POTASSIUM FERTILIZATION FOR PINEAPPLE: EFFECTS ON PLANT GROWTH AND FRUIT YIELD[1]

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ABSTRACT – A field experiment with pineapple (Smooth Cayenne) was carried out on an Ultisol located in the city of Agudos (22º30'S; 49º03'W), in the state of São Paulo, Brazil, with the objective of investigating the effects of rates and sources of potassium fertilizer on plant growth and fruit yield. The experiment was a complete factorial design (4x3) with four rates (0, 175, 350, and 700 kg ha^{-1} of K_2O) and three combinations of K sources (100% KCl, 100% K_2SO_4, and 40% K_2SO_4 + 60% KCl). Plant growth and fruit yield were evaluated. Biomass accumulation of pineapple plants was impaired by chlorine added with potassium chloride. Fruit yield increased with potassium fertilization. At high rates of K application, fertilization with K_2SO_4 showed better results than with KCl. Detrimental effects of KCl were associated with excess of chlorine.
Index terms: potassium chloride, potassium sulphate, *Ananas comosus*, K.

ADUBAÇÃO POTÁSSICA EM ABACAXIZEIRO: EFEITOS NO CRESCIMENTO DAS PLANTAS E NA PRODUÇÃO DE FRUTOS

RESUMO – Foi realizado um experimento de campo com abacaxizeiro Smooth Cayenne num Argissolo Vermelho-Amarelo localizado em Agudos-SP (22º30'S; 49º03'W), com o objetivo de determinar os efeitos de doses e fontes de potássio no crescimento e produção das plantas. O experimento foi estabelecido em blocos casualizados com os tratamentos dispostos em arranjo fatorial (4x3), com quatro doses (0; 175; 350 e 700 kg ha^{-1} of K_2O) e três combinações de fontes de K (100% KCl, 100% K_2SO_4 e 40% K_2SO_4 + 60% KCl). Foram avaliados aspectos do crescimento e produção de frutos. A acumulação de biomassa pelas plantas foi prejudicada pelo cloreto fornecido com o uso de KCl. A produção de frutos aumentou em resposta à adubação potássica. Com as maiores doses de K, a aplicação de K_2SO_4 mostrou-se mais vantajosa do que a de KCl. Os efeitos negativos do KCl foram associados ao excesso de cloreto para o abacaxizeiro.
Termos para indexação: cloreto de potássio / sulfato de potássio / *Ananas comosus* / K.

INTRODUCTION

Brazil is one of the world greatest growers of pineapple producing around 2.5 million tons in 2008 (FAO, 2010). Despite the importance of potassium fertilization for this crop, there is a lack of information about effects of different sources of K on fruit yield. According to results reported by Paula et al. (1991), Souza (1999a) and Spironello et al. (2004), fruit yield of pineapple is very responsive to potassium fertilization in Brazil.

The principal fertilizer compound containing potassium used in Brazil is potassium chloride (KCl). Potassium sulphate (K_2SO_4) is also used but it is restricted to some chlorine-sensitive crops, like tobacco and potato. In fruit crops, it is known that the choice of K source has consequences on yield and quality of pineapples, kiwifruit, grape and citrus among other fruits (KLEINHENZ, 1999). Marchal et al. (1981) observed that pineapple fertilization with KCl decreased dry extract (a measure of sugar content) and flesh color, increased acidity, and reduced fruit yield as compared to K_2SO_4. At the same time, Cl^- may cause leaf scorch in certain conditions. On the other hand, chlorine increases fruit acidity and KCl may be recommended (1/4 to 1/3 of total rate) when fruits lack acidity (Py et al., 1984).

