SHORT, NON-REFEREED PAPER

POTASSIUM DYNAMICS IN THE SOIL-PLANT SYSTEM AND IMPLICATIONS FOR FERTILISER RECOMMENDATIONS

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Abstract

Globally, in the development of potassium (K) fertiliser recommendations, neither non-exchangeable K reserves (reserve-K) nor K fixation are taken into account, due to the difficulties involved in their measurement. However, failure to account for these parameters may contribute to serious inaccuracies in addressing crop K requirements. This study assessed the impacts of including reserve-K and K fixation when developing fertiliser recommendations for sugarcane, and the potential of mid-infrared spectroscopy (MIR) to estimate these parameters. The investigation involved two field trials on soils with contrasting reserve-K and K fixation capacity, as well as a laboratory study on 132 topsoils, which were also used for the calibration and validation of the MIR results. In field trials, K applications increased sucrose yields on the soil with low K reserves and fixation capacity, but not on a soil with high K reserves and fixation capacity. In the laboratory study, wide variations in reserve-K and K fixation capacity, and the relationship between these parameters, were observed. Introducing reserve-K and K fixation factors in the development of fertiliser recommendations resulted in significant reductions in average K requirements. The reserve-K MIR calibration was robust, with a coefficient of determination (r^2) of 0.91 and ratio of performance to deviation (RPD) of 3.36, while the calibration for K fixation capacity had r^2 of 0.71 and RPD of 1.85. This study points to the potential improvements in the reliability of K recommendations, which would result from the routine measurement of K reserves and fixation capacity by MIR.

Keywords: fertiliser recommendations, mid-infrared spectroscopy, potassium fixation, reserve-K, soil K testing, sugarcane

Introduction

Wide variations in soil properties require accurate diagnosis of soil potassium (K) status upon which fertilizer K recommendations are based. Accurate diagnosis of K status will be possible when measurements describing K dynamics in the plant-soil system are included in routine soil K testing. Measurements of exchangeable K, clay content, base status (exchangeable Ca and Mg), together with K reserves and fixation would give a complete picture of K availability to crops (Wood and Meyer, 1986). Current soil K testing and the corresponding fertiliser recommendations are based on exchangeable K and the thresholds are adjusted according to the clay content and base status (Wood and Meyer, 1986; Donaldson *et al*., 1990). It is proposed that including the measurements of K reserves and fixation in current soil K testing will improve the reliability of fertiliser recommendations. Previous studies have emphasised the importance of K reserves and fixation when formulating fertiliser recommendations (Miles and Farina, 2014; Elephant and Miles, 2016). Studies investigating the implications of including both K reserves and fixation capacity in the formulation of fertiliser recommendations are lacking, due to the difficulties involved in their measurements. This study assesses the impacts of including both K reserves and fixation when developing fertiliser recommendations for sugarcane and the potential of mid-infrared spectroscopy (MIR) to estimate these parameters for purposes of routine analysis.

Materials and Methods

Field trials

Two field trials were conducted at Umfolozi (December 2012 to November 2016) and Doringkop (November 2011 to May 2016). At Umfolozi the soil was an Oakleaf form (clay = 35%, organic carbon = 0.73%, pH_{CaCl2} = 5.31, exchangeable K = 110 mg L^{-1}), with high levels of reserve-K (3.84 $cmol_c kg^{-1}$) and high K fixation (KRF = 4.44), while at Doringkop it was a Sweetwater soil form (clay = 33%, organic carbon = 2.45%, pH_{CaCl2} = 4.60, exchangeable K = 110 mg/L), with low levels of reserve-K (0.58 $cmol_c kg^{-1}$) and medium K fixation (KRF = 3.24). Potassium was applied at 0, 120 and 240 kg K ha^{-1} at the commencement of the trials and after sugarcane harvest. Three ratoons were harvested at Umfolozi, and one plant crop and two ratoons at Doringkop. Sucrose yields were measured after each harvest.

