

Potassium supply to cotton roots as affected by potassium fertilization and liming⁽¹⁾

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Abstract – Cotton (*Gossypium hirsutum*) is known to have a high requirement for K and to be very sensitive to low soil pH. Most of K reaches plant roots by diffusion in the soil. As K interacts with Ca and Mg, liming can interfere in K movement in the soil, affecting eventually the plant nutrition. The objective of this work was to study the effect of dolomitic lime and 0, 15, 30, 45 and 60 g kg⁻¹ of K on the supply of K to cotton roots. Cotton plants were grown up to 40 days in 5 L pots containing a Dark Red Latosol (Typic Haplustox) with 68% and 16% of sand and clay, respectively. There was an increase in dry matter yields and in K accumulation due to K fertilization. Root interception of soil K was also increased by K application, but was not affected by lime. Mass flow and diffusion increased linearly with K levels up to 60 mg kg⁻¹, in pots with lime. In pots without lime the amount of K reaching the roots by diffusion increased up to 45 mg kg⁻¹, but decreased at the highest K level. Accordingly, there was more K reaching the roots through mass flow at the highest K level. This happened because there were more fine roots in pots without lime, at the highest K level. As the roots grew closer, there was a stronger root competition leading to a decrease in the amount of K diffused to cotton roots.

Index terms: *Gossypium hirsutum*, mass, diffusion, liming materials, roots, growth, plant nutrition.

Suprimento de potássio a raízes de algodoeiro em razão da adubação potássica e calagem

Resumo – O algodoeiro (*Gossypium hirsutum*) apresenta alta exigência de K e é muito sensível a baixo pH do solo. A maior parte do K chega às raízes das plantas por difusão no solo. Por existir interação do K com Ca e Mg, a calagem pode interferir no movimento do K no solo, afetando a nutrição da planta. O objetivo deste trabalho foi estudar o efeito de calcário dolomítico e de 0, 15, 30, 45 e 60 g kg⁻¹ de K no suprimento de potássio às raízes do algodoeiro. As plantas foram cultivadas por 40 dias em vasos de 5 L contendo um Latossolo Vermelho-Escuro (68% de areia e 16% de argila). Houve um acréscimo na produção de matéria seca e na acumulação de K em função da adubação potássica. A interceptação radicular do K do solo foi também aumentada pela aplicação de K, mas não foi afetada pela calagem. O fluxo de massa e a difusão foram aumentadas linearmente com a aplicação de K até 60 mg kg⁻¹, nos vasos com calagem. Em vasos sem calagem a quantidade de K atingindo as raízes por difusão aumentou até 45 mg kg⁻¹, decrescendo com a dose máxima de potássio. Do mesmo modo, mais K entrou em contato com as raízes por fluxo de massa com a maior dose do nutriente. Isto aconteceu porque havia mais raízes finas nos vasos sem calagem e com a dose máxima de potássio. Com a diminuição da distância média entre as raízes, houve maior competição entre elas, culminando com a diminuição do K difundido até as raízes do algodoeiro.

Termos para indexação: *Gossypium hirsutum*, massa, difusão, correção calcária, raiz, crescimento, nutrição vegetal.

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Introduction

Cotton is known to be very sensitive to soil acidity (Silva et al., 1998; Rosolem et al., 2000), requiring lime application to neutralize toxic Al and Mn as well as to provide for a good Ca and Mg availability.

Potassium is required by cotton plants in large amounts and its deficiency decreases not only fiber yields but also fiber quality (Oosterhuis, 1997).

The negative interaction between Ca and/or Mg and K is well known. The higher the availability of Ca and/or Mg, or the higher the lime recommendation, the higher the amount of K to be applied (Silva, 1999).

Nutrient supply from the soil to roots occurs through a combination of mass flow, diffusion and root interception (Barber, 1984). Diffusion is usually the main mechanism supplying K to plant roots (Barber, 1984; Ruiz et al., 1999) when the soil has high amounts of available K, but under certain circumstances mass flow can play an important role in the process (Oliver & Barber, 1966). In tropical soils, K concentrations in the soil solution and exchangeable K are low (Mielniczuk, 1978). In this case, the K diffusion coefficient will be also low. Considering the equation describing K diffusion in soil, addition of the nutrient causes a decrease in buffer power and an increase in its concentration in soil solution, in K diffusion rates and also in mass flow (Ching & Barber, 1979). When Ca and Mg are added as lime in tropical, low cation exchange capacity soils, K becomes less available to plants (Rajj, 1991).

