

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Phosphate rock fertilisers to enhance soil P status  
and P nutrition on organic cropping farms.**

**A thesis presented in partial fulfilment of the  
requirements for the degree of  
Master of Plant Science  
at Massey University**

**Scott Robert Shaw**

**2009**





# Massey University

College of Sciences

Institute of Natural Resources  
Agronomy  
Private Bag 11 222  
Palmerston North,  
New Zealand  
Telephone: 64 6 356 9099  
Facsimile: 64 6 350 5632

## CERTIFICATE OF REGULATORY COMPLIANCE

This is to certify that the research carried out in the Masterate Thesis entitled Phosphate rock fertilisers to enhance soil P status and P nutrition on organic cropping farms, in the Institute of Natural Resources (Agronomy) at Massey University, New Zealand:

- (a) is the original work of the candidate, except as indicated by appropriate attribution in the text and/or in the acknowledgements;
- (b) that the text, excluding appendices/annexes, does not exceed 40,000 words;
- (c) all the ethical requirements applicable to this study have been complied with as

required by Massey University, other organisations and/or committees (The New Zealand Institute for Plant and Food Research Ltd) which had a particular association with this study, and relevant legislation.

**Candidate's Name: Scott Robert Shaw**

**Supervisor's Name: Dr. James Millner**

**Signature:**

**Signature:**

**Date:**

**Date:**

**Co-Supervisor's Name: Dr. Stephen Trolove**

**Signature:**

**Date:**



## ABSTRACT

The soils used by the East Coast Organic Producers Trust (ECOPT; the grower group that this study is targeted towards) have exceptionally low soil Olsen P concentrations (ca. 6 mg/L). These and other limitations (e.g. poor weed and pest and disease control) result in many ECOPT growers being unable to produce economic yields on anything other than small scale gardens. Fertilisers and manures are seldom used by these growers, which exacerbates the problem. Thus, the object of this research was to provide information to ECOPT on which fertilisers and application strategies would provide the best returns on their phosphorus (P) fertiliser investment.

The experimental work was carried out in two parts. A laboratory study tested a range of phosphate rock (PR) based fertilisers and application rates; Ben Guerir reactive phosphate rock (RPR; 67, 133, 267, 533 and 1,333 mg P/kg soil), BioPhos and BioSuper (267 and 1,333 mg P/kg soil) and a no fertiliser Control. Soil fertiliser mixtures were incubated for 155 days and periodic measurements of PR dissolution, soil pH and Bic-P (analogous to Olsen P but expressed in  $\mu\text{g/g}$ ) were undertaken. The field study used fewer application rates and two application methods; banded and broadcast.

Broadcast plots were applied at 678 mg P/kg soil (488 kg P/ha); banded RPR was applied at 236, 678 and 1475 mg P/kg soil (40, 115 and 250 kg P/ha respectively) and banded BioPhos and BioSuper at 678 mg P/kg soil (115 kg P/ha). A Control was also included. Fertilisers were applied in October 2004 and changes in soil pH and Bic-P were measured in the broadcast plots only over a 344 day period. Potato (*Solanum tuberosum* L. cv. Desiree) was the test crop.

Regression analysis was used to generate exponential equations to describe the changes in Bic-P over time ( $\Delta\text{Bic-P}$ ). Differences between fertilisers in the amount of P dissolved and pH fluxes were used to explain the differences in  $\Delta\text{Bic-P}$ . BioSuper dissolved quicker and generated greater  $\Delta\text{Bic-P}$  than RPR and BioPhos, which were similar. Higher application rates produced greater increases in Bic-P than lower rates but decreased the % of P applied that dissolved. The increase in Bic-P over time from

fertiliser application was much slower in the field compared with the laboratory. This was put down to differences in experimental conditions; mainly soil pH and soil aggregate surface area.

Potato tuber yield (mean = 35 t/ha) did not respond to any of the fertiliser treatments despite a significant increase in P concentration of the shoots mid-way through the season in all broadcast treatments (shoot P concentration was not analysed in the banded plots). Water and N availability were the main limiting factors in this season as the crop was not irrigated and soil N supply was insufficient to produce a full canopy.