Regardless of depressive effects of chlorine on pineapple plant growth and fruit yield described in several studies (SAMUELS; GANDÍA, 1960; LACOEUILHE, 1978; MARCHAL et al., 1981 and ZEHLER et al., 1986), KCl has been the main potas-

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sium source for pineapple in Brazil due to its lower price compared with K_2SO_4 (SOUZA, 1999a). Furthermore, Hepton (2003) stated that the better effects of K_2SO_4 are not universal, and considerable areas of pineapple fertilized with KCl with do not show any apparent adverse effect on either yield or fruit quality. To solve this issue in any particular growing area, Hepton (2003) recommended that comparative trials testing K sources should be established. So it is necessary to assess the effect of total or partial replacement of KCl by K_2SO_4 on yield and on some important characteristics of the pineapple fruit before more expensive K sources be recommended.

The objective of the present study was to evaluate the effects of rates and sources of potassium fertilizer on pineapple growth and fruit yield.

MATERIAL AND METHODS

The field was planted in June 2003, on a sandy and low fertility Ultisol located at the city of Agudos (22º30'S; 49º03'W), State of Sao Paulo, typical of this important pineapple production region in Brazil. The soil prior to set up of the experiment presented the following chemical characteristics: pH($CaCl_2$) 4.1; organic matter 17 g dm^{-3}; P_{resin} 6 mg dm^{-3}; exchangeable K, Ca, and Mg 0.7, 3.0, and 2.0 $mmol_c$ dm^{-3}, respectively, H+Al 38 $mmol_c$ dm^{-3} and soil base saturation 13%.

The experiment was set up using a complete factorial design (4x3) with four rates (0; 175; 350, and 700 kg ha^{-1} of K_2O) and three combinations of K sources (100% KCl; 100% K_2SO_4, and a combination of 40% K_2SO_4+60% KCl), with four blocks (replications). In the combined treatment, 40% of K rates, as K_2SO_4, were split in the first two applications and 60% of K rates were applied as KCl in the last two applications.

Phosphorus was applied 30 days after planting (80 kg ha^{-1} of P_2O_5 as single superphosphate-SSP). Nitrogen (600 kg ha^{-1} of N), as ammonium nitrate and potassium rates were split in four applications along pineapple cycle according to recommendations of Spironello and Furlani. (1997). Fertilizers were surface applied, close to plant base, on an area of maximum root activity. Three months before planting, the soil was limed. Lime requirement was calculated to increase the soil base saturation to 50% of the CEC at pH 7.0 according to Spironello and Furlani (1997).

The plots were composed of three double rows (0.5 m by 1.15 m) 8 m long, summing up 39.6 m^2. The plant spacing within the rows was 0.4m, resulting in a plant population of about 34600 plants ha^{-1}. Selected slips of the 'Smooth Cayenne' variety previously treated with fungicides and pesticides were planted. Seven meters (approximately 35 plants) of central double row was sampled for evaluations.

Flower induction occurred spontaneously in about 65-85% of the plants. The remaining plants were artificially induced to flower with 3 L ha^{-1} of Ethrel® (Etephon 21.7%) + urea (2%) in September 2004, approximately 15 months after planting.

Pineapple plant growth evaluations, such as shoot plant and D-leaf mass and percentage of flowering (natural induction), were done in September 2004. Shoot plant dry matter was evaluated weighing five plants per plot. D-leaf measurements were done with 10 leaves. D-leaf S, K and Cl contents were analyzed according to Bataglia et al. (1983). Leaf area was assessed using the total leaf dry matter per plant and the weight of 70 leaf disks with known area.

Fruits were harvested in January 2005, 19 months after pineapple was planted. Fruits were picked when bottom eyes turned from pale-green color to yellow. They were harvested by hand, breaking off stalks of fruits. All fruits of central double line were harvested, counted and weighed.

The effects of treatments (sources and rates of K) were evaluated using analysis of variance (ANOVA). When the effects of K sources were statistically significant ($p<0.05$ for the F test), differences among sources were compared with Tukey multiple range test ($\alpha=0.05$). Regression equations were fit for the variables significantly affected by rates of K. Only models (equations) statistically significant ($p<0.05$) were presented. If the interaction between sources and rates was significant, the regressions for rates were done by sources.

