POTASSIUM DYNAMICS IN MEXICAN SUGARCANE SOILS

By

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Abstract

A POSSIBLE explanation for the variable response of sugarcane to the addition of potassium (K) was found by studying how the crop affects the content of soluble K (Ks), exchangeable K (Ke), non-exchangeable K (Kne), and buffer capacity (CIC) after various times of cane cultivation. Three sugarcane plantations at Tabasco, Mexico with 10, 20, and 30 years of sugarcane cropping history in a fluvisol and a vertisol were compared to areas where sugarcane had never been grown. A composite sample of 100 kg of air-dried soil was collected from each location and blended and sieved before taking five, 250-g sub-samples from each soil. K was added to each subsample and incubated for 0, 1, 3, 7, 15, 30 and 60 days. Ks was extracted with 0.01 M CaCl₂, Ke with 1N ammonium acetate at pH 7, and Kne with 1N HNO₃. Results showed that the decrease of K in its soluble and exchangeable forms, to the non-exchangeable form, was complete after 30 days of incubation. The vertisol showed a higher buffer capacity compared to the fluvisol. The Ks and Ke reserves were greater in the fluvisol compared with the vertisol. The fluvisol tended to accumulate more K throughout the years of cultivation compared with the vertisol which exhibited a decline in K status. This may be due to the lower clay content and shrink/swell properties of the clay in the fluvisol that will reduce K losses in the surface layer of the soil due to ash leaching, especially in fields with little or no slope. A better understanding of the K dynamics of soils from the sugar mill zone at Santa Rosalía, Tabasco, Mexico will facilitate improved diagnosis of K deficiencies and fertiliser recommendations for the soils in the milling zone.

Introduction

Potassium (K) is essential for the growth and development of crops. The demand for K by sugarcane is greater than the demand for all other essential elements. The K extracted by sugarcane may become a limiting factor to productivity if there is insufficient K in the pool of readily available K in the soil solution to compensate for losses. Exchangeable K (Ke) is in equilibrium with K in the soil solution (Ks), and also with the other forms of K.

Thus Ke is responsible for replacing the K lost from the soil solution. Simultaneously this protects the K added as a fertiliser by releasing it gradually to the soil solution according to the established equilibrium (Aguado-Lara et al., 2002; Rodriguez, 1993).

Fluvisol and vertisol soils in the sugarcane area at Santa Rosalía (SR), Tabasco, Mexico have been planted to cane for more than 30 years. Fertiliser is applied to the crop in the SR area to provide N, P and K at rates of 120, 60 and 60 kg/ha, respectively, without considering cultivar or soil type. Average yield of 50 t/ha of sugarcane is obtained.

This yield is lower than the average 70-t/ha yields obtained nationally. Results from Salgado et al. (2000) demonstrated that the application of 160, 80 and 80 kg/ha of N, P, K, respectively, can produce 110 and 95 t/ha yields of sugarcane in vertisol and inceptisol soils, respectively.

To ascertain the need for modifications to K fertilisation strategies and the sustainability of the system in the SR area, studies were conducted to determine if Ks, Ke, and Kne levels and the buffer capacity (CIC) changed in soils of the region subjected to continuous sugarcane production for long periods of time.
Methodology

The study was conducted from April 2003 to February 2004 under laboratory conditions in the Colegio de Postgraduados-Campus Tabasco, in Tabasco, Mexico. Three cane plantations were identified with 10, 20 and 30 years of continuous sugarcane production history, respectively, in fluvisol and vertisol soils from the sugar mill zone at SR. The chemical and physical characteristics of these soils are presented in Table 1. A cacao plantation was selected as the control for the fluvisol soil and a rain-forested site as the control for the vertisol soil, and these were assumed to be year ‘0’ of the study. These soils have received organic matter from the remnants of vegetation growing on the sites for more than 40 years and have not been altered by the constant passing of heavy machinery, burning of the residues, or fertilisation. Five soil samples (0 to 30 cm depth) were taken from each area of land (Figure 1), and were used to make a composite sample (100 kg). The soil was air dried and later ground and sieved (2 mm).