Laboratory studies

The investigation involved 132 topsoil samples that varied widely in clay content (5-70%), organic carbon (0.44-9.72%), pH_{CaCl2} (3.70-6.92), and total cations (1.4-38.7 $cmol_c kg^{-1}$). The release of K from non-exchangeable reserves was measured using 1.0 *M* boiling HNO_3 and termed reserve-K. The capacity of the soil to fix added K was estimated through six weeks incubations and termed the K requirement factor (KRF, the amount of fertiliser K required to raise exchangeable K by a single unit; Johnston *et al*., 1999). Modifications to recommendations to account for reserve-K were adapted from Haysom (1971) and for K fixation, current recommendations were multiplied by a ratio of measured KRF/3.

Mid-infrared spectroscopy

The MIR calibrations for reserve-K and KRF were developed using wet chemistry data for 112 soils on Bruker Optics: Tensor 2, HTS-XS, which employs partial least squares, and developed models were validated using 20 soils.

Results and Discussion

Field trials

There was no sucrose yield response to K application ($p > 0.05$) at Umfolozi, on the soil with high reserve-K and K fixation (Figure 1a). On the soil with low reserve-K and fixation K, significant sucrose yield increase to K application was evident in the second ratoon crop only (Figure 1b). Delayed response to K application has been observed in previous studies (Chapman 1980; Wood and Meyer 1986) and in the current study it is most likely associated with a decline in exchangeable K with time in the control plot (data not shown) which is in agreement with findings by Chapman (1980). The depletion of exchangeable K is related to the levels of reserve-K, while the combination of high reserve-K and high K fixation is suggested to regulate exchangeable K levels.

Laboratory studies

Wide variations in reserve-K and K fixation capacity were observed (Figure 1c). These variations should be accounted for in soil K testing because they influence crop response to applied K. Furthermore, there were wide variations in the relationship between reserve-K and K fixation capacity (Figure 1d). These variations have implications for K availability and fertiliser requirements and may be associated with the release rate of reserve-K. Wood and Schroeder (1991) found that soils with low reserve-K had higher release rates compared to those with high reserve-K; this finding contradicts kinetics studies which show that release of reserve-K follows first order kinetics, i.e. it depends on the levels of reserve-K (Martin and Sparks, 1985). The various combinations of reserve-K and K fixation capacity may explain these discrepancies.

