

JCU ePrints

This file is part of the following reference:

Nake, Steven (2010) *Potassium fixation and release in alluvial clay soils of Milne Bay, Papua New Guinea: effects of management under oil palm*. Masters (Research) thesis, James Cook University.

Access to this file is available from:

<http://eprints.jcu.edu.au/16179>



**POTASSIUM FIXATION AND RELEASE IN ALLUVIAL
CLAY SOILS OF MILNE BAY, PAPUA NEW GUINEA:
EFFECTS OF MANAGEMENT UNDER OIL PALM**

Dissertation submitted by:

Steven Nake

in August 2010

A thesis submitted in partial fulfillment of the requirement for the degree of
Master of Science (by Research) in the School of Earth and Environmental
Sciences at James Cook University, Cairns, Queensland



STATEMENT OF ACCESS

I, the undersigned author of this thesis, understand that James Cook University will make it available for others to use. All users consulting this thesis will have to sign the following statement:

“In consulting this thesis, I agree not to copy or closely paraphrase it in whole or part without the written consent of the author; and to make proper written acknowledgement for any assistance which I have obtained from it”.

Beyond this, I do not wish to place any restriction on access of this thesis.

28/2/2011

.....

Steven Nake

.....

Date

DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

28/2/2011

.....

.....

Steven Nake

Date

ACKNOWLEDGEMENT

First, I would like to express my sincere gratitude to Australian Centre for International Agricultural Research (ACIAR) for kindly offering me the scholarship under the “John Allwright Fellowship” to study in Australia.

I am deeply obliged to my supervisor, Dr. Paul Nelson. His great supervision and bright ideas helped me complete this thesis. I thank him very much for his patience, enthusiasms in reading, discussing and rewording the drafts of this thesis. I am also indebted to Sue Berthelsen for helping me out with all the soil analysis for this work and with the interpretation of some of the analysis results. I wish to thank Nick Salmon for his technical support. Thanks to John Broughton and Jeremy Kinley for helping out with the laboratory work. I would like to convey thanks to John Armour (Department of Environment and Resource Management) for providing some of the equipments used in the laboratory work.

Many thanks to Ian Orrell (Managing Director, PNGOPRA) for allowing me time away from work to conduct this study. Special thanks to Dr. Harm van Rees for providing technical advice and support, especially with the field work. Thanks to Dr. Murom Banabas for his assistance in providing some of the information required for the completion of the thesis. Thanks also to Mrs Pole Crompton (Administrator, PNGOPRA) for providing the logistical support. I am indebted to Wawada Kanama (Agronomy Supervisor) and all his field staff in Milne Bay Research Centre for helping out with the field work.

The following people also provided moral support and encouragement and I am heartily thankful to them: Dr. Mike Webb (CSIRO), Elizabeth Smyth, John Berthelsen, Hanington Tate, Titus Kakul and Anton Lata.

Finally, but not the least, special thanks to my wife (Barbra) and the kids (Genesis, Nathan and Crystal) for their invaluable support and encouragement throughout this adventure. I dedicate this thesis to them.

ABSTRACT

Potassium deficiency is pronounced in oil palm and other crops on alluvial clay soils of Milne Bay Province in Papua New Guinea. These clay soils contain clay minerals that can fix K. This, coupled with large amounts of exchangeable Mg and Ca, triggers the K deficiency problem in oil palm growing in this area. Oil palm yield and other growth parameters had responded positively to K fertiliser application for the last 12-13 years in long-term factorial fertiliser trials. However, a K use efficiency study showed that 40% of the added K was taken up by the oil palm while more than 50% had accumulated in the top 60 cm of the soil. There is currently limited information to explain why K accumulated in the soil and the implications for management. Fixation of K could be one of the factors contributing to K accumulation. Therefore, this study was carried out to determine fixation and release characteristics of K in alluvial clay soils under oil palm cultivation in relation to soil and management factors.

All the work was carried out using soil samples collected in 2007 from plots with different K fertiliser history in two long-term fertiliser trials, trial 502b and 504, which had been operating since 1995 and 1994, respectively. Soil mineralogy was predominantly smectite in trial 502b and vermiculite in trial 504. In Experiment 1 (Chapter 3), the effects of management (K fertiliser history and surface management) on the amounts and forms of K in the soil was examined by measuring exchangeable (ammonium acetate extractable) and non-exchangeable (sodium tetraphenyl borate extractable minus ammonium acetate extractable) K. The results showed that in both trial sites, the management zones receiving K fertilizer (frond pile [FP], frond tip [FT] and between other zones [BZ]) had significantly ($p < 0.001$) higher concentration of both exchangeable and non-exchangeable K than the other zones (weeded circle [WC] and harvest path [HP]). The exchangeable and non-exchangeable K concentrations differed significantly between sites, and there was a significant interaction between sites and K fertiliser history. In the plots and zones that had received fertiliser, exchangeable and non-exchangeable K contents were higher in trial 502b than 504, whereas in the plots that had received no fertiliser they were higher in trial 504 than 502b. In the plots that had received no K fertiliser, contents of exchangeable and non-exchangeable K were very low and could be considered deficient at both sites. The difference between the two sites was related to the mineralogy of the soils.

