Effect of the application of potassium on the yield of corn (*zea mays* L.) in La Frailesca, chiapas Mexico

Efeito da aplicação de potássio na produção de milho (*zea mays* L.) em La Frailesca, chiapas, México

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ABSTRACT
In recently soil analysis in La Frailesca Chiapas, it has been detected that most soils have low exchangeable potasium (K) concentrations, therefore maize plants show symptoms of deficiency of this nutrient, which can affect the yield. The maize response was evaluated at four doses of K (0, 90, 180 and 270 kg K2O ha-1) in three locations with non-acid soils. A randomized block design with five replications was used, and potassium chloride (KCl) as a potassium source. KCl was applied by manual broadcasting and was incorporated to the soil 10 and 15 cm deep with a disc harrow. In all three locations a significant positive response was observed ($p < 0.05$) to which a lineal-plateau model was adjusted, with an average increase in yield of 1 964 kg ha-1 (150% higher than without K) with 90 kg K2O ha-1. No response was observed to higher doses. The regression equation for the linear part of the response model is: Yield (kg ha-1) = 3 855 + 22 kg K2O ha-1. The agronomic efficiency of K at the dose of 90 kg K2O ha-1 was higher than the reference range (7 to 15 kg grain.kg-1 K2O). At the same time, this treatment had the highest net benefit and a marginal rate of return of 370%. Under the conditions of this study, the application of 90 kg K2O ha-1 presented the highest yield, economic benefit and agronomic efficiency.

Keywords: potasium, maize, chiapas.

RESUMO
Em análises recentes do solo em La Frailesca Chiapas, foi detectado que a maioria dos solos têm baixas concentrações de potássio (K) permutáveis, pelo que as plantas de milho apresentam sintomas de deficiência deste nutriente, o que pode afectar o rendimento. A resposta do milho foi avaliada em quatro doses de K (0, 90, 180 e 270 kg K2O ha-1) em três locais com solos não ácidos. Foi utilizado um desenho de blocos aleatórios com cinco réplicas, e cloreto de potássio (KCl) como fonte de potássio. O KCl foi aplicado por difusão manual e foi incorporado no solo a 10 e 15 cm de profundidade com uma grade de discos. Nos três locais foi observada uma resposta positiva significativa ($p < 0,05$) à qual foi ajustado um modelo lineal-plateau, com um aumento médio no rendimento de 1 964 kg ha-1 (150% mais elevado do que sem K) com 90 kg K2O ha-1. Não foi observada qualquer resposta a doses mais elevadas. A equação de regressão para a parte linear do

modelo de resposta é: Rendimento (kg ha-1) = 3 855 + 22 kg K2O ha-1. A eficiência agronómica de K na dose de 90 kg K2O ha-1 foi superior à gama de referência (7 a 15 kg grão.kg-1 K2O). Ao mesmo tempo, este tratamento teve o maior benefício líquido e uma taxa de rendimento marginal de 370%. Nas condições deste estudo, a aplicação de 90 kg de K2O ha-1 apresentou o maior rendimento, benefício económico e eficiência agronómica.

Palavras-chave: potássio, milho, chiapas.

1 INTRODUCTION

The region of La Frailesca is one of the most important for agriculture in the state of Chiapas because 179,000 hectares of corn are planted there, representing 17% of the state surface, with an average yield of 2.2 t ha^{-1} (Cadena *et al.*, 2009; SIAP, 2014).

Among the main problems that affect corn yield is low soil fertility, due, among other reasons, to the low amounts of nutrients they contain, as a result of their loss due to soil erosion and unbalanced fertilization practices.

In Mexico, a positive effect of potassium on corn grain yield has not been observed, or this effect has been very low (Maya and Ramírez, 2002). In the Frailesca region of Chiapas, until recent years it was considered that the soils had sufficient amounts of potassium (K) to meet the nutritional needs of maize, so this nutrient was not included in the technical recommendations for fertilization doses.