Phosphorus response curves generated using the fertiliser response model PARJIB (Reid, 2002), and an economic analysis, indicated that for RPR and BioPhos the optimum economic application rate was 200 kg P/ha and for BioSuper it was 100 kg P/ha (applied every third and second year respectively).

## ACKNOWLEDGEMENTS

I am extremely grateful for, and would like to acknowledge the commitment, guidance and support of my supervisors Dr Stephen Trolove and Dr James Millner throughout this research project. Thank you both!

Thanks also to Dr Huub Kerckhoffs, without your support this research would not have been possible. I would also like to acknowledge one of my greatest mentors Dr Peter Stone. And Dr Jeff Reid and Robert Zykowski for your time spent assisting with the crop-model simulations. Also, Isabel Sorensen for your help in the laboratory.

Special thanks go to Moana Puha for your technical input and enthusiasm on our long and sometimes extended trips away to the East Coast, and to your parents John and Violet Puha for their hospitality when we stayed with them. Thank you also Wallace and Roberta Atkins for hosting the field experiment. I learnt a lot from you both and was truly humbled by your commitment, patience and perseverance. You are great leaders for the region and your lead-by-example style is exactly what the region needs more of. Keep up the great work!

Finally, thanks to all the wonderful people I met on "the Coast" during the time I spent there. I look forward to meeting each of you again in future.

This research was funded by the Foundation for Science Research and Technology (FRST), under the research program - Science for Community Change (contract C02X0305).

# CONTENTS

Abstract.....	i
Acknowledgements.....	iii
Contents.....	iv
List of figures.....	vi
List of tables.....	viii
List of abbreviations.....	x
Chapter 1.....	1
1 Introduction.....	1
1.1 Production Limitations Of The East Coast Organic Producers Trust.....	1
1.2 Problem background.....	4
1.3 Objectives.....	6
Chapter 2.....	7
2 Literature Review.....	7
2.1 Phosphorus nutrition.....	7
2.1.1 Phosphorus nutrition in organic agriculture.....	7
2.1.2 Plant response to phosphate rock fertilisers.....	8
2.1.3 Fertiliser placement and incorporation.....	11
2.2 Phosphate rock dissolution and agronomic effectiveness.....	12
2.2.1 Reactivity and particle size.....	14
2.2.2 Proton supply.....	15
2.2.3 Products of dissolution.....	17
2.2.4 Soil moisture and texture.....	18
2.2.5 Time.....	19
2.2.6 Application rate.....	21
2.2.7 Measuring phosphate rock dissolution.....	21
2.3 Beneficiation of phosphate rock using organically approved methods.....	23
2.3.1 BioPhos.....	24
2.3.2 BioSuper.....	28
2.4 Summary.....	30
Chapter 3.....	34
3 Laboratory study.....	34
3.1 Overview.....	34
3.2 Objectives.....	35
3.3 Methodology.....	36
3.3.1 Treatment preparation.....	36
3.3.2 Sample preparation and analysis.....	37
3.3.3 Data analysis.....	38
3.4 Results.....	39
3.4.1 Physical and chemical properties of the soil and fertilisers.....	39
3.4.2 Fertiliser dissolution.....	41
3.4.3 Changes in soil pH.....	44
3.4.4 Changes in Bic-P.....	46
3.5 Discussion.....	50
3.6 Conclusions.....	55

Chapter 4 .....	57
4 Field study .....	57
4.1 Overview .....	57
4.2 Objectives .....	58
4.3 Methodology .....	59
4.3.1 Site .....	59
4.3.2 Experimental .....	60
4.3.3 Soil sampling .....	61
4.3.4 Crop management .....	62
4.3.5 Crop measurements .....	64
4.3.6 Climate measurements .....	65
4.3.7 Data analysis .....	65
4.4 Results .....	66
4.4.1 Environment .....	66
4.4.2 Crop .....	69
4.4.3 Soil .....	78
4.5 Discussion .....	82
4.6 Conclusions .....	89
Chapter 5 .....	91
5 Integrating laboratory and field studies .....	91
5.1 Introduction .....	91
5.2 Calibrating the laboratory models .....	92
5.2.1 Approach .....	92
5.2.2 Outcomes .....	93
5.2.3 Curve smoothing .....	93
5.2.4 Curve calibration .....	95
5.3 Economic analysis .....	97
5.3.1 Approach .....	97
5.3.2 Outcomes .....	98
5.3.3 Discussion .....	103
5.4 Differences in $\Delta\text{Bic-P}$ between laboratory and field studies .....	104
5.4.1 Soil pH .....	105
5.4.2 Soil aggregate size distribution .....	108
5.4.3 Soil moisture .....	110
5.4.4 Soil temperature .....	111
5.5 Summary .....	112
Chapter 6 .....	115
6 Summary and Conclusions .....	115
7 Appendices .....	119
Appendix 1 .....	119
Appendix 2 .....	121
Appendix 3 .....	123
References .....	125