Besides K diffusion rates in soil, root growth rate, root length and surface have been associated with K acquisition efficiency of root systems (Silberbush & Barber, 1983; Chen & Gabelman, 2000). The rate of K uptake by cotton depends on root length density and total surface area (Brouder & Cassman, 1990), though cotton root system is known by its low density relative to other major row crops (Gerik et al., 1987). Rosolem et al. (2000) observed that liming, by decreasing Al toxicity, caused an increase in cotton root length and surface, which would favour K uptake. Rosolem et al. (1998) observed that not only cotton root length, but also root diameter was increased by liming, which can also affect the rate of K reaching the roots by diffusion.

The objective of this work was to study the effect of lime and potassium application to the soil on the supply of K to cotton roots.

Material and Methods

This experiment was carried out in a greenhouse at Faculdade de Ciências Agrônomicas de Botucatu, State of São Paulo, in 5 L pots filled with topsoil from a Dark-Red Latosol (Typic Haplustox) with 68%, 15% and 16% of sand, silt and clay, respectively. Dolomitic lime was applied to half of the pots at 0.90 g kg⁻³ and the soil was wet incubated at 80% of water holding capacity (WHC) for 15 days. After this, all pots received 50 and 150 mg kg⁻¹ of N and P as ammonium sulphate and simple superphosphate, respectively. At the same time, 0, 15, 30, 45 and 60 mg kg⁻¹ of K were applied as potassium chloride. Pots were incubated for another period of 15 days, after soil water correction, to 80% WHC. Soil samples were taken from each pot and analysed according to Rajj & Quaggio (1983). Selected results are shown in Table 1.

Two cotton (*Gossypium hirsutum*, cv. Deltapine 90) plants were grown per pot up to 40 days after plant emergence (DAPE) and four extra pots were conducted without plants to estimate water evaporation. Soil moisture content was maintained close to 80% WHC by weighing the pots and quantitatively replenishing water daily. Plant transpiration was calculated subtracting evaporation from water consumption in each pot. Soil solution was extracted at 10, 23 and 40 DAPE applying vacuum to porous capsules installed in the pots, filtered and analysed for K contents by atomic absorption spectrophotometry.

After the last soil solution extraction, plants were harvested and separated into roots and shoots, oven dried to constant weight at 65°C and grounded. A shoot sample

Table 1. Selected soil chemical properties at planting time⁽¹⁾.

K rates (mg kg ⁻¹)	pH (CaCl ₂)	K -----	Ca (mmolc dm ⁻³)	Mg -----	CEC ⁽²⁾
Without lime					
0	5.0	1.0	25	7.6	68
15	5.1	1.3	23	7.6	66
30	5.1	1.6	26	7.7	71
45	5.0	1.8	24	7.1	68
60	5.1	2.2	22	6.5	63
With lime					
0	5.7	1.2	37	13.9	82
15	5.8	1.3	37	12.9	80
30	5.7	1.5	31	13.1	74
45	5.7	2.0	36	13.9	81
60	5.8	2.3	36	15.0	82

⁽¹⁾K, Ca, and Mg were extracted with anion cation exchange resin. ⁽²⁾Cation exchange capacity (CEC) was calculated.

was taken and wet digested for potassium determination by atomic absorption spectrophotometry.

Roots were separated from soil, washed in tap water and then in distilled water over a 0.5 mm screen. Debris were hand picked. A subsample (about 20% of total) was taken (Baldwin et al., 1973), and stored in 30% ethanol solution. Root length, volume and diameter were determined in the subsamples using a scanner and Winrhizo 3.8.

The amount of K intercepted by roots was estimated multiplying ion concentration in soil solution (averaged across three extractions) by root volume. The amount of K supplied by mass flow was estimated multiplying transpiration in each period by ion concentration in soil solution (averaged across two successive extractions), and diffusion was estimated subtracting the amounts of K supplied by root interception and mass flow from total K uptake.