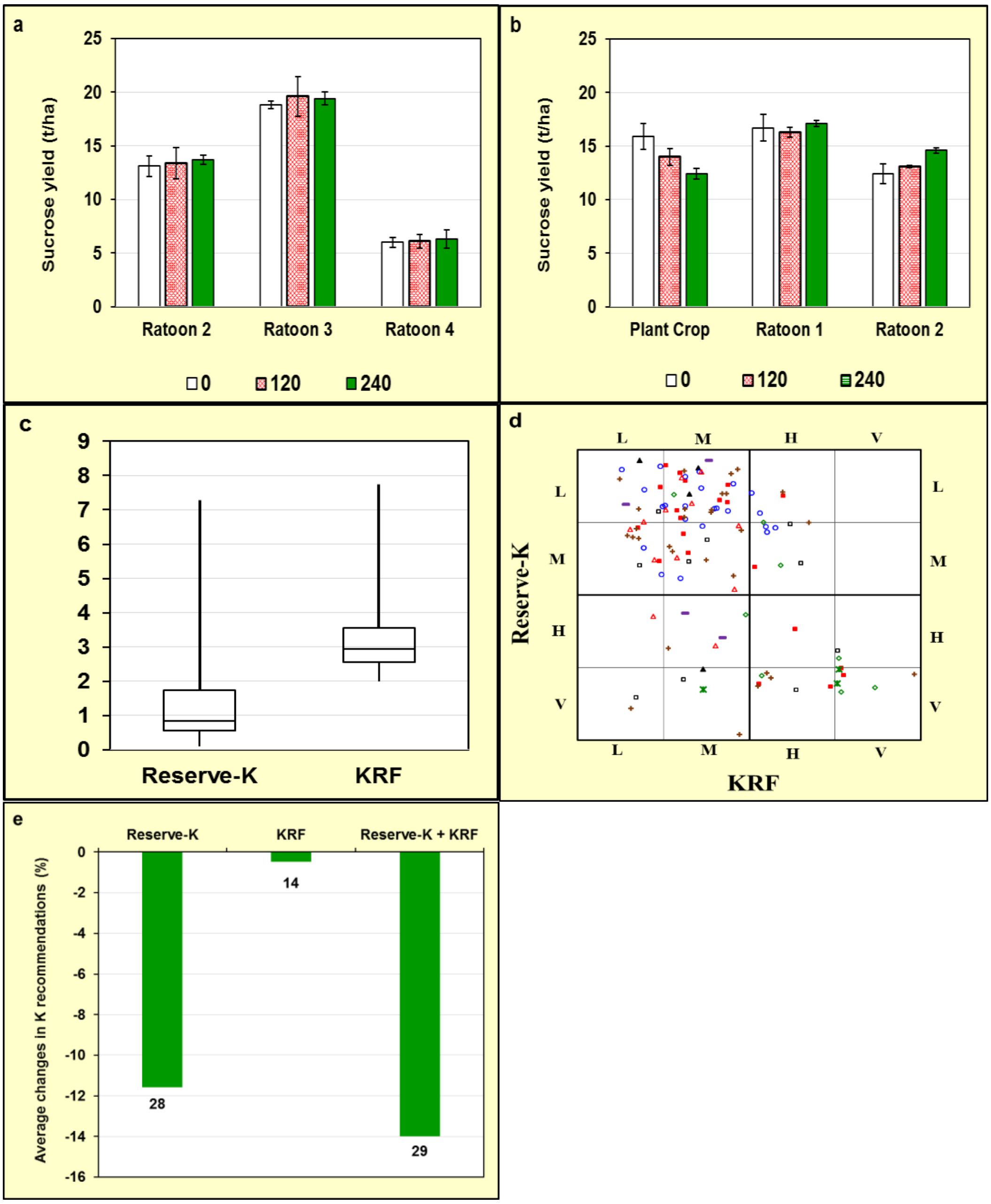

Figure 1: Sucrose yields response to potassium (K) application at Umfolozi (a) and Doringkop (b); (c) variations in reserve-K and K requirement factor (KRF) for 132 topsoils as indicated by boxplot; (d) a grid representation of various combinations of the reserve-K and KRF; and (e) changes in K recommendations as a result of including reserve-K, KRF, and both reserve-K and KRF when formulating K requirements. Vertical bars on yield response graphs represent standard error bars. Numbers in the bar charts represent standard deviation for a given data set.

Introducing reserve-K and fixation factors in the development of fertiliser recommendations resulted in significant reductions in average K requirements (Figure 1e). The current approach appears to overestimate K requirements, due to overestimated K fixation for soils that have low to medium reserve-K and low KRF. Similarly, for samples with a combination of high to very high reserve-K and low KRF, the current approach will underestimate reserve-K and overestimate K fixation capacity, which will consequently overestimate K requirements.

Mid-infrared spectroscopy

Reserve-K had a robust MIR calibration with a coefficient of determination (r^2) of 0.91 and ratio of performance to deviation (RPD) of 3.36, while the calibration for K fixation capacity had r^2 of 0.71 and RPD 1.85. The prediction of reserve-K using the MIR model and an independent validation set was successful with r^2 of 0.79 and standard error of prediction (SEP) of 0.78 compared to the model for KRF which had r^2 of 0.66 and SEP of 0.50 (Figure 2). Thus, the MIR reserve-K calibration is suitable to estimate reserve-K while the KRF calibration should be used only for screening purposes.