## LIST OF FIGURES

Figure 1.1. Eastland district, New Zealand. Inset is the location of the field experiment.....	3
Figure 2.1. Changes over time in the amount of P dissolved and Bic-P from phosphate rock applied at 800 µgP/g soil.....	20
Figure 2.2. Changes in soil solution P after application of 800 mg P/kg soil of single superphosphate and BioPhos compared with no fertiliser .....	26
Figure 3.1. Changes in the amount P dissolved over time for RPR, BioPhos and BioSuper applied at two application rates.....	41
Figure 3.2. Changes in the amount P dissolved over time for RPR, BioPhos and BioSuper applied at two application rates.....	42
Figure 3.3. Changes in soil pH over time for RPR, BioPhos and BioSuper at two application rates .....	45
Figure 3.4. Changes in Bic-P over time relative to the Control for RPR, BioPhos and BioSuper at two application rates.....	48
Figure 3.5. Fit of the model $\Delta Bic-P = -B(1-R^x)$ describing changes in Bic-P over time for RPR, BioPhos and BioSuper.....	49
Figure 3.6. The relationship between Bic-P and P dissolved from RPR, BioPhos and BioSuper .....	49
Figure 3.7. The relationship between fertiliser P application rate and <i>B</i> parameter values for the equation $y = -B(1-R^x)$ .....	51
Figure 3.8. Expected changes in Bic-P over time for various rates of RPR, BioPhos and BioSuper under field conditions .....	52
Figure 3.9. Yield response of potato to different Olsen P concentrations. ....	54
Figure 4.1. Mean monthly rainfall for Hicks Bay.....	58
Figure 4.2. The crop on 17 January 2005.....	62
Figure 4.3. Proportion of aggregates in each size class. ....	67
Figure 4.4. Planted rows on planting date (20 October 2004) .....	70
Figure 4.5. The crop on 3 December 2004.....	70
Figure 4.6. The crop on 15 December 2004 (early flowering).....	71
Figure 4.7. The crop on 6 January 2005 (late flowering). ....	71
Figure 4.8. The crop on 17 January 2005 (post flowering) .....	72
Figure 4.9. The relationship between soil moisture content (% w/w) measured on 16 February 2005 and log <sub>10</sub> of tuber yield measured on 22 February 2005. ....	73
Figure 4.10. Changes in soil pH over time for RPR, BioPhos and BioSuper applied at 678 mg P/kg soil.....	78

Figure 4.11. Changes in Bic-P over time for RPR, BioPhos and BioSuper applied at 678 mg P/kg soil .....	81
Figure 4.12. Simulated SWD, soil (mineral) nitrogen, green leaf area index and crop yield/biomass graphs from the Potato Calculator for the potato crop grown in the field experiment .....	83
Figure 4.13. The relationship between changes in Bic-P and soil moisture content as measured on 16 February 2005 .....	87
Figure 5.1. Smoothed curves of changes in Bic-P over time for RPR/BioPhos and BioSuper applied at 67, 133, 267, 533 and 1333 mg P/kg soil .....	93
Figure 5.2. Natural log (Ln) of the predicted vs. observed Bic-P at 155 days after fertiliser application using the smoothed models.....	93
Figure 5.3. Changes in Bic-P over time for the laboratory and field experiments for RPR/BioPhos and BioSuper applied at 678 mg P/kg soil.....	94
Figure 5.4. Modelled changes in the fraction of the Bic-P value from the field study compared with the DAFA adjusted laboratory study data.....	95
Figure 5.5. Forecast yield response in relation to application rate and days after fertiliser application for BioSuper and RPR or BioPhos .....	98
Figure 5.6. Comparison between the modelled changes in pH over time in the Control treatments of the field and laboratory studies .....	106
Figure 5.7. Surface area per kg soil (m <sup>2</sup> /kg soil) for various sized soil aggregates.....	108
Figure 5.8. The relationship between the change in Bic-P per unit of P applied and P-saturation from the laboratory study.....	109
Figure 5.9. Soil moisture content fluxes over the growing season in the top 10 cm of the soil profile of the field study .....	110

