁻³ -----				%
4.0	20.0	3.0	12.6	34.8	36.0
Cu	Fe	Mn	Zn	B	
-----DTPA-----				Warm water	
0.4	21.0	46.0	0.8	0.2	

Source: Instituto Brasileiro de Análises – (IBRA AgriSciences). Campinas, SP, Brazil – 2009.

Table 10. Chemical analysis of the soil in layer from 0 to 20cm. Performed by the Instituto Brasileiro de Análises – (IBRA AgriSciences). UEMS. Cassilândia, MS, Brazil. 2009.

For the installation of the experiment, seedlings of the “Pearl” pineapple tree, from the own University matrix mill located in the production sector. In soil preparation, liming was performed to increase the saturation by bases to 50% and the magnesium content to a minimum of 5 mmol_c dm⁻³. The experiment was installed in April 2007, with 0.80 X 0.30 m spacing with a density of 41,666.66 plants ha⁻¹, conducted in single lines. The fertilization in the planting furrow with 140 kg ha⁻¹ P₂O₅ (320 kg ha⁻¹ triple superphosphate) and top-dressing fertilization performed six times during the performance of the experiment with 222.22 Kg ha⁻¹ urea (100 kg ha⁻¹ N), in each fertilization, according to soil analysis (Table 11). For the treatments constitution fertilization, the following doses of potassium (K₂O) were used: 0, 200, 400, 600, 800 kg ha⁻¹, applied in 4 subdivisions, in June and December 2007; March and June 2008.

The control of weeds, plagues and diseases were made during the whole period of the experiment, with herbicide Glyphosate (1 L ha⁻¹), associated to mechanical methods; application of Imidacloprid insecticide 700 WG (30g 100 L H₂O) and Tiametoxam 250 WG (300g 100 L H₂O); fungicide Tebuconazole 200 EC (1L ha⁻¹), respectively. The phytosanitary control was performed specifically to preclude problems related to diseases that enable the bad development of the culture. Floral induction was performed at 13 months of age, period in which the plant obtained enough size and age to respond to respond to floral differentiation stimulation. The product applied was Ethrel 720 (720 g etephon L⁻¹), at the dose of 1.0 L ha⁻¹, being performed late in the afternoon to improve the efficiency of the product.

The experimental design used was random blocks with four repetitions and 5 treatments, with experimental division composed by 7 plants, 5 central plants composing the useful portion. The treatments employed are in Table 11.

Treatments	K ₂ O Rates -----Kg ha ⁻¹ -----	KCl Rates *
1	0.0	0.0
2	200.0	333.3
3	400.0	666.6
4	600.0	1000.0
5	800.0	1333.3

*Potassium chloride (60% K₂O), used in the application of treatments.

Table 11. Treatments used in the experiment with potassium fertilization. UEMS. Cassilândia, MS, Brazil. 2009.

4.8. Results

a. Potassium fertilization and productivity

The results obtained evidenced that the productivity of fruits was influenced by potassium fertilization applied in top-dressing. The regression analysis evidenced a quadratic behavior whose estimated value was 409.38 Kg ha⁻¹ K₂O associated to a productivity of 52,507.30 Kg ha⁻¹ (Figure 10). The quadratic response of the pineapple tree to the KCl doses (Figure 10), may be associated to the depressive effect of the chloride ion, mainly at the higher doses, because according to [75], it is a plant sensitive to chloride toxicity.

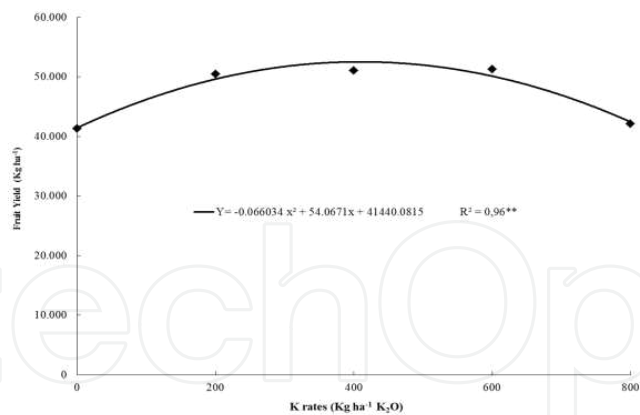


Figure 10. Effect of potassium doses in the productivity of the cultivar Pearl pineapple plant. UEMS. Cassilândia, MS, Brazil. 2009.

According to [42], a positive and significant association was verified within the production of fruits of the "Pearl" pineapple tree. The application of potassium promoted a productivity of 79 t ha⁻¹ of fruits with the estimated dose of 22 g K₂O plant⁻¹.

The potassium content available in the soil and the source used has a promising effect on the way that the pineapple is responsible to potassium fertilization. In an essay performed in the

region of Bauru, in Argisoil with $0.7\text{mmol}_c \text{ dm}^{-3}$ K available, the productivity of the Smooth Cayenne cultivar increased 9.2 t ha^{-1} in response to the application of KCl and 15 t ha^{-1} with the use of potassium sulphate, increases of 18% and 29% related to the control without K application were found, respectively [70]. According to [43, 76], the division of potassium doses in 4 applications during the culture cycle is efficient, regarding the maintenance of fruit quality, and mainly minimizes the losses by lixiviation, increasing the efficiency of the fertilization.

2. Potassium fertilization and fruit quality

In this experiment the quality of the fruits was evaluated from chemical attributes, soluble solids, titratable acidity, *ratio* (SS/AT) and ascorbic acid.

