Nutrient management for sugar beet (*Beta vulgaris* L.) on K-fixing soils

Abdul Wakeel[A, B], Diedrich Steffens[A], and Sven Schubert[A]

[A] Institute of Plant Nutrition, Justus Liebig University, Heinrich-Buff-Ring 26 - 32, 35392 Giessen, Germany
[B] Email: Abdul.Wakeel@agrar.uni-giessen.de

Abstract

Alluvial soils with illite and vermiculite clay minerals are highly potassium (K)-fixing. Such soils have been reported to require a huge amount of K fertilization for optimum plant growth. For halophytic plants such as sugar beet, sodium (Na) can be an alternative to K under such conditions. This study was conducted to investigate the possible substitution of K by Na fertilization with reference to K-fixing soils. Three soils i.e. Kleinlinden (sub-soil), Giessen (alluvial), and Trebur (alluvial) differing in K-fixing capacity, were selected and sugar beet plants were grown in Ahr pots with 15 kg soil pot^{-1}. Plants were grown till beet maturity and beets were analyzed for sucrose concentration and other quality parameters such as α-amino nitrogen to calculate white sugar yield with the New Brunswick formula. The results showed that growth and quality of sugar beet were not affected by Na application and ultimately there was no decrease in white sugar yield. The soils with more K-fixing capacity were more effective for K substitution by Na. It is concluded that Na can substitute K in sugar beet nutrition to a high degree and soils with high K-fixing capacity have more potential for this substitution.

Key Words

potassium, sodium nutrition, K-fixing soil, *Beta vulgaris* L.

Introduction

Sometimes plant growth does not respond to generally recommended K fertilization in the soils with expandable clay minerals such as vermiculite. Doll and Lucas (1973) reported for Michigan State that in such sandy clay loam soils, about 92% of the applied K fertilizer had been fixed. A response of K application to a tomato crop was obtained at 1600 kg K/ha. These soils are rich in illite and vermiculite, weathered from mica and are able to fix a huge amount of K. In such soils a major portion of applied K is fixed and becomes unavailable to plants immediately. Similar results have been achieved in other parts of the USA (Mengel and Kirkby 2001).

Potassium is involved in three important functions i.e. enzyme activation, charge balance and osmoregulation in plants (Mengel 2007). Plants need a smaller amount of K for specific functions that occur in the cytoplasm and a major portion (90 %) of K is localized in vacuoles where it acts as an osmoticum (Subbarao *et al*. 2000). Maintenance of osmotic equilibrium in vacuole and cytoplasm, a non-specific function of K, can be replaced by other cations such as the Na ion (Subbarao *et al*. 1999).

In sugar beet, application of Na (equivalent to K fertilizer) prevented the occurrence of K deficiency symptoms (Wakeel *et al*. 2009). The possibility of substitution of K by Na in physiological processes is not only of academic interest but is also of practical importance in relation to fertilizer application. It seems essential to examine the possibilities of the practical application of these findings. In highly K-fixing soils an enormous amount of K fertilizer is needed to stimulate plant growth and yield formation. Application of a huge fertilizer amount is very expensive and hardly practicable. In this study we investigated the possibility of K substitution by Na with reference to K-fixing soils. This may lead us to consider Na as an alternative to K fertilization and the development of an improved fertilizer strategy for sugar beet on K-fixing soils.

Methods

A soil experiment was carried out in Ahr pots at the experimental station of the Institute of Plant Nutrition, Giessen. Three soils i.e. Kleinlinden, Giessen and Trebur, differing in K-fixing capacities (Tab. 1) were filled into Ahr pots at the rate of 15 kg each. A lower concentration of exchangeable K was achieved by dilution with sand at ratios of 1:1 (Kleinlinden and Giessen) and 1:10 (Trebur). The soils were mixed with $MgCO_3$, $Ca(H_2PO_4)_2$ + $CaSO_4$ (superphosphate), NH_4NO_3 and H_3BO_3 at rates of 0.133, 1.910, 0.380 and 0.003 g/kg of soil, respectively. There were three treatments, i.e. (1) no K or Na application, (2) K application according to the K-fixing capacity of the soil, and (3) Na application equivalent to a regular K fertilization (145 kg Na/ha), with four replications for each. Plants were harvested at beet maturity about four months after sowing. Then the plants were washed in distilled water and were separated into young leaves, old leaves, and beet for fresh weight measurements. Oven-dried (80°C) plant materials were weighed and ground to pass a 1.0 mm sieve. Shoot and beet samples were analyzed for K, Na, Ca and Mg. Beet was analyzed for sucrose and α-amino N.