## LIST OF TABLES

Table 1.1. Selected soil chemical properties of 14 paddocks of the East Coast Organic Producers Trust.....	3
Table 2.1. Total P content and solubility in various chemical extractants of a range of different phosphate rocks.....	14
Table 2.2. Chemical analysis of BioPhos. ....	24
Table 2.3. Tomato yield and quality components for single super phosphate and BioPhos applied at 120 kg P/ha .....	26
Table 2.4. Total (yam bean) shoot biomass and pH of various fertiliser mixtures of PR and elemental sulphur with or without <i>Thiobacilli</i> spp. after 60 day <i>in-vitro</i> incubation; and changes in plant-available P and soil pH after 90 days where 100 kg P/ha was applied .....	29
Table 3.1. Treatment structure and nutrient (P and S) application rates used in the laboratory study.....	36
Table 3.2. Physical and chemical properties of the <2mm sieved soil fraction used in the laboratory study. ....	39
Table 3.3. Physical and chemical properties of the fertilisers used in the laboratory study.....	40
Table 3.4. Percentage dissolution of the PR-based fertilisers on each sample date.....	41
Table 3.5. Parameters for the exponential equation ( $\Delta P = -B(1-R^x)$ ) describing the percent dissolution of RPR, BioPhos and BioSuper over time at different application rates .....	43
Table 3.6. Changes in soil pH for RPR, BioPhos and BioSuper on each sample date .....	44
Table 3.7. Changes in Bic-P relative to the Control for each sample date. ....	46
Table 3.8. Parameters for the exponential equation $\Delta Bic-P = -B(1-R^x)$ describing the changes in Bic-P over time at different fertiliser application rates .....	48
Table 4.1. Treatment structure and nutrient application rates for the field study .....	60
Table 4.2. Soil fertility parameters for the 0-15 and 15-30 cm depth increments.....	66
Table 4.3. Key climate variables for the field experiment .....	68
Table 4.4. P concentration (% w/w) of the shoots and tubers .....	69
Table 4.5. In season estimates of crop leaf area index and measured shoot and tuber biomass at final harvest.....	76
Table 4.6. Tuber yield and size distribution at final harvest.....	76
Table 4.7. Tuber common scab ( <i>Streptomyces</i> spp.) scores.....	77
Table 4.8. Changes in soil pH over time.....	77
Table 4.9. Changes in Bic-P relative to the Control at an application rate of 678 mg P/kg soil.....	79

Table 4.10. Parameters for the exponential equation $\Delta Bic-P = -B(1-R^x)$ describing the changes in Bic-P over time at an application rate of 678 mg P/kg soil .....	80
Table 5.1. <i>B</i> parameter values for the smoothed curves .....	92
Table 5.2. <i>B</i> parameter values for the smoothed calibrated curves .....	96
Table 5.3. The cost (\$/ha) of each application rate for each fertiliser used in the yield simulations and economic analysis. ....	100
Table 5.4. Phosphate rock persistence, fraction of P applied that was taken up by the crop and total P uptake between reapplications .....	100
Table 5.5. Cumulative net return on investment (\$/ha) for RPR, BioPhos and BioSuper applied at 100, 200, 400 and 1,000 kg P/ha .....	101
Table 5.6. Percentage return on investment (ROI) over 7 years for RPR, BioPhos and BioSuper applied at 100, 200, 400 and 1,000 kg P/ha .....	102