In order to compare the profitability of K fertilization with different K sources, income increase due to K application was calculated. For this comparison, the fruit price (FOB) was R$852.00 Mg^{-1}, KCl cost R$ 1442.00 Mg^{-1} and K_2SO_4 cost R$ 2332.00 Mg^{-1} (average prices from 2004 to 2009). All these prices were collected in April, 2010, when $1USD=R$ 1.80.

RESULTS AND DISCUSSION

Plant growth

Biomass accumulation, leaf area and D-leaf mass of pineapple plants were significantly affected by sources of potassium (Table 1). A linear increment of plant mass was observed in response to K application as K_2SO_4 and K_2SO_4+KCl (Figure 1). With the application of 700 kg ha^{-1} of K_2O as KCl, shoot plant dry matter was increased 56 g in comparison with control treatment. For the same K rate, the treatment with K_2SO_4+KCl showed a positive variation of 112 g per plant. According to these data, K_2SO_4 seems to be more efficient than KCl to increase plant size. Those gains in dry matter accumulation is important because fruit weight is usually correlated with plant mass at pineapple flowering as indicated by Bartholomew et al. (2003) and Hepton (2003). Leaf area was affected by treatments in the same manner as plant mass (Figure 2).

It was observed that pineapple plant mass decreased linearly as Cl-leaf increased (Figure 3). No chlorine damage symptoms were found on the leaves, but K fertilization with KCl decreased biomass accumulation as compared to K_2SO_4 (Table 1). So, probably, the negative effects on plant growth of K fertilization using KCl may be related to the increase of chlorine availability on soil. These results corroborate to those reported by Lacoeuilhe (1978), Zehler et al. (1986) and Kleinhenz (1999).

The spontaneous flowering (Figure 4) was delayed by increasing K application as KCl, as demonstrated by the percentage of plants flowered on September 2004 (natural induction). The use of K_2SO_4 did not cause any significant delay on plant flowering. Delaying flowering frequently result in bigger pineapple plants and consequently, improved fruit size and quality. But in this case, postponement of flowering probably is due to detrimental effects of chlorine on plant development, as cited by Zehler et al. (1986).

In general, the use of K_2SO_4 as potassium source on pineapple nutritional program promoted superior results on pooled variables related to plant growth, compared with KCl. These effects are probably associated with excess of chloride, which may reduce leaf size and plant growth rate as previously reported by Eaton (1973). Although K_2SO_4 is also a source of S, the correlation between S-leaf content and fruit yield was not significant ($p>0.05$). The effect of S carried by K_2SO_4 may be also diminished by the use of single superphosphate (11% S) as a source of P at planting.

Fruit yield

As pointed by Hepton (2003), it is necessary to have pineapple plants with satisfactory dry matter accumulation before forcing in order to attain adequate fruit size for fresh market or canning. A significant relationship was observed between plant mass at forcing and fruit yield (Figure 5). So, the effects of K fertilization on plant growth showed strong relation with fruit yield.

Fruit yield of pineapple plants showed positive responses to K fertilization. Fruit production increased linearly in response to potassium applied as K_2SO_4 or K_2SO_4+KCl, whereas for KCl, fruit yield changed in a quadratic manner as shown in Figure 6. Fruit yield was strongly correlated with the amount of K built up in D-leaf (D-leaf weight X K concentration) demonstrating the importance of potassium for pineapple nutrition and production (Figure 7). These results are in agreement with those reported by Paula et al. (1991), Souza (1999b) and Spironello et al. (2004) in Brazil.

The yield of fresh fruit without K fertilization was approximately 51.6 Mg ha^{-1}. Maximum yield (MY) of fresh fruit was 66.6 Mg $^{-1}$ and 63.8 Mg $^{-1}$ attained with application of 700 kg ha^{-1} of K_2O as K_2SO_4 and K_2SO_4+KCl, respectively. For KCl, the maximum fruit yield of 60.9 Mg ha^{-1} was reached with the rate of 525 kg ha^{-1} of K_2O (Figure 6). The quadratic response of pineapple yield to rates of KCl may be associated to excess of chlorine mainly at the higher rates of K. Pineapple has been considered chlorine sensitive according to Teiwes and Grüneberg (1963) and Kleinhez (1999). The relationship among the K leaf and the Cl leaf contents and fruit yield (Figure 8) also supports the positive effect of potassium and the detrimental effects of chlorine.