Recent and multiple soil analyzes carried out in joint projects of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), the International Plant Nutrition Institute (IPNI) and the International Maize and Wheat Improvement Center (CIMMYT) have shown that in most of the soils of La Frailesca, even in fluvisol soils considered to be of high productivity, there are low concentrations of exchangeable K that do not allow to meet the needs of maize (Camas *et al.*, 2015; Camas, 2015).

Therefore, it is common to see plants with symptoms of deficiency of this nutrient, such as an initial striped chlorosis in the oldest leaves from the tip and along its entire edge, which later turns yellow and necrosis. Despite detecting these problems, there has been a lack of experimental work to determine the response of this crop to applications of K.

In 2014, significant responses were observed in acid soils to the simultaneous application of K with amendments to correct acidity, confirming the hypothesis that correcting acidity and adding calcium (Ca) and magnesium (Mg) (in the case of dolomitic

lime) or Ca alone (by adding gypsum) conditions conducive to a better use of K are created (Tasistro and Camas, 2015). The present study deals with the response of maize to K in non-acidic soils, and is part of a project whose objective is to improve the nutritional management of maize in La Frailesca, Chiapas.

2 MATERIALS AND METHODS

The work was carried out during the Spring-Summer 2015 cycle in three locations in the municipality of Villaflores, Chiapas, selected for having soils with aluminum (Al) saturation below the critical level for corn, estimated at 20% (Tasistro, 2012). And low contents of available K in the soil (Soil Fertility Commission-RS/SC, 1997; Sawyer et al., 2002) (Table 1). The following determinations were made to the soil samples: pH 1:2 in water, exchangeable Al extracted with KCl 1 N, Ca, Mg, K and sodium (Na), extracted with ammonium acetate 1 N pH7 (Knudsen *et al.*, 1982). The experimental design used was a randomized block design with five replications, and the treatments were: 0, 90, 180 and 270 kg K_2O ha^{-1}, using K chloride as a source. Each plot had 8 rows 0.8 m apart and 6 m long.

Table 1. Exchangeable potassium, calcium, magnesium and sodium content, pH_{water} and saturation of exchangeable aluminum in the soils of the three localities.

Location	Depth (cm)	pH_{water}	K	Ca	Mg	Al	CICe	K	Ca	Mg	Al
			$cmol_c$ kg^{-1}					% saturation			
Humberto	0-15	5	0.2	2.3	0.7	0.8	4	5	58	18	20
	15-30	5	0.2	2.8	0.6	0.9	4.5	4	62	13	20
Esperanza	0-15	5	0.1	4.1	1.2	0.3	5.7	2	72	21	5
	15-30	5.4	0.1	8.2	1.9	0.1	10.3	1	80	18	1
Aladino	0-15	5	0.4	1.5	0.7	0.5	3.1	13	48	23	16
	15-30	5	0.3	2.4	0.9	0.5	4.1	7	59	22	12