The experimental design was a factorial 5x2 (five K rates with and without lime), set in completely randomized blocks with four replications. ANOVA was performed in all data to determine significant interactions. Regressions were fitted when appropriate and means were compared using the standard error.

Results and Discussion

Exchangeable K in soil was increased accordingly with increasing K rates applied but exchangeable Ca and Mg were not affected by potassium fertilization (Table 1). Liming caused an increase in exchangeable Ca and Mg with no significant effect on exchangeable K (Table 1). Potassium in soil solution was increased linearly with increasing K rates and no significant effect of lime (Figure 1). However, K concentrations in soil solution were depleted with time, showing a 10 fold decrease from the first extraction at 10 DAPE to the third extraction 40 DAPE. Part of this K was taken up by the plants.

According to the equilibrium laws, solution K can be exchanged with Ca and Mg from the solid phase (Raij, 1991) and this could account for some of the depletion. However, this hypothesis is not supported by the results of this experiment because there was no significant effect of lime on soil solution potassium. Rosolem et al. (1993) observed that the exchange between K-solution and K-exchangeable and even between K-exchangeable and K-nonexchangeable can be fast in both directions

in tropical soils, depending on K concentration in each pool. This is supported by the increase in exchangeable K observed in response to fertilization (Table 1).

Potassium concentration in the shoots and shoot dry matter yields were increased by K fertilization up to 60 mg kg⁻¹ (Figure 2). In this kind of soil, cotton is expected to respond to K fertilization when exchangeable K is below 2.4 mmol_c dm⁻³ (Silva, 1999) (Table 1). Potassium concentration above 20 mg kg⁻¹ in the youngest fully expanded leaf is considered as optimum for cotton production (Rosolem & Boaretto, 1989), but in the present experiment, dry matter yields were increased as K contents increased up to 32 mg kg⁻¹, probably because the whole shoot was analysed instead of the youngest fully expanded leaf. The amounts of K found in cotton roots and shoots increased accordingly (Figure 2).

There was no effect of lime in K uptake or dry matter production by cotton plants. At the pH observed in the pots after liming and fertilization, probably Al was not present in toxic concentrations (Raij, 1991). Manganese toxicity in cotton was observed when soil pH_{CaCl₂} was below 5.2 (Rosolem et al., 2000), which is very close to the pH observed in pots without lime (Table 1), allowing for the inference that there was no Mn toxicity.

Root interception accounted for less than 1% of total K uptake. This fact was expected because in

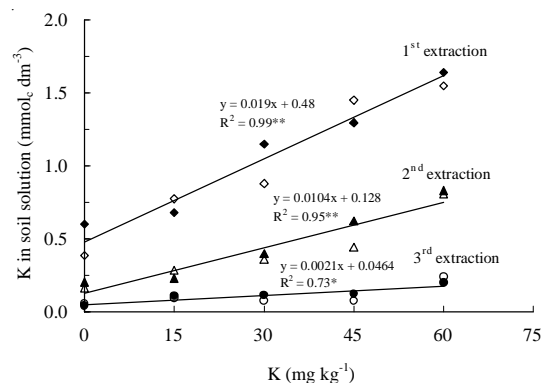


Figure 1. Potassium concentration in soil solutions extracted at 10, 23 and 40 days after plant emergence as affected by K rates, with lime (open symbols) and without lime (solid symbols). * and **Significant at 5% and 1% of probability, respectively.

soils with high amounts of exchangeable and solution K, root interception usually accounts for less than 2% of total K uptake (Barber, 1984). The amount of K