In Experiment 2 (Chapter 4), the effects of site and previous management on K fixation were determined. Solutions with nine different concentrations of KCl (equivalent to 0, 3.2, 9.6, 12.8, 16.0, 19.2, 22.4 and 25.6 mmol K kg⁻¹ soil) were added to the soil, centrifuged and decanted.

Exchangeable K was then extracted from the soil with 1 M ammonium acetate. The decanted equilibrium solutions and ammonium acetate extracts were analysed for K using an atomic absorption spectrophotometer. Fixed K was determined using the formula: Fixed K = added K minus decanted equilibrium solution K minus ammonium acetate extractable K. Potassium fixation was significantly ($p < 0.001$) affected by the K fertiliser history and surface management. In soils and zones that had received no K fertiliser, an average of 27% of added K was fixed in both trials, whereas in the plots with a history of K fertiliser, there was little net fixation or release in the WC zone and a considerable release of non-exchangeable K in the BZ and FP zones.

In Experiment 3 (Chapter 5), the release of K from non-exchangeable form into solution was studied. Firstly, the exchangeable K in the soil was removed by rinsing the soil three times with 0.25 M CaCl_2 . Then the soil was equilibrated with 0.01 M CaCl_2 for 480 hours. At various intervals during that period, the supernatant was removed, analysed for K, and replaced with fresh 0.01 M CaCl_2 . In the plots that had received no K fertiliser, more K was released from the native non-exchangeable pool in trial 504 than trial 502b. In the plots that had received K fertiliser, a substantial amount of K was released. In those plots more K was released in trial 502b than 504. In both trials, more K was released from the FP zones than the other zones, and K release in both trials increased in the order; HP < WC < BZ < FT < FP. The kinetics of K release from non-exchangeable K pool was described well by the Elovich function in all samples ($r^2 = 0.957-0.989$; $se = 0.002-0.179$). Over all samples, the parameters α and $1/\beta$ were linearly related to the amount of non-exchangeable initially present; i.e. the rate of release of non-exchangeable K was positively related to the amount present. The rate of release was greater for trial 502b than trial 504.

This study showed that management has a large effect on the fixation and release of K in alluvial soils of PNG under oil palm cultivation. Soil behaviour differed considerably between management zones, suggesting that K fertiliser placement might have a considerable effect on uptake efficiency.

Table of Contents

STATEMENT OF ACCESS.....	ii
DECLARATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT.....	v
Table of Contents.....	vii
List of Tables	ix
List of Figures.....	x
1 Introduction.....	1
1.1 Background and aims.....	1
1.2 Literature review.....	2
1.2.1 Role of K in plant nutrition.....	2
1.2.2 Potassium bearing minerals	3
1.2.3 Crystalline silicate clays	4
1.2.4 The 1:1 silicate clays.....	5
1.2.5 The 2:1 silicate clays.....	5
1.2.6 Forms of soil potassium.....	8
1.2.7 Methods of evaluating K availability in soil.....	10
1.2.8 Factors affecting K availability in clay soils.....	12
1.3 Conclusions.....	21
2 Site description.....	22
2.1 Introduction.....	22
2.2 Trial 502b and 504 descriptions.....	23
2.2.1 Trial 502b.....	23
2.2.2 Trial 504.....	25
2.3 Climate.....	27
2.4 Soil characteristics	29
2.4.1 Soil physical characteristics.....	29
2.4.2 Soil chemical properties.....	31
2.4.3 Soil mineralogy.....	31
2.5 Conclusions.....	32
3 Forms of potassium in soil.....	33
3.1 Introduction.....	33
3.2 Materials and methods	33
3.2.1 Experimental design and soil sampling	33
3.2.2 Laboratory analysis.....	36
3.3 Results.....	38
3.3.1 Soil organic C content, pH, exchangeable acidity, electrical conductivity (EC) and clay content	38
3.3.2 Particle size distribution.....	41
3.3.3 Exchangeable cations and non-exchangeable K.....	42
3.4 Discussion.....	45
3.5 Conclusions.....	47
4 Fixation of potassium.....	48
4.1 Introduction.....	48