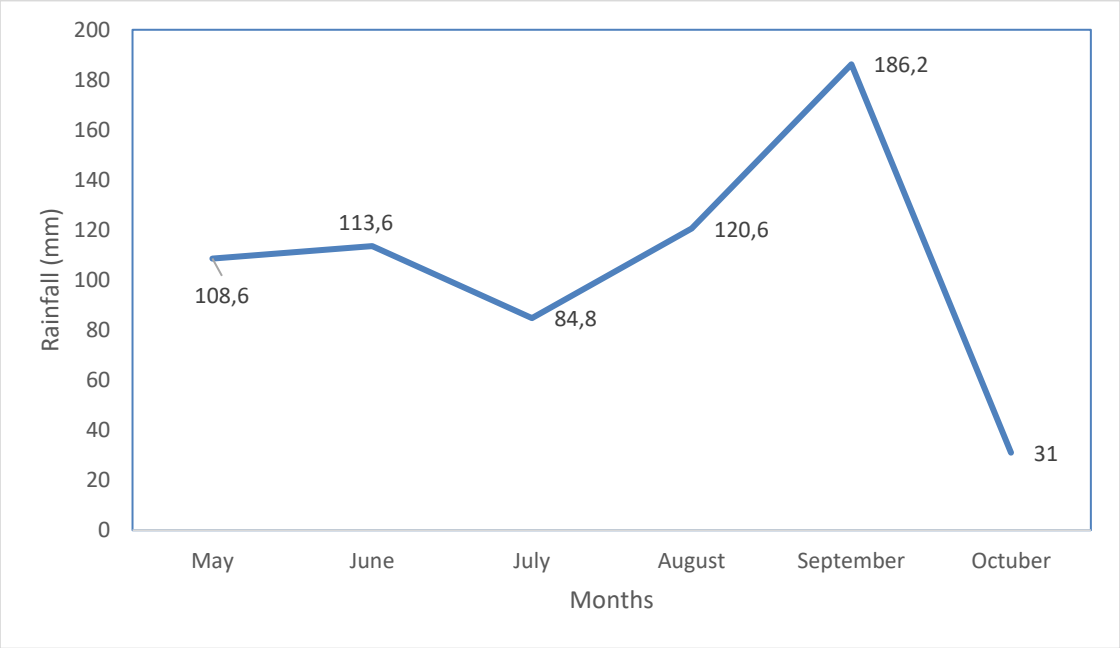
Soil preparation was done conventionally with two crawls at a depth of 10 to 12 cm. The treatments were applied broadcast and incorporated with the second screening.

83,333 seeds ha^{-1} of corn 'H-516' were sown manually. In all locations, a basic fertilization was applied with 200 kg of nitrogen (N) ha^{-1} and 60 kg of P_2O_5 ha^{-1}, using urea and diammonium phosphate for N and diammonium phosphate for P as sources. 20% of the N at sowing, 40% in V5 and 40% in V10. All the phosphorus was applied together with the first application of N. In all cases the fertilizers were covered. Provided efficient weed and pest control.

Between May and October, the total rainfall was 644.8 mm, which represents 68% of the annual average in the region (Figure 1), with low rainfall during the months of June

to August, coinciding with the maize development stage until flowering. In addition, the rains were erratic, that is, there were rainy events every 15 days or more in some areas. Due to the fact that in the Esperanza locality there was access to water, an auxiliary irrigation was provided when the plant was between R1-R2.

Figure 1. Total monthly rainfall between May and October 2015 in the Municipality of Villaflores, Chiapas.



Yield was evaluated in the four central rows 4 m long and adjusted to 14% humidity. Statistical analysis of the data was performed using Genstat v. 18 © (Genstat, 2016) and SigmaPlot v. 13 © (SigmaPlot, 2016). The agronomic efficiency of applied K_2O (EAK) was evaluated, defined by the kg of grain produced per kg of K_2O applied. An economic analysis was performed using a partial budget, dominance analysis and marginal rate of return (CIMMYT, 1988).

3 RESULTS AND DISCUSSION.

The analysis of variance of the corn yield indicated highly significant effects of the localities and the doses of K_2O application, with the response to the nutrient being similar between localities. Yields increased in response to the application of 90 kg K_2O ha^{-1}, without showing significant variations with the application of higher doses (Table 2). This differs from what was obtained by Maya and Ramírez, 2002, who did not find a response at 120 and 140 K units, only that in this case they did not verify that the sites presented limiting levels of that element, as it was in our case. On the other hand, Tosquy