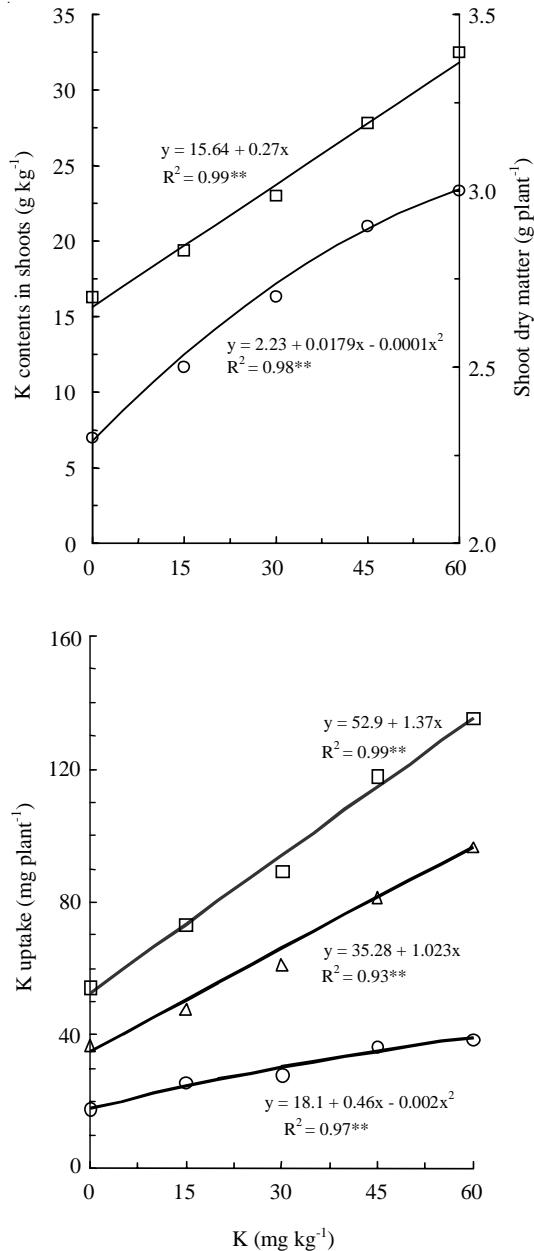


Figure 2. Potassium concentrations (\square) and dry matter (\circ) of shoots and K uptake by cotton plants (roots, \circ ; shoots, Δ ; total plant, \square), as affected by K rates. **Significant at 1% of probability.

encountered by growing roots increased with K rates applied (Figure 3) due to a higher K concentration both in the exchange phase and solution (Table 1, Figure 1). Besides, cotton root length responded to K rates showing an increase up to 45 mg kg⁻¹ (Figure 4), contrary to Rossetto et al. (1995), who observed that in a soil low in K, in an attempt to maintain the plant nutrition and growth, soybean grew more roots than in fertilized soil.

The response of K reaching cotton roots through mass flow and diffusion in limed pots was linear up to 60 mg kg⁻¹ of K (Figure 3). In pots with no lime, mass flow and diffusion also increased with K fertilization, but at the highest K rate, mass flow was much higher and diffusion was lower than in limed pots. An increase in mass flow and diffusion due to K fertilization was expected because there was an increase in solution K (Figure 1), which enhances both mass flow and diffusion (Ching & Barber, 1979). However, K concentrations in soil solution were not affected by liming and there was a differential increase in these processes when lime was applied, showing that K concentration in soil solution must not be the sole reason explaining these results.

Besides the effect of lime and K fertilization on the amount of K transported to cotton roots by mass flow and diffusion, the percentage of the nutrient reaching the roots by each mechanism was also affected (Figure 5). In limed pots there was a drop in K reaching the roots by diffusion from 74% to 64% with K fertilization. Without lime application, there was an increase in K diffusion from 68% to 78% with 15 mg kg⁻¹ of K, and then a decrease down to 41% with 60 mg kg⁻¹ of potassium.

Root growth rate is the main factor affecting K acquisition by plants (Silberbush & Barber, 1983; Chen & Gabelman, 2000). In the present experiment, root length was increased by K fertilization up to 45 mg kg⁻¹, but was decreased by liming (Figure 4). Rosolem et al. (1998) observed an increase in cotton root length when soil Ca was raised to 16 mmol_c kg⁻¹ but total root length was decreased, probably due to Zn deficiency when lime increased soil Ca up to 26 mmol_c kg⁻¹. Considering the highest K rate, both root lengths with and without lime decreased as compared with 45 mg kg⁻¹ of potassium. Considering these aspects, it is impossible to associate the

response observed for mass flow and diffusion with total root length. However, there was a linear response of fine roots up to 60 mg kg⁻¹ of K in unlimed pots