![Section of soil consisting of the row and interrow that constituted a soil subsample used in these studies (20 kg approximately).](image)

Five (replicates) 250 g samples of vertisol and fluvisol soil from each site were weighed and placed in a propylene beaker to which was added 0.048 g of KCl to achieve an increased soil K concentration of 100 mg K/kg. Each beaker was shaken manually 10 times in order to incorporate the K with the soil. Samples were then maintained at field capacity and room temperature and covered with plastic to maintain constant conditions during incubation times of 0, 1, 3, 7, 15, 30 and 60 days.

$K_s$ was determined at the end of each incubation period with 0.01 M CaCl$_2$, Ke with 1N ammonium acetate (pH 7), and Kne with 1N HNO$_3$. Buffer capacity was determined using the formula $CK=K_s/Ke$ at 0 and 1 day (Rodriguez, 1993). The size of pools of $K_s$ and $Ke$ was determined 60 days after the first extraction.

A similar amount of 0.01 M CaCl$_2$ was again added to the same soil sample and the successive extractions were repeated until the amount of K extracted was reduced to a minimum. For this reason filtration was carried out carefully to avoid the loss of fine material from the soil (Aguado-Lara et al., 2002). The sum value of successive extractions was used to calculate the size of the $K_s$ and $Ke$ pools.

Results and discussion

The dynamics of K in the soil can be explained by studying the interactions between the different pools of K. An analysis of the vertisol and fluvisol soils from the sugar mill zone at SR was made at the beginning of the study. Results are presented in Table 1. Both soils had acid pH, no salinity problems, and high contents of extractable phosphorus (P-Olsen), exchangeable potassium (Ke), extractable calcium (Ca), and magnesium (Mg). The Ca/Mg ratio for the vertisol ranged from 0.62 to 2.43 while the ratio for the fluvisol ranged from 1.96 to 2.25. Both are low according to the ratio of 6 recommended by González et al. (1974) for soils planted to sugarcane. All of the vertisol soils had clayey and clayey-loam textures which indicate high moisture retention (Table 1). The soil texture in the fluvisol soils was silty-clay-loam.
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Table 1—Chemical and physical properties of sugarcane soils from the sugar mill zone at Santa Rosalia, Tabasco, Mexico.

<table>
<thead>
<tr>
<th>Years of cultivation</th>
<th>pH (H₂O)</th>
<th>EC (Ds/m)</th>
<th>Organic matter (%)</th>
<th>Total nitrogen</th>
<th>Phosphorus P-Olsen (ppm)</th>
<th>Exchangeable cations (Cmol (+) /kg)</th>
<th>CEC</th>
<th>Particle size fractions (%)</th>
<th>Textural classif.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vertisol soil</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rain forest soil, year 0</td>
<td>5.4</td>
<td>67.6</td>
<td>2.36</td>
<td>0.15</td>
<td>15.6</td>
<td>0.44</td>
<td>5.4</td>
<td>8.6</td>
<td>0.38</td>
</tr>
<tr>
<td>10</td>
<td>5.7</td>
<td>40.9</td>
<td>2.10</td>
<td>0.12</td>
<td>32.0</td>
<td>0.26</td>
<td>11.9</td>
<td>5.6</td>
<td>0.16</td>
</tr>
<tr>
<td>20</td>
<td>5.1</td>
<td>30.6</td>
<td>2.36</td>
<td>0.15</td>
<td>17.0</td>
<td>0.28</td>
<td>11.1</td>
<td>6.7</td>
<td>0.20</td>
</tr>
<tr>
<td>30</td>
<td>6.2</td>
<td>51.2</td>
<td>2.36</td>
<td>0.15</td>
<td>28.1</td>
<td>0.24</td>
<td>16.8</td>
<td>6.9</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>Fluvisol soil</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cocoa plantation soil, year 0</td>
<td>5.8</td>
<td>59.8</td>
<td>2.17</td>
<td>0.12</td>
<td>10.8</td>
<td>0.38</td>
<td>5.1</td>
<td>2.7</td>
<td>0.05</td>
</tr>
<tr>
<td>10</td>
<td>5.7</td>
<td>62.5</td>
<td>2.10</td>
<td>0.13</td>
<td>9.2</td>
<td>0.92</td>
<td>7.6</td>
<td>4.2</td>
<td>0.09</td>
</tr>
<tr>
<td>20</td>
<td>5.5</td>
<td>41.3</td>
<td>1.81</td>
<td>0.12</td>
<td>5.5</td>
<td>0.28</td>
<td>8.0</td>
<td>4.0</td>
<td>0.10</td>
</tr>
<tr>
<td>30</td>
<td>5.8</td>
<td>88.6</td>
<td>2.82</td>
<td>0.13</td>
<td>14.5</td>
<td>0.66</td>
<td>9.6</td>
<td>4.9</td>
<td>0.12</td>
</tr>
</tbody>
</table>

CEC = cation exchange capacity at pH 7.0; EC = electrical conductivity.