4.2	Materials and methods	50
4.2.1	Field work – soil sampling.....	50
4.2.2	Soil treatment and laboratory analysis	50
4.3	Results.....	51
4.3.1	Exchangeable K content	51
4.3.2	Net fixation of K.....	53
4.3.3	K fixation as a proportion of that added (net).....	55
4.3.4	K exchange isotherms	56
4.4	Discussion	57
4.5	Conclusions.....	58
5	Release of non-exchangeable potassium into solution	60
5.1	Introduction.....	60
5.2	Materials and methods	61
5.2.1	Field work – soil sampling.....	61
5.2.2	Soil treatment and laboratory analysis	61
5.3	Results.....	62
5.3.1	Cumulative K release.....	62
5.3.2	Cumulative K release as a proportion of the non-exchangeable K.....	64
5.3.3	Kinetics of K release	66
5.4	Discussion	69
5.5	Conclusions.....	71
6	General discussion	72
6.1	Factors affecting forms of K, K fixation and K release.....	72
6.1.1	Effects of trial site.....	72
6.1.2	Effects of K fertiliser application history.....	74
6.1.3	Effects of surface management.....	76
6.2	Yield response of oil palm in relation to forms of K, K fixation and K release characteristics of the soils	76
6.3	Implications for plantation management	77
6.4	Conclusions.....	78
7	Bibliography	79

List of Tables

Table 1. Methods used to measure various conceptual soil K pools	11
Table 2. CEC Values for different soil colloids.....	16
Table 3. Amount of fertiliser and EFB used in Trial 502b	24
Table 4. Amount of fertiliser used in Trial 504	26
Table 5. Trial 502 soil profile description (control plot)	30
Table 6. Trial 504 soil profile description (control plot)	30
Table 7. Soil chemical properties for trial 502b and 504.....	31
Table 8. The soil mineralogy and total elemental analysis from the 0-10 and 70-80 cm depth increments from trials 502b and 504.....	32
Table 9. Treatment details for plots from which soil samples were taken.	35
Table 10. Significance (p values) of treatment effects on soil chemical properties.	39
Table 11. Soil chemical properties (mean of 2 replicate plots).	40
Table 12. Particle size determination (PSD) of the soils in trial 502b and 504.....	42
Table 13. Correlation coefficients (r) between between selected soil chemical properties in trial 502b and 504	47
Table 14. Significance of treatments effects (p values) on exchangeable K content at each value of added K.	52
Table 15. Amounts of exchangeable K (mmol kg^{-1}) in the different treatments and at various levels of added K.....	52
Table 16. Significance of treatment effects (p values) on fixed K content at each value of added K.	54
Table 17. Amounts of K fixed (mmol kg^{-1} soil) with the different treatments and at various levels of added K	54
Table 18 Treatment effects on cumulative amount of K released (mmol K kg^{-1} soil) at different times	63
Table 19. Elovich curve fitting to cumulative K release (mmol kg^{-1}), from Sigma Plot for each treatments.....	67
Table 20. Main effect of MOP on yield and leaf K content at the two trial sites over the 2005-2007 period.	77

List of Figures

Figure 1. Chemical structure of mica (muscovite)	4
Figure 2. The Potassium Cycle	8
Figure 3. Equilibrium relationship between the three K pools in soils.....	15
Figure 4. Map of Papua New Guinea, indicating location of Milne Bay Province	23
Figure 5. Trial 502b, main effects of SOA and MOP on yield and tissue nutrient concentration over the duration of the trial.....	25
Figure 6. Main effects of SOA and MOP on yield and tissue nutrient concentration over the duration of Trial 504.	27
Figure 7. Annual rainfall recorded at Waigani and Sagarai estate for the last 23 years (1987-2008).....	28
Figure 8. Monthly rainfall recorded at Waigani and Sagarai estate for the last 23 years (1987-2008).....	28
Figure 9. Surface management zones in two inter-rows at the two sites	35
Figure 10. Mean contents of soil (a) organic C content, (b) electrical conductivity (EC), (c) pH and (d) exchangeable acidity for the different treatments.....	41
Figure 11. Proportion of silt and clay found in the plots with a history of no K fertiliser in trials 502b and 504.....	42
Figure 12. Mean contents of exchangeable (a) Ca, (b) Mg, (c) effective cation exchange capacity (ECEC) and (d) K.	43
Figure 13. Mean non-exchangeable K contents for the different treatments.....	44
Figure 14. Soil exchangeable K content versus net added K in the two trials (502b and 504) in plots with (+K) or without (-K) a history of K fertiliser application	53
Figure 15. Proportion of net added K that was fixed in WC, BZ and FP zones in trials 502b and 504.....	55
Figure 16. Exchange isotherms and amounts of fixed K in the two trials (502b and 504) in plots with (+K) or without (-K) a history of K fertiliser application.	56
Figure 17. Release of non-exchangeable K into solution in trial 502b and 504.	64
Figure 18. K release as a proportion of non-exchangeable K in trial 502b and 504.	65

Figure 19. Relationship between cumulative release of non-exchangeable K and the amount initially present.....66

Figure 20. Release rate parameter for trial 502b and trial 504, as a function of the amount of non-exchangeable K measured prior to the release experiment.68