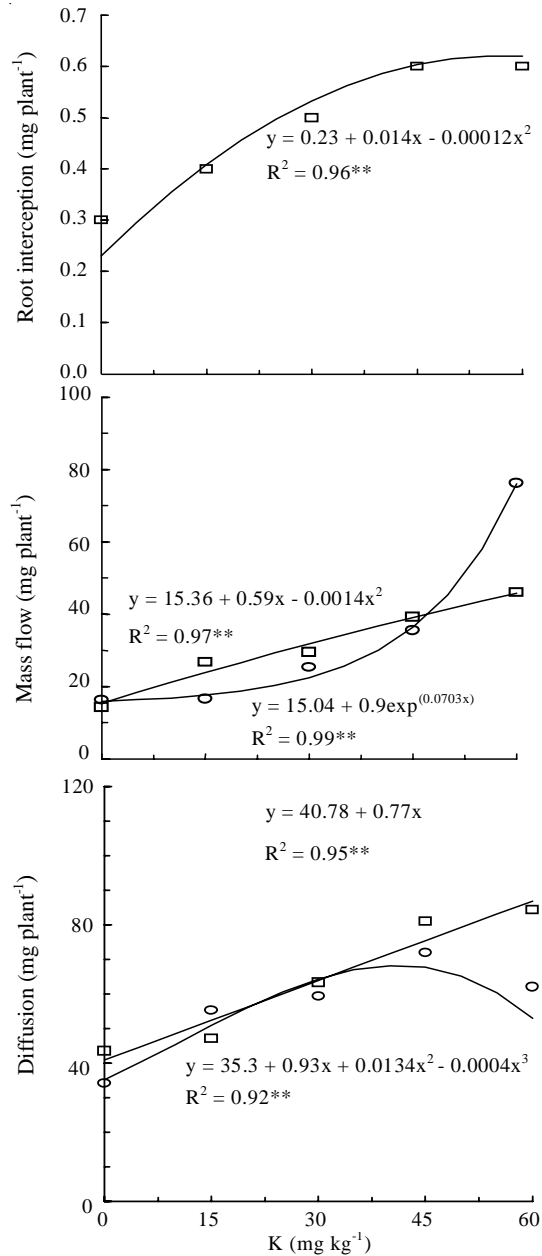


Figure 3. Amount of potassium reaching cotton roots through root interception, mass flow and diffusion as affected by K rates, with lime (□) and without lime (○). **Significant at 1% of probability.

(Figure 5) while the response in limed pots was quadratic.

Thinner roots have a geometry that favours K movement from soil to roots by diffusion (Barber, 1984), but the half distance between roots is also important in K transport regulation. When the half distance is shorter than 4 mm, there is competition between adjacent roots for K uptake (Yamaguchi &

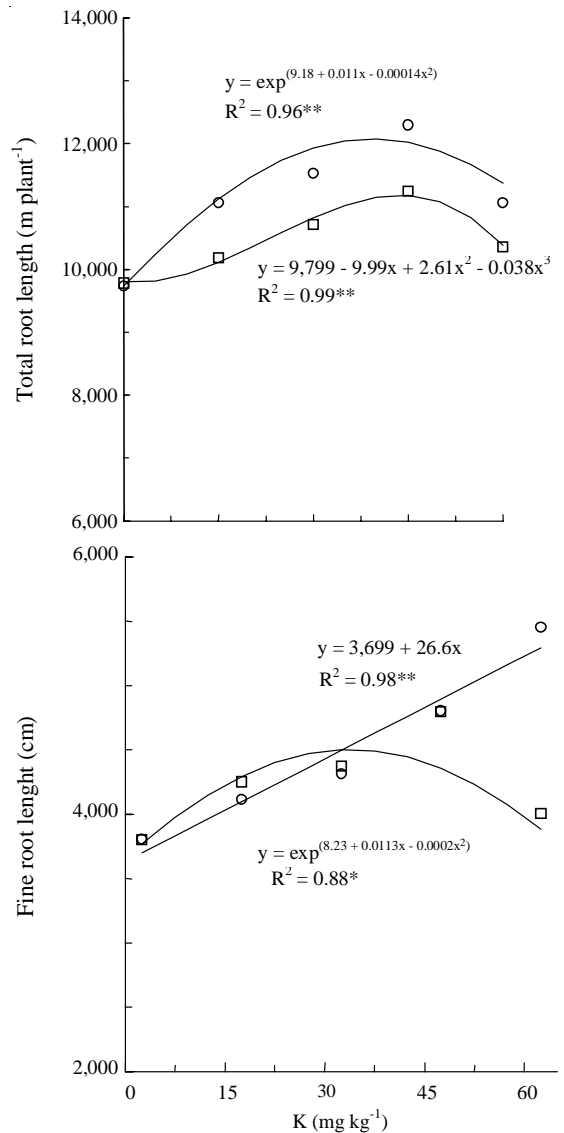


Figure 4. Total and fine root lengths as affected by K rates applied to cotton with lime (□) and without lime (○). * and **Significant at 5% and 1% of probability, respectively.