The relation between K fertilization and fruit yield (Figure 6) showed a reasonable agreement with fertilizer recommendations for pineapple crop in the State of São Paulo proposed by Spironello & Furlani (1997). For an expected yield higher than 50 Mg ha^{-1} and soil K lower than 0.15 $mmol_c$ dm^{-3}, it is recommended to apply 600 kg ha^{-1} of K_2O. This recommendation is between the rate to achieve maximum yield with KCl (525 kg ha^{-1} of K_2O) and the rate of K_2SO_4 or KCl + K_2SO_4 (700 kg ha^{-1} of K_2O) that gave rise to maximum fruit yield.

The yield increase due to the use of 700 kg ha^{-1} of K_2O as K_2SO_4, in comparison to KCl was 5.7 Mg ha^{-1}, equivalent to approximately R$ 4 900.00 ha^{-1}. It was sufficient to pay back the higher cost of K_2SO_4 of R$ 2 086.00 ha^{-1} due to application of 700 kg ha^{-1} of K_2O as K_2SO_4 instead of 491 kg ha^{-1} of K_2O as KCl (Table 2). The higher cost of K_2SO_4 was balanced by the increase of fertilizer efficiency especially for the highest rate of application. Fertilizer efficiency for K_2SO_4 was around 2 000 kg ha^{-1} of fruits per each 100 kg ha^{-1} of K_2O, slightly higher than for K_2SO_4+KCL, while fertilizer efficiency for the rate of 700 kg ha^{-1} of K_2O as KCl was approximately 1 400 kg ha^{-1} of fruits per each 100 kg ha^{-1} of K_2O. In terms of net profit due to K application, the combination of K sources for pineapple is also feasible. To apply approximately 40% of recommended K as K_2SO_4 (first two applications) and the rest as KCl merged agronomical advantages of K_2SO_4 with the lowest cost of KCl.

TABLE 1 - Means of plant mass, leaf area, D-leaf mass and flowering for potassium sources, 15 months after pineapple planting.

Source of K	Plant mass[1]	Leaf area[2]	D-leaf mass[1]	Flowering
	g	m^2	g	%
KCl	362 b[3]	1.16 b	7.4 ab	72 a
K_2SO_4	413 a	1.30 a	7.8 a	77 a
K_2SO_4+KCl	376 ab	1.18 ab	7.2 b	75 a

[1] Dry matter mass of one plant. [2] Leaf area of one plant. [3] Within columns, values followed by the same letter indicate that K sources are not significantly different according to Tukey's test ($p<0.05$).

TABLE 2 - Economic analysis of pineapple K fertilization for the experiment conditions.

Source[1]	Rate[2]	Yield[3]	Gross income[4]	Cost of K fertilization[5]	Yield increase[6]	Income increase[7]	Net profit of K fertilization[8]
	kg ha^{-1} K_2O	Mg ha^{-1}	---------- R$ ha^{-1} ---------		Mg ha^{-1}	----------- R$ ha^{-1} ----------	
--	0	51.6	44 019	0	0	0	0
K_2SO_4	700(MY)	66.6	56 736	3 265	14.9	12 717	9 452
KCl+K_2SO_4	700(MY)	63.8	54 395	2 315	12.2	10 376	8 061
KCl	525(MY)	60.9	51 878	1 261	9.2	7 859	6 598
KCl	491(MPY)	60.8	51 837	1 179	9.2	7 818	6 639

[1] KCl+K_2SO_4: 60% KCl + 40% K_2SO_4. [2] MY: maximum yield – K rate to reach highest possible yield; MPY: maximum profit yield - K rate to get the highest net return with fertilization. [3] Yield per ha (pineapple fruit+crown). [4] Yield X fruit price (FOB) (R$ 852.00 Mg^{-1} – average price 2004 to 2009). [5] KCl=R$ 1442.00 Mg^{-1}; K_2SO_4=R$ 2332.00 Mg^{-1} (average price 2004 to 2009); [6] Yield increase compared to control treatment without K. [7] Gross income increase compared to control treatment. [8] Gross income increases due to K use minus cost of K fertilization. Prices collected in April, 2010, when $1USD=R$ 1.80.

