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Interactions between potassium, calcium and magnesium in sugarcane grown on two contrasting soils in South Africa

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ABSTRACT

The correction of soil fertility constraints is necessary for the successful production of sugarcane. Inhibition of potassium (K) uptake by sugarcane plants in the presence of high concentrations of calcium (Ca) and magnesium (Mg) has been reported, with some sugarcane-growing countries adjusting K fertiliser recommendations accordingly. Although the depressive effect of K on Ca and Mg uptake is well documented for other crops, this phenomenon has not been widely recognised in sugarcane, and is not taken into account when making Ca and Mg recommendations. The interactions between K, Ca and Mg were therefore investigated on two contrasting soil types (Oxisol and Inceptisol) on the east coast of KwaZulu-Natal, South Africa, in factorial-designed field trials. Trials at each site included the plant crop (first crop after planting) and two ratoon crops (crops which regrow following harvest). This paper deals with the impact of the treatments on leaf nutrient levels and crop yields. Potassium treatments (0, 100, 200 and 300 kg K ha^{-1}, as KCl) resulted in significant ($P < .001$) increases in leaf K concentrations, along with relatively consistent increases in sugarcane and sucrose yields with increasing leaf K. Increased leaf K concentrations led to decreases in leaf calcium (Ca) and magnesium (Mg). Calcium silicate products Calmasil® (a calcium silicate slag) and blast furnace cement, applied at rates to supply 0 and 300 kg Si ha^{-1}, also supplied large amounts of Ca and Mg. Application of these products resulted, at times, in increased leaf Ca and Mg. Silicate application increased sugarcane and sucrose yields in three out of the four ratoon crops under study. Despite recorded increases in leaf Ca and Mg, leaf K was not decreased by silicate application on the Oxisol, and seldom so on the Inceptisol. It is proposed that the inhibitory effect of Ca and Mg on K uptake has historically been overestimated in sugarcane, and that the reverse effect – K suppression on Ca and Mg uptake – may have been underestimated.

1. Introduction[1]

Understanding the effects of available soil nutrients on plant uptake, plant nutrient concentrations and yield is key to managing crop nutrition and successful crop production. Available soil nutrients may comprise both those from exchangeable sources, as well as those applied in fertiliser or other ameliorants,

The extent of nutrient uptake by plants is complicated by interactions which occur between nutrients, both in the soil and in the plant itself. An example of such an interaction is the cationic antagonism that exists between calcium (Ca), magnesium (Mg) and potassium (K) such that high levels of one or more of these nutrients can result in decreased uptake of another, despite sufficient soil levels (Garcia et al., 1999; Gosnell and Long, 1971; Marschner, 1995). Many researchers have reported the results of such antagonism in other plants (Grunes et al., 1992; Karlen et al., 1978; Toumi et al., 2016; Wilkinson et al., 2000; Zharare et al., 2011). In sugarcane (*Saccharum officinarum* x *S. spontaneum* hybrid), a number of researchers have reported reduced uptake of K in soils with high concentrations of Ca and Mg (Donaldson et al., 1990; Kingston et al., 2009; Meyer, 2013). Less research documents evidence of the opposite effect, however, i.e. a reduction in Ca or Mg uptake by sugarcane under conditions of high soil (or applied) K. Gosnell and Long (1971) attributed decreased sugarcane uptake of Ca and Mg with K fertilisation to cationic antagonism, while Sakaigaichi et al. (2014) recorded an increase in sugarcane Ca and Mg concentration upon reduction of K_2O application, suggesting suppression of Ca and Mg uptake at higher K levels. In the South African sugarcane industry, K fertiliser recommendations are amended under conditions of

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[1] Abbreviations not standard in the field: FAS = Fertiliser Advisory Service. Soil, leaf and water testing laboratory providing nutrient recommendations at the South African Sugarcane Research Institute (SASRI). SASRI = South African Sugarcane Research Institute.

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high base status, i.e. in soils where Ca and Mg saturation is high. No allowance is made, however, in the current South African, Australian, American, Brazilian or Cuban recommendations for the reverse situation, where soil K concentrations are high (Meyer, 2013; Miles, 2014). The Fertiliser Advisory Service (FAS), an analytical laboratory at the South African Sugarcane Research Institute (SASRI), processes 3000–4000 research and commercial leaf samples annually, along with approximately 11 000 soil samples (Van der Laan and Miles, 2010), originating from southern and central Africa. High K, Ca and Mg concentrations in some soils, both within and beyond South Africa's borders, make cationic antagonism a potential challenge for the efficient uptake of these nutrients. Understanding the dynamics of the interactions between these nutrients in terms of plant uptake has a bearing on soil threshold levels and nutrient application rates, not only in Africa but in the worldwide sugarcane industry.

This study was therefore designed to determine the effect of varying application rates of K, Ca and Mg on the uptake of these nutrients by sugarcane. The ultimate goal was to guide the refinement of nutrient recommendations both locally and internationally.

2. Materials and methods

2.1. Trial sites

Two trial sites on contrasting soil types were selected. One trial was situated in the coastal hinterland in the Inanda area, on the farm 'Inanda', inland of Maidstone on the KwaZulu-Natal north coast, South Africa (29.629°S, 30.928°E; 560 m a.s.l.) (Fig. 1). Mean annual rainfall is approximately 1 100 mm annum^{-1}, with most of the rainfall occurring during the summer months from October to March (Fig. 2A). The mean daily maximum temperature is 25.7 °C and mean daily minimum, 16.2 °C. The soil type is an Oxisol (Humic Eutrustox; Soil Survey Staff, 2014); Humic Ferralsol (IUSS Working Group WRB, 2014); Inanda form, Glenariff family (Soil Classification Working Group, 1991), with an effective rooting depth of over 1 000 mm. The parent material is Natal Group Sandstone (Mariannhill Formation, Tulini Member) (Marshall and Von Brunn, 1999).