The content of soluble solids estimates the concentration of sugars, which, in most cases, determine the flavor of the fruit. The measurement of soluble solids is used as an indicator of the maturation and quality of the fruits. The fruits destined to *in natura* consumption should have a content of soluble solids higher than 12°Brix [77]. In this experiment the influence of potassium on the soluble solids content, which values ranged from 13 to 13.50°Brix , was not verified. According to observations performed by [78], the soluble solids contents, found in fruits of Smooth Cayenne fruit tree, which varied from 13.74 to 15.50°Brix , were also not directly influenced by K_2O treatments. In a trial performed by [79], the positive effect of potassium fertilization on total soluble solids contents (TSS) was observed, which the application of $490 \text{ kg ha}^{-1} \text{ K}_2\text{O}$ increased the TSS in about 6%.

For the characteristic titratable acidity, the data adjusted to a linear ascending equation related to the dose of K_2O . The maximum value of $1.01 \text{ mL } 100\text{g citric acid}^{-1}$ was found, when associated to the application of $800 \text{ Kg ha}^{-1} \text{ K}_2\text{O}$ (Figure 11). Observations made by [80] indicate that the pineapple fruits subjected to low temperatures, both before and after harvesting, increase the incidence and severity of internal darkening of the fruit (*blacheart* or *internal browning*). It has also been observed that the affected fruits are mildly acid and have low levels of ascorbic acid.

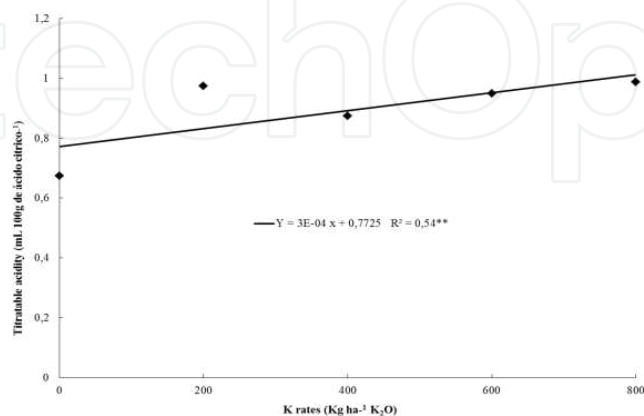


Figure 11. Effect of potassium doses in total titratable acidity of cultivar 'Pearl' pineapple tree fruits. UEMS. Cassilândia, MS, Brazil. 2009.

Regarding the *ratio*, the increment in K_2O doses verified that with the dose increase there was a decrease in the index. The values found were 17.78, with no application of K_2O and 12.78, when the maximum dose was used (800 Kg ha^{-1}). The reduction in the index coupled to potassium dose increments was attributed to a higher increase in acidity related to soluble solids content (Figure 12). This observation corroborates [79], who verified that in Smooth Cayenne pineapple tree, the potassium fertilization acted in two ways in the formation of the *ratio*, as a function of the type of potassium source used. Thus, the increment in titratable acidity was bigger only when KCl was employed as a source of K than the one observed with K_2SO_4 application. Thus, the applications over $400 \text{ Kg ha}^{-1} K_2O$ under the form of KCl, implicated in the production of fruits with a *ratio* below 20. When potassium sulphate was employed as K source, it was possible to employ higher K doses, without the *ratio* being lower than 25.

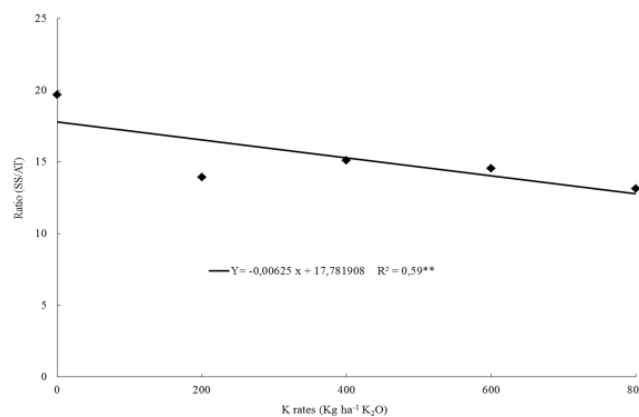


Figure 12. Effect of potassium doses in the *ratio* of cultivar 'Pearl' fruits of pineapple tree. UEMS. Cassilândia, MS, Brazil. 2009.

4.9. Conclusions

With the results obtained, the potassium fertilization coupled with the division of doses met the requirement of the plants, according to its development cycle, mainly at the association of K_2O to the dose of 410 Kg ha^{-1} .

5. Final considerations

For the improvement of the quality of the fruits it is important the use of soil analysis, foliar analysis and visual diagnosis. Those tools are extremely important because they enable the clear evaluation of the availability of potassium and further nutrients available for the plants. Those tools also help in the rational use of fertilizers because besides the producer refraining the waste with excessive fertilization, it does not apply some nutrient that could be limited in production, thus improving the economic results of cultivation with no damages to the environment.

Thereby the efficiency in the use of K is directly related to the direct effects on the amount and quality of fruits, being the handling of the fertilization one of the factors that strongly influences the sustainability in the production of fruit trees. In addition to the choice of K source, strategies should be sought for the handling of solo-plant systems that minimize the loss of this nutrient, taking the example of dose division, minimizing losses by lixiviation.

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