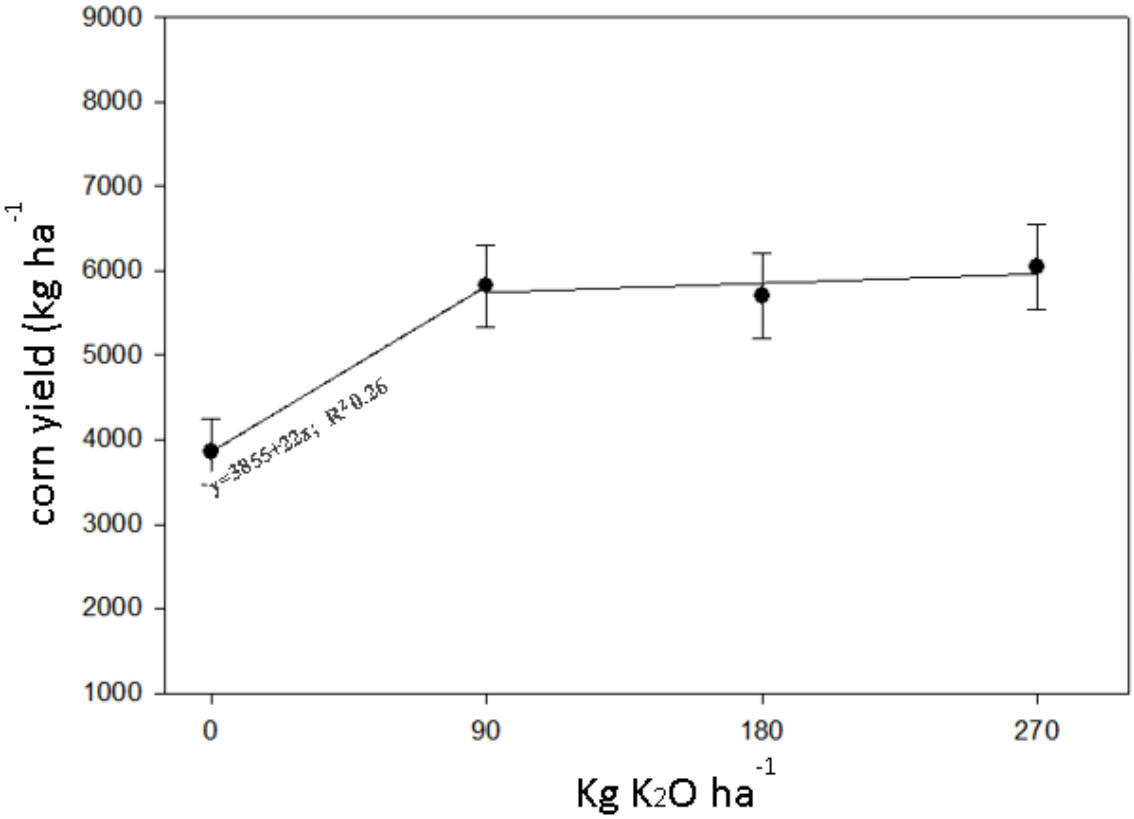
and Castañon, 1998 found an effect of potassium to increase grain yield even when increasing plant density.

Table 2. Effect of the application of four doses of K on the yield of three locations

K_2O (kg ha^{-1})	Location		
	Humberto	Esperanza	Aladino
	(kg of corn ha^{-1})		
0	4528	4725	2311
90	5972	7746	3739
180	6032	7538	3539
270	6215	8229	4278
Coefficient of variation (%)	12	11	23
Minimum Difference significant (5%) (kg ha^{-1})	906	1049	1096

A linear and Plateau model was fitted to the combined yield response to K in the three locations (Fig. 2). In the linear portion, the corn yield grew by an average of 22 kg grain kg K_2O^{-1}.

Figure 2. Response of corn production to the application of potassium. (bars indicate standard errors).