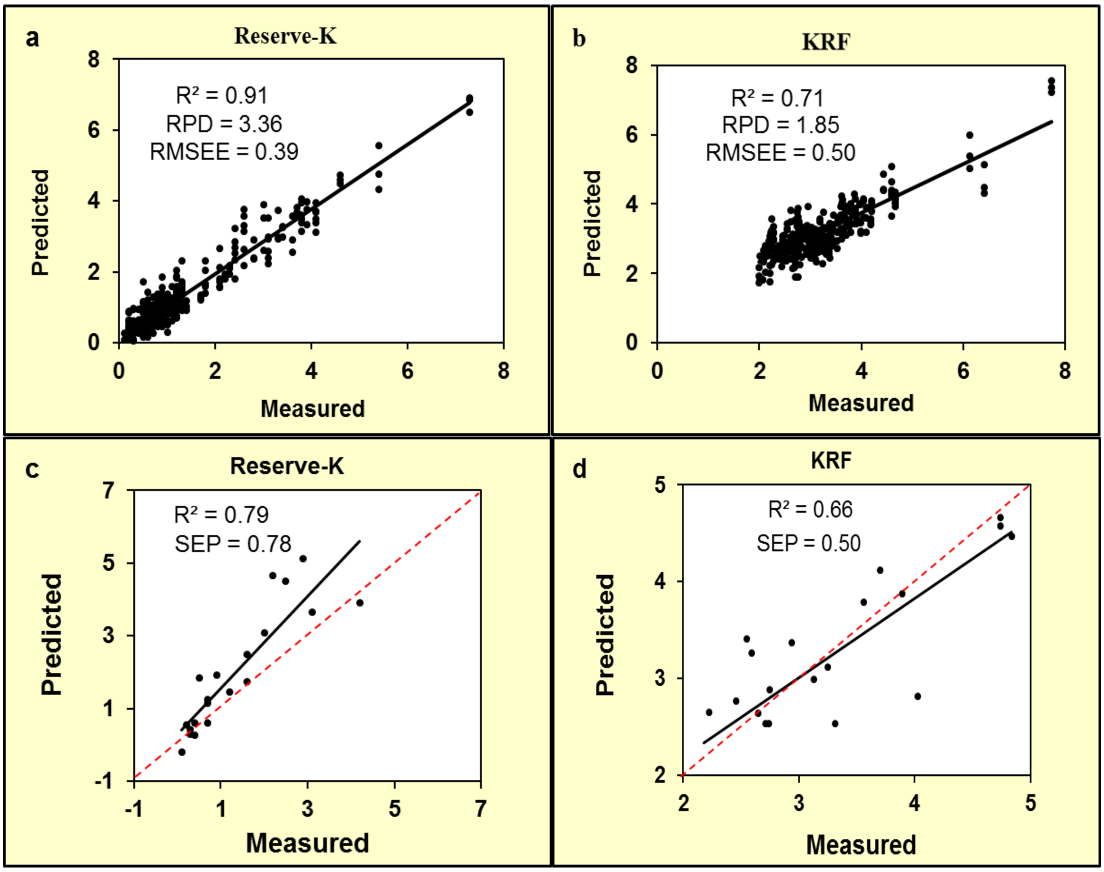

Figure 2. Mid-infrared (MIR) calibrations for (a) reserve-potassium (K) and (b) K requirement factor (KRF) and the corresponding prediction of (c) reserve-K and (d) KRF on an independent validation set. Coefficient of determination (r^2) and ratio of performance to deviation are MIR model quality indicators.

Conclusion

This investigation has underlined the importance of including reserve-K and fixation capacity in soil K testing and in the subsequent development of fertiliser K recommendations. The evidence that these parameters can be measured using MIR is of major significance in terms of their inclusion in routine soil testing programmes.

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