Tanaka, 1990). More thin roots would favor K transport to roots by diffusion, contrary to results shown in Figures 3 and 4.

In this experiment, the half distance between roots was always less than 4.0 mm, mainly in unlimed pots, implying that there was root competition for potassium. The percentage of K transported to root surface through diffusion decreases as the nutrient is depleted in the rhizosphere (Hylander et al., 1999) and a high root concentration leads to a sharp depletion of K at the root neighbourhood (Seiffert et al., 1995). If root competition for K is established, K will be depleted in this region of the soil, and the diffusion of the nutrient to root surface will not benefit from an increased root length density. Barber (1984) reported that at high root density, changes in

solution K, buffer power and K diffusion coefficient have little effect on potassium uptake, as long as exchangeable K remains constant. Furthermore, considering that root growth rate is known as the main factor affecting K uptake (Silberbush & Barber, 1983), any restriction in root growth would favour mass flow as a mechanism for K transport from soil to roots.

At high root densities, K movement to root surface will depend more on mass flow and soil exchangeable K than solution K, K buffer power and K diffusion in the soil. In soils with Ca contents over $41 \text{ mmol}_c \text{ dm}^{-3}$, cotton will have a shorter root system, with less fine roots, leading to an increase in the importance of mass flow in K uptake when the exchangeable soil K is higher than $2.3 \text{ mmol}_c \text{ dm}^{-3}$.

Conclusions

1. In the presence of lime, higher K availability causes a linear increase in K amounts reaching cotton roots by diffusion and mass flow.
2. Without lime, the amount of K reaching the roots by diffusion shows a quadratic response with maximum at 45 mg kg^{-1} of potassium.
3. Without lime, there is a linear increase in fine root length with the increase in K availability, and eventually a decrease in the amount of K reaching the roots by diffusion.
4. The proportion of K transported to cotton roots by mass flow is increased with K availability and the increase is sharper in the absence of liming.

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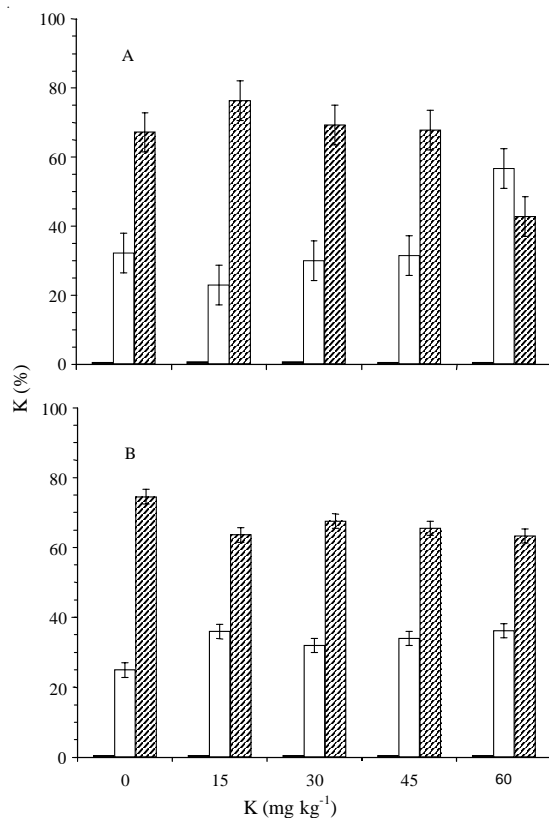


Figure 5. Percentage of K reaching cotton roots by root interception (■), mass flow (▨) and diffusion (□) as affected by K rates in pots without (A) and with (B) lime. Bars show the standard error.

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