## LIST OF ABBREVIATIONS

<b>Abbreviation</b>	<b>Description</b>	<b>Abbreviation</b>	<b>Description</b>
Al	Aluminium	DM	Dry matter
ANOVA	Analysis of variance	ECOPT	East Coast Organic Producers Trust
ARL	Analytical Research Laboratories	e.g.	Example
BaCl <sub>2</sub> -TEA	Barium chloride-Triethanolamine	F <sup>-</sup>	Fluoride ion
Bic-P	Bicarbonate (pH 8.5) soluble phosphorus (analogous to Olsen P except is expressed as w/w)	Fe	Iron
BioP	BioPhos (ex. Sieber Technologies Ltd)	FRST	Foundation for Research Science and Technology
BioP1	BioPhos applied at 67 mg P/kg soil	FW	Fresh weight
BioP2	BioPhos applied at 133 mg P/kg soil	FRI	Fraction of radiation intercepted
BioP3	BioPhos applied at 267 mg P/kg soil	GAI	Green leaf area index (m <sup>2</sup> /m <sup>2</sup> )
BioP4	BioPhos applied at 533 mg P/kg soil	GDD	Growing degree days
BioP5	BioPhos applied at 1333 mg P/kg soil	ha	Hectare
BioS	BioSuper; a 5:1 blend of Ben Guerir RPR and S <sup>o</sup> (ex. Ravensdown Ltd)	H <sub>2</sub> PO <sub>4</sub>	Phosphoric acid
BioS1	BioSuper applied at 67 mg P/kg soil	HCO <sub>3</sub> <sup>-</sup>	Bicarbonate ion
BioS2	BioSuper applied at 133 mg P/kg soil	i.e.	Specifically
BioS3	BioSuper applied at 267 mg P/kg soil	ICP-OES	Inductively coupled plasma-optical emission spectrometry
BioS4	BioSuper applied at 533 mg P/kg soil	K	Potassium
BioS5	BioSuper applied at 1333 mg P/kg soil	KCl	Potassium chloride
C	Carbon	LAI	Leaf area index (m <sup>2</sup> /m <sup>2</sup> )
Ca	Calcium	LSD <sub>0.05</sub>	Least significant difference at the 5 % probability level
ca.	Circa	MC	Moisture content
CaCO <sub>3</sub>	Calcium carbonate	Mg	Magnesium
CEC	Cation exchange capacity	N	Nitrogen
cf.	Compare	n	Number
CI	Confidence interval	Na	Sodium
DAFA	Days after fertiliser application	NAC	Neutral ammonium citrate
		NaHCO <sub>3</sub>	Sodium bicarbonate
		NH <sub>4</sub> <sup>+</sup>	Ammonium ion
		NO <sub>3</sub> <sup>-</sup>	Nitrate ion
		OH <sup>-</sup>	Hydroxide ion
		P	Phosphorus
		P <sub>i</sub>	Inorganic phosphorus
		PR	Phosphate rock
		P <sub>sat</sub>	P-saturation of the soil (mg P/m <sup>2</sup> soil)
		P <sub>ylid</sub>	Potential yield
		ROI	Return on investment

<b>Abbreviation</b>	<b>Description</b>
RPR	Reactive phosphate rock
RPR1	Ben Guerir RPR applied at 67 mg P/kg soil
RPR2	Ben Guerir RPR applied at 133 mg P/kg soil
RPR3	Ben Guerir RPR applied at 267 mg P/kg soil
RPR4	Ben Guerir RPR applied at 533 mg P/kg soil
RPR5	Ben Guerir RPR applied at 1333 mg P/kg soil
S	Sulphur
S <sup>o</sup>	Elemental sulphur
SA	Specific surface area
SD	Sample date
SF	Scaling factor
SEM	Standard error of the mean
SFP	Soil fertiliser P (concentration)
spp.	Species
SR	Solar radiation
SWD	Soil water deficit
TSP	Triple superphosphate
viz.	Visibly
$X_B^{95}$	DAFA for 95 % of model asymptote (-B)
SFP	Soil fertiliser-P concentration (mg P/kg or l of soil)
$\Delta$ Bic-P	Change in Bic-P
$\Delta$ Ca	Change in Calcium