The other trial was located on the farm 'Thornwood' at Doringkop (29.220 °S, 31.240 °E; 427 m a.s.l.), inland of Darnall (Fig. 1). Mean annual rainfall is just over 1 000 mm annum^{-1}, with most occurring between September and March (Fig. 2B). The mean daily maximum temperature is 26.7 °C and the mean daily minimum 16.5 °C. The soil type is an Inceptisol (Typic Haplustept; Soil Survey Staff, 2014); Leptic Cambisol (IUSS Working Group WRB, 2014); Glenrosa form, Dumisa family (Soil Classification Working Group, 1991), with an effective rooting depth of approximately 800 mm. The parent material is the same as at Inanda.

Pre-trial soil test data for both trial sites are presented in Table 1. The Oxisol had almost 4% organic carbon in the topsoil (0–20 cm), and ≥40% clay to a depth of 80 cm. Effective cation exchange capacity (ECEC) was 8.4 $cmol_c$ L^{-1} in the topsoil, and the soil had low (< 0.25 $cmol_c$ kg^{-1}) nitric acid (slowly available) K resources. In contrast, the Inceptisol had lower organic carbon (≤1.4%) and clay (mean clay 29%) over 0–80 cm. Total cations were also lower in the Inceptisol than in the Oxisol, while nitric K resources were greater in the Inceptisol, at ≥0.7 $cmol_c$ kg^{-1} throughout the profile. The soils displayed similar acid saturations in the topsoil, but the Oxisol had greater acid saturation at depth, with a profile maximum of 60% as compared to 36% in the Inceptisol (Table 1).

The trials were conducted between 2009 and 2014. Both trial sites received rainfall close to the long-term mean (LTM, Inanda 1960–2014; Doringkop 1979–2013) for each crop. There was, however, a severe in-

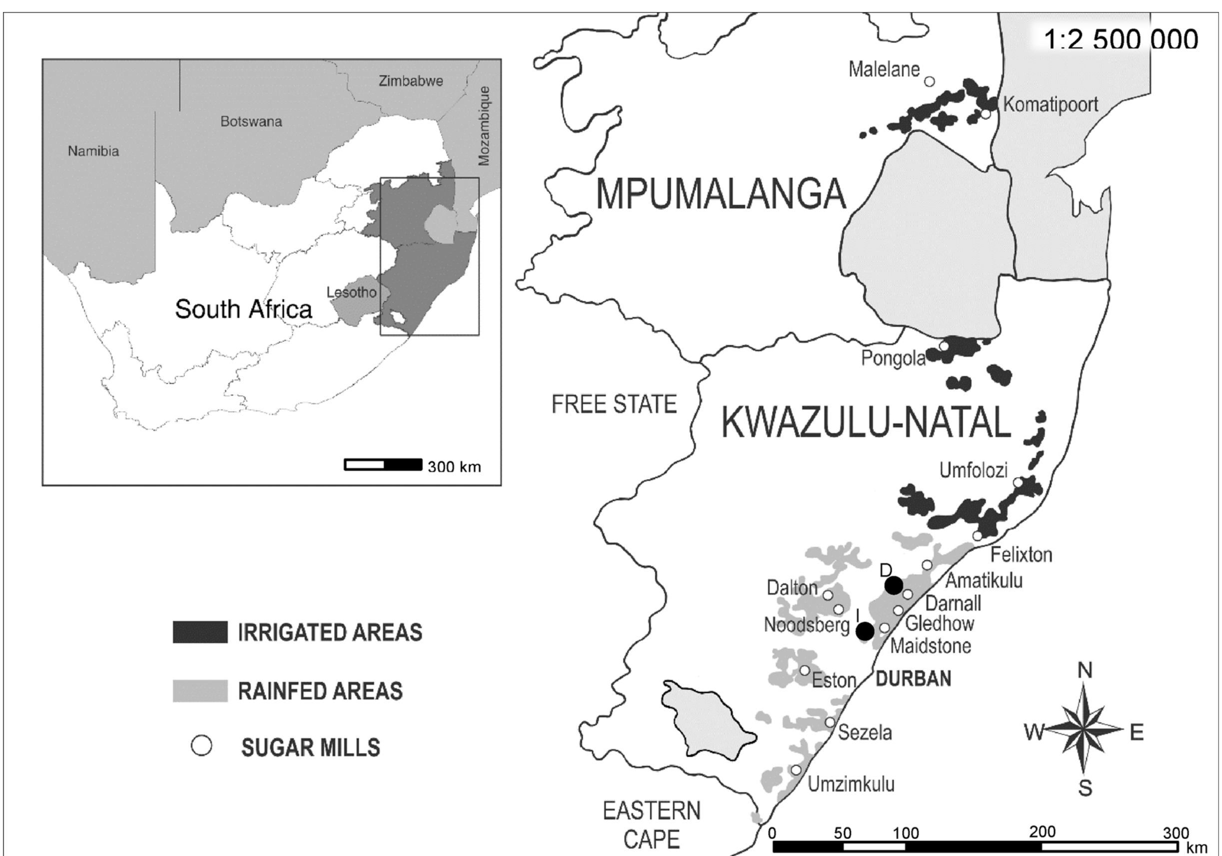

Fig. 1. Situation of trial sites within the South African sugarcane industry. Black circles with 'I' (Inanda/Oxisol) and 'D' (Doringkop/Inceptisol) indicate the location of each trial site.