Fixation of K

The Fluvisol soil showed a higher mean value of Ke than the vertisol (Table 2). A different pattern was observed over the years of sugarcane cultivation where the Ke was higher in the fluvisol than vertisol soil only in the samples collected in fields subjected to sugarcane production for 10 and 30 years. The reduction of K from the soluble and exchangeable forms to the non-exchangeable form was complete at 30 days (Figures 1 and 2).

The fixation of K is not due to a chemical reaction or compound formation, but to a physical trapping reaction of K ions carried out by the silicon tetrahedron layers of argillaceous minerals, particularly from the 2:1 minerals that provide fixation sites (Rodriguez, 1993). No consistency was found in the amounts of K fixed in either soil across the different years of sugarcane cultivation.

The average K fixation was 68% for both soils. These results were higher than the K fixation of 31% and 12% in vertisol and fluvisol soils planted to grass and not subjected to fertilisation (Lopez, 1990).

Table 2—Dynamics of potassium in soils cropped with sugarcane.

<table>
<thead>
<tr>
<th>Years of cultivation</th>
<th>Vertisol</th>
<th>Fluvisol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ke 0 days (mg/kg)</td>
<td>Ke 30 days (mg/kg)</td>
</tr>
<tr>
<td>0</td>
<td>190</td>
<td>193a†</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>137c</td>
</tr>
<tr>
<td>20</td>
<td>110</td>
<td>172b</td>
</tr>
<tr>
<td>30</td>
<td>90</td>
<td>121d</td>
</tr>
<tr>
<td>LSD(P&lt;0.05) Mean:</td>
<td>122.5</td>
<td>207</td>
</tr>
</tbody>
</table>

† Means followed by the same letter are not statistically different at the P<0.05 level.
Ke = exchangeable potassium; CK = buffer capacity; PS = pool size of potassium.
Buffer capacity

Soils with a high buffer capacity have a lower CK ratio, thus as the CK value decreases, the buffering capacity increases. Therefore, the vertisol had a greater buffer capacity than the fluvisol (Table 2). This indicates, that the concentration of Ks in the vertisol will be constant for a longer period, thus minimising the depletion of exchangeable K reserves. Simultaneously this secures the availability of K in the soil solution (Aguado-Lara et al., 2002).

Fig. 2—Dynamics of potassium (K) in a vertisol soil (A) under forest and (B) cropped with sugarcane for 30 years.

Size of K pools

The pools of available K (Ks and Ke) were greater on average in the fluvisol compared with the vertisol soil, but the difference between soils was not consistent across cropping history (Table 2). This agrees with the results from other soils of these series reported by Aguado-Lara et al. (2002). There is a general tendency for the amounts of K in the available pools to increase throughout the years of sugarcane culture in the fluvisol (Table 2). This is attributed texturally to the low cracking properties of the soil, which reduces losses of K when ash is washed away after the sugarcane harvest. This favours K accumulation in the surface layer of soils with relatively flat topographies (Naranjo et al., 2004). On the other hand, the vertisol displayed a tendency towards a reduction of K storage, as also indicated by Ribón et al. (2003), which implies that the rate of K fertiliser application should be increased. Increasing the amount of K applied to 80 kg K/ha in this soil has been suggested, to raise sugarcane yields (Salgado et al., 2000).

Fig. 3—Dynamics of potassium (K) in a fluvisol soil (A) under cocoa and (B) cropped with sugarcane for 30 years.

Conclusions

The dynamics of K in sugarcane soils differ according to the type of soil. A reduction in K concentration was observed in the vertisol over the years of sugarcane culture, whereas in the fluvisol, K concentration increased generally, contributing to the sustainability of the system in this type of soil. In the
vertisol soil the rate of K fertiliser should be increased to improve the nutrition of sugarcane and, hence, sugarcane yields.