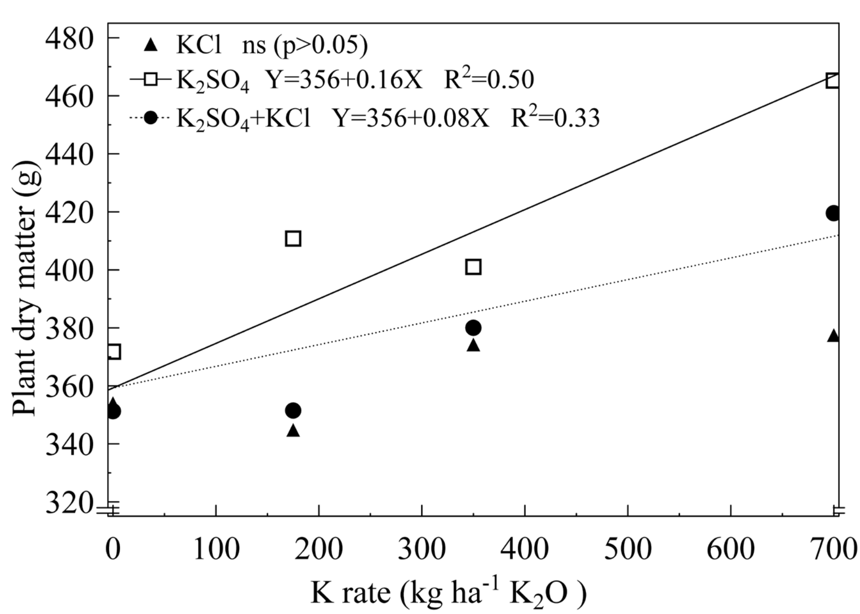

FIGURE 1 - Dry matter mass of pineapple plants influenced by rates and sources of potassium. Sampling in September, 2004.

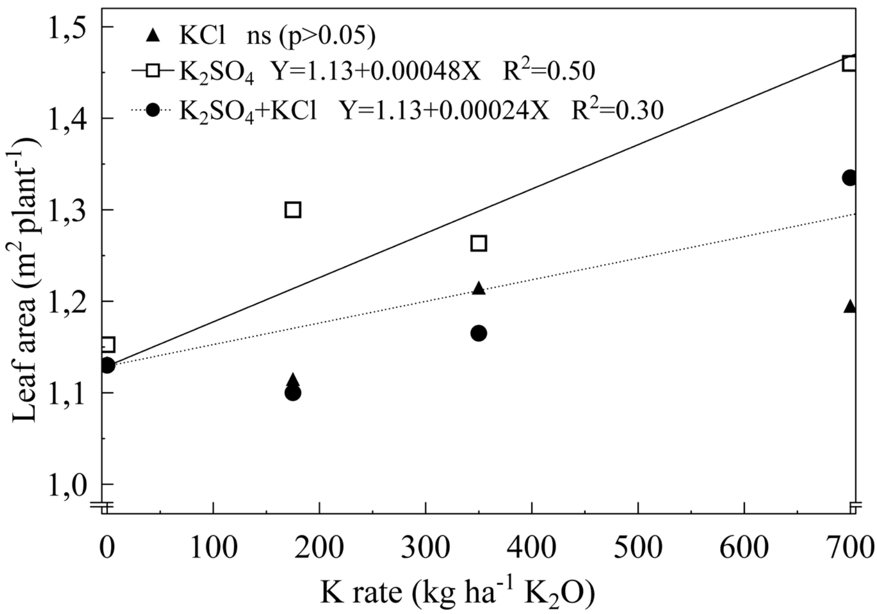

FIGURE 2 - Leaf area of pineapple plants influenced by rates and sources of potassium. Sampling in September, 2004.