In the three locations, a significant positive response ($p<0.05$) was observed in yield when applying 90 kg ha^{-1} of K_2O without significant changes ($p>0.05$) when increasing to 180 and 270 kg. The greatest increase occurred in the towns of Aladino and

Esperanza. In the latter, which presents the lowest levels of K, the effect was similar to that detected by Barbazán *et al.*, 2011, who found a response to the application of K in soils with low levels of exchangeable K (less than 0.20 meq/100 g), but as the amount of K increased, the responses decreased. Also the greatest response was influenced by the relief irrigation provided.

On average, the increase in yield obtained with 90 kg ha^{-1} of K_2O was almost 2 t ha^{-1} (1,964 kg ha^{-1}). This increase, verified under conditions of severe stress caused by drought and high temperatures, demonstrates the versatile capacity of the crop to take advantage of the applied K and suggests that at least part of the beneficial effect of K has also been expressed in the improvement of the capacity of the maize to better withstand the adverse environmental conditions that prevailed during the study cycle. In this sense, it is worth remembering that when K is in adequate amounts and balanced with other nutrients, the growth and proliferation of roots is greater, those that penetrate deeper into the soil and have greater access to water, resulting in plants with higher K content that require less water to produce a given yield (Marschner, 1995; IPI, 1977).

The agronomic efficiency of K (EAK) was evaluated at a dose of 90 kg K_2O ha^{-1}, since no response was detected at higher doses (Table 3). The EAK in the three localities reached values higher than the range considered typical by Fixen *et al.*, (2015) (7 to 15 kg grain kg K_2O^{-1}), being particularly high in the Esperanza locality, where irrigation was available. . In this regard, (Dobermann, 2007) mentions that these efficiencies are realistic for soils lacking high reserves of available K. Considering the value of 0.2 cmol+ K kg^{-1}, as the critical level (Black, 1993).

The economic analysis based on a partial budget showed that the treatment of 90 kg ha^{-1} of K_2O is the most suitable, because it presented the lowest variable cost and the highest net benefit. Due In the absence of yield increases in the 180 and 270 kg K_2O ha^{-1} treatments, these are economically dominated since they present a greater increase in variable costs but less net benefit (Table 4).

Table 3. Agronomic efficiency (kg grain kg K_2O^{-1}) of potassium applied to 90 kg of K_2O ha^{-1} in three localities**.**

	Location		
	Humberto	Esperanza	Aladino
Agronomic efficiency (kg grain kg K_2O^{-1})	16.0	33.6	15.9

The treatment of 90 kg ha^{-1} of K_2O presented a marginal rate of return of 370%, which is very attractive economically since if the producer decided to apply that amount of K_2O for every $1.0 invested, he could recover the $1.0 invested and an additional $3.7.

Table 4. Partial budget for the application of four doses of K_2O in corn.

	kg K_2O ha^{-1}			
	0	90	180	270
Average yield (kg/ha)	3855	5819	5703	6241
Adjusted yield (kg/ha)	3470	5237	5133	5617
Gross field benefit ($/ha)	10621	16549	16175	17909
K chloride cost ($/ha)		990	1980	2970
K chloride freight to community ($/ha)		100	200	300
Freight from the community to the plot ($/ha)		25	50	75
Labor cost for broadcast KCl application ($/ha)		150	300	450
Cost totals that vary ($/ha)	0	1265	2530	3795
Net benefit ($/ha)	10621	15284	13645 D	14114 D
Marginal rate of return		370%		

90, 180 and 270 kg of K_2O are supplied with 150, 300 and 450 kg of potassium chloride, respectively
D=Dominated treatments. When a treatment increases its variable cost and presents a lower net benefit.

4 CONCLUSIONS

For the agroecological conditions of the experiments, a significant response to the application of K was detected.

The EAK in the three locations measured at a dose of 90 kg K2O ha-1 was above the acceptable reference values.

The maximum yield and economic benefit was obtained with the application of 90 kg/ha of K2O. The occurrence of rainfall well below the average and the higher yield observed in the locality with auxiliary irrigation, suggest that the response to higher doses of K was limited by the availability of water.

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