Another experiment was conducted in big containers (170 kg soil each) using Kleinlinden soil. Three treatments, i.e. control without application of Na and K, K according to regular K fertilization (415 kg K/ha) and Na equivalent to K fertilization were applied. Harvesting was done similarly to the previous experiment.

Table 1: Physicochemical characteristics of the soils used for the experiments.

Soils	Soil type	pH (0.01M $CaCl_2$)	Clay (g/kg)	Silt (g/kg)	Sand (g/kg)	N_{total} (%)	Exch. Mg (mg/kg)	CAL*-K (mg/kg)	K-fixing capacity of soil (mg K/kg)
Kleinlinden	Sub-soil	5.8	207	338	455	0.042	245	49.1	488
Giessen	Alluvial	5.2	303	631	47	0.241	296	26.9	526
Trebur	Alluvial	7.4	446	436	112	0.432	229	254.0	617

*Calcium acetate lactate extractable

Results

In a preliminary experiment, K and Na application resulted in an increase of leaf and white sugar yield of sugar beet compared to the control treatment and on each soil the highest leaf and white sugar yields were obtained in the treatment with K, since the K fertilization was equivalent to the K-fixing capacity of the soil. However, Kleinlinden soil for showed significantly higher yields for K treatment as compared to the Na treatment because of better K response due to low K-fixing capacity (Figure 1). In the container experiment, leaf fresh and leaf dry weights were not affected by Na and K treatments as compared to those of the control treatment, however beet fresh and dry weights in the K and Na treatments were significantly higher than those in the control treatment but not different to each other (data not shown) and similar results were found for white sugar yield (Figure 1).

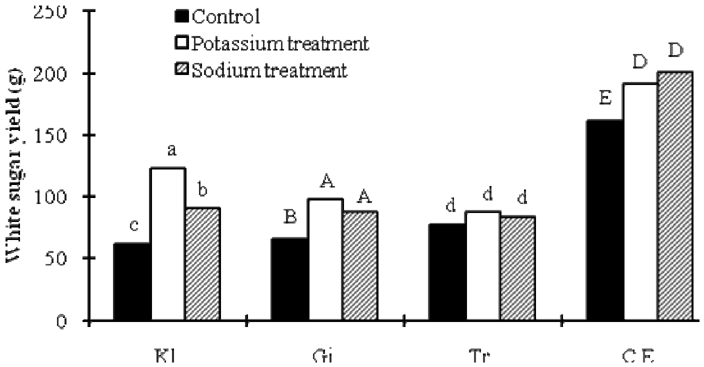

Figure 1. Effect of K substitution by Na on white sugar yield of sugar beets harvested at maturity in three soils (Kl. = Kleinlinden, Gi. = Giessen,Tr. = Trebur and C.E. = container experiment). In Ahr pot experiment K fertilizer was applied according to the K-fixing capacity of soil i.e. 950, 1026, and 240 kg K/ha in Kl., Gi., and Tr. soils, respectively. In the container experiment K was applied according to regular K fertilization (415 kg K/ha). Sodium was applied equivalent to regular K fertilization. Means followed by the same letter for the same soil are not significantly different according to LSD test at 5% level of probability.

Sodium treatment reduced the uptake of K without disturbing the growth of the plants. Ca and Mg concentrations decreased in the leaves when K was substituted by Na but this response was not consistent in all the soils. Interestingly, Na + K concentration in beet was decreased when K was substituted by Na, which definitely improved the quality of beet by decreasing the molassegenic effect. The concentrations of sucrose and α- amino N were not affected by K substitution by Na.

Discussion

Many essential metabolic processes can function equally well with a number of different but chemically similar elements. According to Subbarao *et al.* (2003), it is possible for similar elements such as Na and K to replace each other completely in certain non-specific metabolic functions. Our experiments with sugar beet showed peculiar effects of Na application on plant growth and Na was able to eliminate the K deficiency symptoms of sugar beet leaves. Surprisingly, despite a very low K ion concentration K deficiency symptoms were not observed in the Na treatment. Subbarao *et al.* (2003) concluded that Na can replace K for vacuolar functions for which 95% of total acquired K is required. In our experiments, we applied a lower amount of Na, which may have taken over the osmotic functions of K in vacuoles without disturbing K concentrations in the cytosol (Jeschke 1977). Therefore, the plant growth was maintained. Apparent growth stimulation by Na in the plants of the family *Chenopodiaceace* was observed (Jafarzadeh and Aliasgharzad 2007). Similarly, Nunes *et al.* (1983) found that growth of halophytic plants was stimulated by Na, mainly through an effect on cell expansion.