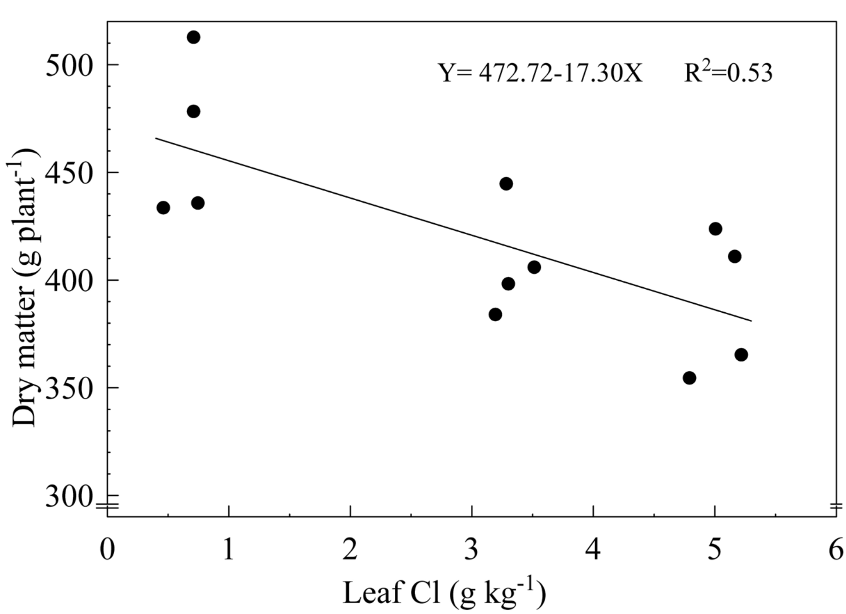

FIGURE 3 - Dry matter mass of pineapple plants as a function of "D" leaf Cl content at the rate of 700 kg ha^{-1} K_2O. Sampling in September 2004.

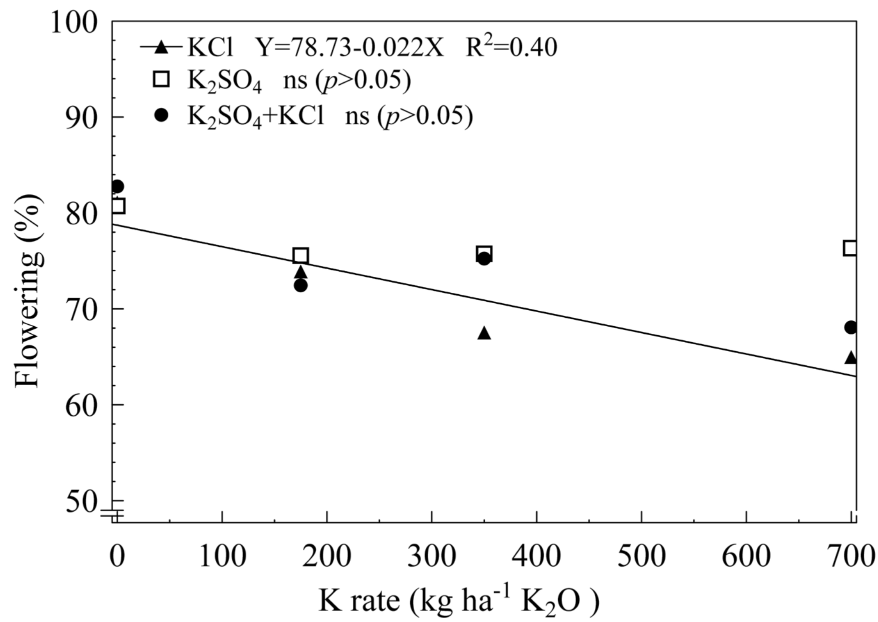

FIGURE 4 - Pineapple spontaneous flowering as influenced by rates and sources of potassium. Sampling in September 2004.