Acknowledgements

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REFERENCES


MOBILITES POTASSIQUE DANS LES SOLS SOUS LA CULTURE DE LA CANNE À SUCRE AU MEXIQUE
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MOTS CLÉS: Fixation, Vertisol, Fluvisol, Pouvoir Tampon.

Résumé
La Teneur en potassium soluble (Ks), échangeable (Ke), fixe (Kne), et le pouvoir tampon (CK) du sol après divers périodes de culture de canne pourraient fournir une explication plausible à la réponse variante de la canne à sucre aux apports de potasse. Une comparaison a été faite à Tabasco au Mexique entre certains secteurs où la canne n'a jamais été cultivée et trois champs étant sous culture de canne à sucre durant 10, 20, et 30 ans dans un fluvisol et un vertisol. Pour chaque champ un échantillon composé séchés à l'air d'environ cent kilos de terre ont été prélevés, mélangés, tamisés et à partir du quel cinq sous-échantillons d'environ 250 grammes ont été retenue. A chacun de ces sous-échantillon de terre, K a été ajouté pour être incubé durant 0, 1, 3, 7, 15, 30 et 60 jours. Après chaque période, le Ks a été extrait avec 0.01 M CaCl₂, le Ke avec 1M acétate d'ammoniaque à pH 7, et le Kne avec 1M HNO₃. Les résultats ont démontré qu'après 30 jours d'incubation, la diminution de K sous ses formes solubles et échangeables, à la forme fixée, a été complète. Le vertisol a montré un pouvoir tampon plus élevé que le fluvisol tandis que la réserve en Ks et Ke étaient plus grandes dans le fluvisol. En revanche le fluvisol avait une tendance d'accumuler plus de K durant toutes ces années de cultivation, quant au vertisol, il montrait une baisse dans la teneur en K. Ceci peut être dû à un faible taux d’argile dans la fluvisol qui est expansible et contractile ce qui aménérerait conséquemment à une réduction des pertes en potasse du sol arable aussi bien que la lixivation des bases particulièrement pour des champs ayant peu ou pas de pente. Une meilleure compréhension de la mobilité de K des terres sous canne de la zone du sucriculture de Santa Rosalía, Tabasco, au Mexique qui aidera à peaufiner d’avantage le diagnostic des insuffisances de K et aussi les recommandations d’engrais dans ces sols.

DINAMICA DEL POTASIO EN SUELOS CULTIVADOS CON CAÑA DE AZÚCAR
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Resumen
Para explicar la respuesta del cultivo a la aplicación de K es necesario estudiar como se comportan las fracciones potasio soluble (Ks), potasio intercambiable (Ki), potasio no intercambiable (Kni) y la capacidad amortiguadora (CK), a través de diferentes tiempos de cultivo con caña de azúcar. Se seleccionaron tres plantaciones de caña con 10, 20 y 30 años de cultivada para un fluvisol y vertisol, y un testigo respectivamente en Tabasco, México. Se tomó una muestras compuesta de 100 kg, el suelo se seco a la sombra, se molió y tamizado (2 mm). Se pesaron 250 g de suelo con 5 repeticiones. A cada vaso se le adicionó 0.04771 g de K, se agito, se humedeció a capacidad de campo, se cubrieron con plástico para mantener las condiciones constantes y se colocaron a incubar, durante 0, 1, 3, 7, 15, 30 y 60 días. Al final de la incubación, se determinó el Ks con CaCl₂ 0.01 M, Ki con acetato de amonio 1N, pH 7 y Kni con HNO₃ 1N. Los resultados indican que la disminución de K de las formas solubles e intercambiables a las no intercambiables, finaliza a los 30 días de incubación. El vertisol presenta mayor capacidad amortiguadora que el fluvisol. El reservorio de Ks y Ki fue mayor en el fluvisol en comparación con el vertisol. El fluvisol mostró una tendencia a incrementar la cantidad de K a través de los años de cultivo contrariamente al vertisol, lo que se atribuye a que este suelo no se agrieta por lo que se reducen las perdidas de K por el lavado de cenizas, favoreciendo su acumulación en la capa superficial del suelo.

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