The Ahr pot experiment with soil Kleinlinden showed decreased plant growth and white sugar yield when K was substituted by Na (Figure 1). Elevated K concentration of the leaves of plants grown in Kleinlinden soil revealed that the higher growth response was due to better K availability in the K treatment as compared to the other soils due to low K-fixing capacity of the Kleinlinden soil, which was about 40 mg K (kg soil)$^{-1}$ less than of Giessen soil used in the same experiment (Tab. 1). In the container experiment, Na and K treatment did not show a significant difference because K applied was relatively less (equal to regular K fertilization). Giessen soil showed no significant difference in plant growth and white sugar yield when K was substituted by Na. In Trebur soil, K and Na both did not show a significant effect on leaf growth and white sugar yield in comparison to the control. Similar results have been found in a field study conducted at Trebur with similar soil (unpublished). Such types of soil are able to release K from the huge amount of total K present in the soil (Schubert *et al.* 1989) when its concentration in soil solution decreases (Figure 2). The total amount of K in this soil was 16 g K (kg soil)$^{-1}$.

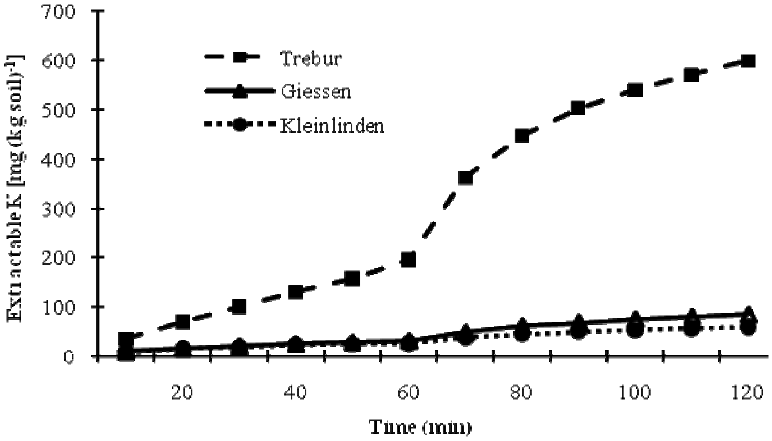

Figure 2. Cumulative curve of extractable K in three different soils determined with electro-ultra filtration (EUF). Soil extract was taken every 5 min. Potassium released during the first 60 min at 200V/20°C is considered as easily available for plants and K release in following 60 min at 400V/80°C is known to be slowly available for plants.

Higher concentrations of α–amino N and K + Na decrease the quality of beet because their presence in the beet interferes with the crystallization process, which causes a great proportion of the sugar to be recovered as molasses with a reduction in refined sugar (Hilde *et al.* 1983; Carter, 1985). Application of Na fertilizer could decrease the quality of the sugar beet if its major accumulation occurred in the beets. Wang *et al.* (2007) found that most of the halophytic plants accumulated a huge amount of Na in their shoots. For *Suaeda maritima*, a halophytic plant growing in 150 mM NaCl, he found that 95% of the total Na was accumulated in plant shoots. We also found that a major portion (90% of total plant Na content) was accumulated in sugar beet shoots.

Haneklaus *et al.* (1998) concluded that the sugar beet root was negatively affected by Na fertilization due to an increase in Na content in the beet. Our studies also showed a slightly significant higher Na concentration in the beet in Na-fertilized plants as compared to K-fertilized plants, but K concentrations in the beets of the Na treatment were much lower than those in the K treatment. Farley and Draycott (1974) concluded that Na and K have similar molassegenic effects on sugar extraction. We calculated that the K + Na concentration was significantly decreased in the Na treatment as compared to that in the K treatment improving the beet quality in this regard. Sucrose and α–amino N concentrations in the beet were similar in the K and Na treatment.

It is concluded that substitution of K by Na stimulates plant growth without affecting beet yield and quality. Soils with higher K-fixing capacity have more potential for this substitution and application of a huge amount of expensive K fertilizer can be replaced with small amounts of cheaper Na fertilizer.

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