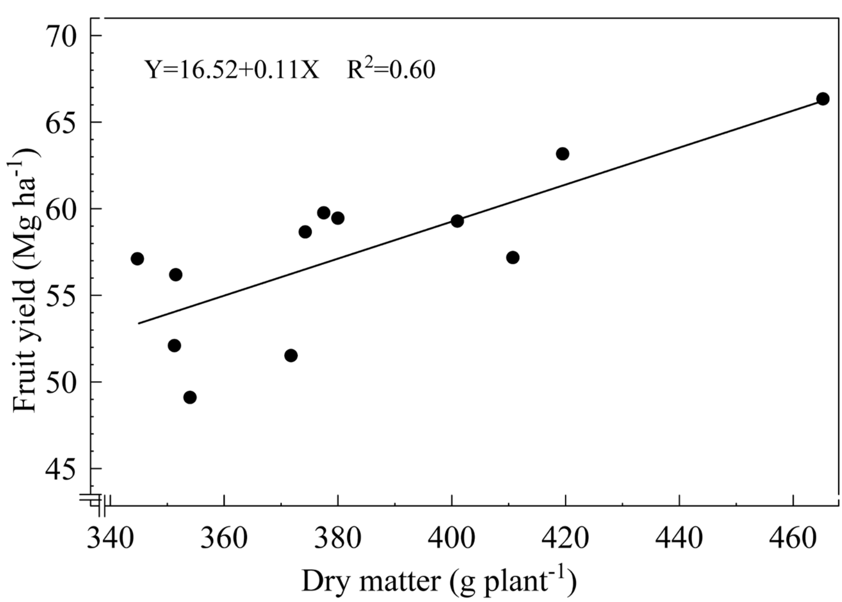

FIGURE 5 - Fruit yield as influenced by dry matter accumulation of pineapple plants at forcing.

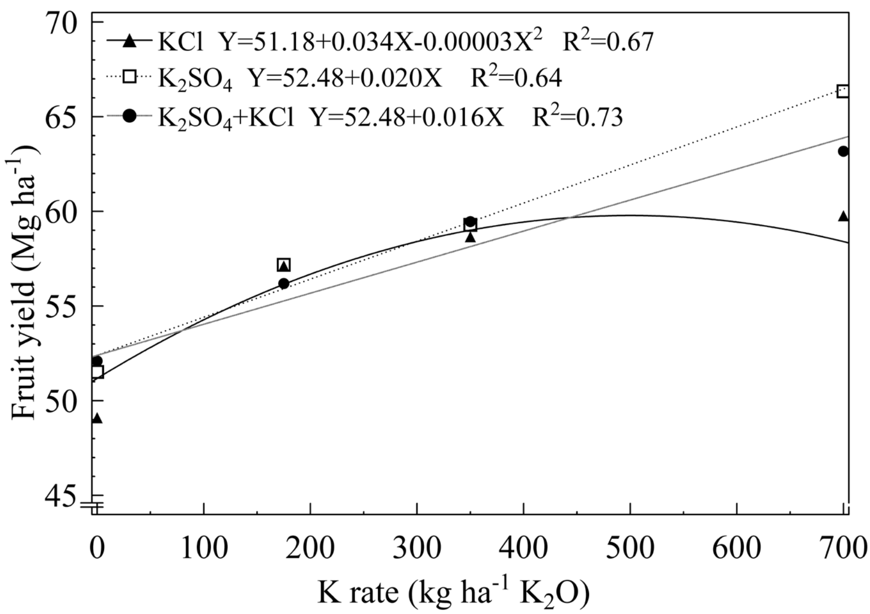

FIGURE 6- Fruit yield as influenced by rates and sources of potassium. Sampling in January 2005, 19 months after pineapple was planted.

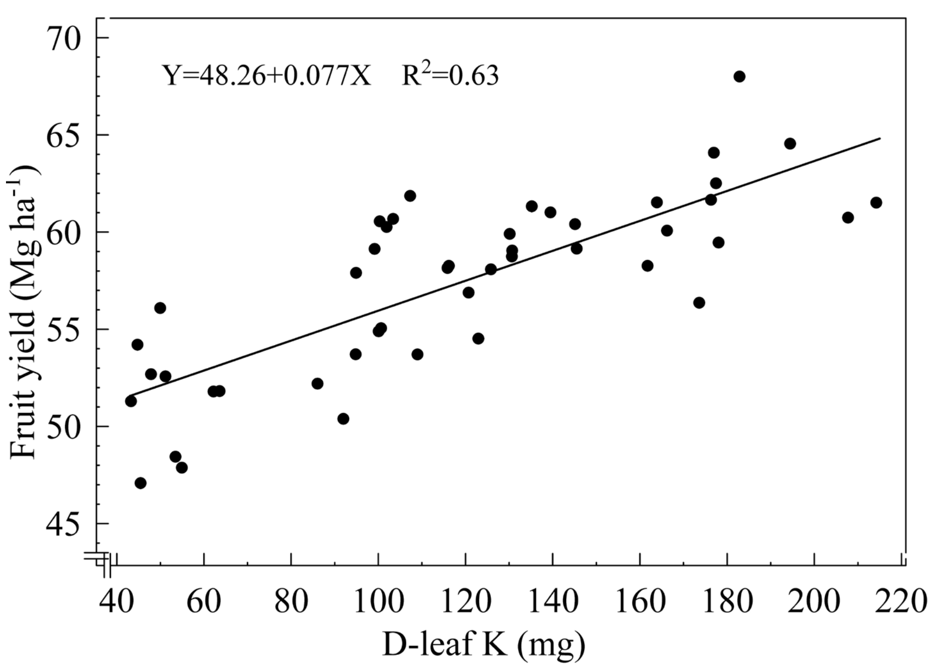

FIGURE 7 - Relationship between fruit yield and D-leaf K amount.

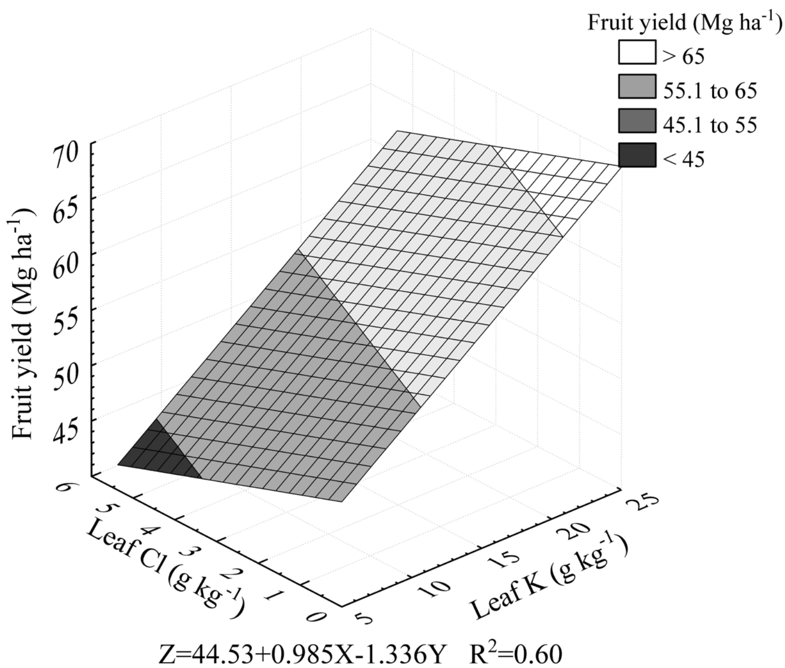

FIGURE 8 - Relationship between fruit yield of pineapple plants (Z), leaf K (X) and leaf Cl (Y) contents.

CONCLUSIONS

1-Pineapple plants showed a positive yield response to K applications. At high rates of K application, fertilization of pineapple with K_2SO_4 showed better results than with KCl. Detrimental effects of KCl were associated with the excess of chlorine.

2-The profit of fertilization of pineapple with K_2SO_4 (exclusively or combined with KCl) was higher than using only KCl as K source at the experiment conditions.

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