SULFUR SOURCES FOR FLOODED AND NON FLOODED RICE AND PASTURES

BY

MADE DANA

A THESIS SUBMITTED FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

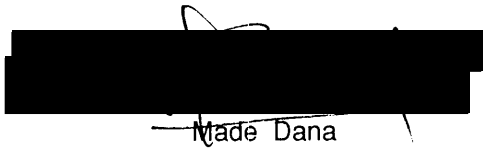
UNIVERSITY OF NEW ENGLAND

FEBRUARY 1992

PREFACE

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree.

I certify that to the best of my knowledge any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.



Made Dana

ABSTRACT

It has long been known that sulfur is an essential element for plant growth, however it has received little attention compared to the three main elements, nitrogen, phosphorus and potassium. Sulfur deficiency in crop production has been reported in many parts of the world and has resulted in a decline in both the quality and quantity of crops. Little information is available on the behaviour of different sources of S in flooded and non-flooded rice and in pasture, hence this study.

Using an S-deficient granitic Aquic Haplustalf soil, two nested experiments planted to rice were conducted in a heated glasshouse of the Department of Agronomy and Soil Science, University of New England. The experimental components were S rate and S source, two water regimes (flooded and non-flooded) and two consecutive crops. In the S rate study, gypsum was applied at rates equivalent to 0, 5, 10 and 20 kg S ha^{-1}. Yield, S uptake and fertiliser S recovery were determined at active tillering (AT), 59 days after transplanting (dat), maximum tillering (MT, 89 dat) and maturity (M, 144 dat). The effectiveness of six commercial S-containing fertilisers, gypsum (G), elemental sulfur (E) of particle size < 0.01 mm, urea-S melt (US), sulfur-coated urea (SCU), elemental S coated triple superphosphate (HF) and S bentonite (SB), and three experimental elemental S coated triple superphosphates (TSP) which were developed at the University of New England, were investigated in comparison to a zero S control (C). In the experimental coatings, three different adhesives were used to bind elemental S to the TSP : polyvinyl alcohol (PVA), calcium ligno sulfonate (LS) and slack wax (SW). In the S source experiment, all fertilisers were applied at 10 kg S ha^{-1}. In both experiments S was applied to the first crop only. The release of S from the fertilisers was also investigated at different growth stages (AT, MT and M). The use of ^{35}S labelled soil allowed the study of fertiliser transformation and movement through the soil and plant system.

In the S response study and under both flooded and non-flooded conditions, there was a significant response in grain yield and total S uptake with applications up to 20 kg S ha^{-1}. The percentage recovery of applied fertiliser S in the whole plant declined with increasing S application rate at each growth period.

In the first crop under flooded conditions, highest grain yields were recorded in the G, PVA and LS treatments and the lowest in the SB and control (C) treatments. In this crop, the highest recovery of fertiliser S in the whole plant was recorded in the G treatment (51.6 %), whilst the lowest rate was in the SB treatment (23.1%). The ranking of the recovery of fertiliser S in the whole plant was G > PVA = LS > US = E = SW ≥ HF > SCU = SB.

In the second flooded crop, grain yield and recovery of fertiliser S in the whole plant were inversely related to that in the first crop. The highest grain yield was recorded in the SB treatment, although this was not significantly different from SCU, HF, SW, US, E, PVA and LS treatments, and the lowest grain yield was in the control, although this was similar to that of G. The recovery of fertiliser S was directly related to the grain yield; 39.6 % of the fertiliser S was recovered in the SB compared to 14.3 % in the G treatment.

In general, a similar trend in grain yield and fertiliser S recovery was observed under non-flooded and flooded conditions. The exception was in the SCU treatment where the yield and fertiliser S recovery in the whole plant, relative to gypsum, as higher under non-flooded than flooded conditions.

The effectiveness of different S and P sources was also evaluated on pastures. This experiment was conducted in the glasshouse using intact pasture cores containing the same soil as in the rice experiments and consisted of a factorial combination of 2 S sources : elemental S (E) and gypsum (G), 2 P sources : triple superphosphate (TSP) and rock phosphate (RP), 2 methods of S and P application (S mixed with the granulated TSP or granulated rock phosphate and S coated to TSP or RP granules) and two soil moisture conditions (leached and non-leached treatments). One non-fertilised treatment (C) was included in the experiment under both soil moisture regimes in order to calculate the percentage of S in plant derived from the fertiliser. In this experiment, the same amounts of S (20 kg S ha^{-1}) and P (40 kg P ha^{-1}) were applied in all fertilised treatments. At the same time, a separate experiment was also undertaken to study the effectiveness of different S coated fertilisers under non-leached conditions. In this experiment, five S coated fertilisers : PVA, LS, HF, SW and TSP + gypsum (G) and one non-fertilised treatment (C) were evaluated. Data for the PVA and C treatments were derived from the main experiment. The soil cores were oversown with perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) and once these species were established. Harvesting was conducted every four to eight weeks up to 96 weeks, depending on the growth rate of the pastures. The reverse dilution ^{35}S technique was used to enable fertiliser S recovery to be calculated.

The combination of triple superphosphate (TSP) with gypsum resulted in a higher yield than that of the combination of elemental S with TSP in the early harvests. The TSP combinations produced higher yields than the rock phosphate treatments. A higher S loss through leaching was also recorded in the gypsum compared to the elemental S treatments. Under non-leached conditions, the cumulative recovery of fertiliser S in the gypsum treatments did not differ significantly from that in the elemental S treatments. However, under leached

conditions, a higher recovery of fertiliser S in the pasture tops was found in the elemental S than in the gypsum treatments.

The comparison of different S sources in this experiment showed that the G treatment produced the highest yield in the early harvests (13.5 g pot^{-1} at weeks 4 + 8), but significantly lower than that of PVA and LS 24 weeks after application. HF and SW produced the lowest response in the early harvest and did not differ from that of PVA and LS after week 17. The lowest yield was recorded in the control. These differences were generally reflected in the S content and the recovery of the fertiliser S in the harvested pasture.

Up to week 8, highest recovery of fertiliser S (35.7 %) was recorded in the G treatment compared to less than 11 % in the other sources. After week 17, G treatment resulted in the lowest recovery (6.0 % at weeks 24 + 28 and 2.9 % at weeks 36 + 44). Among the elemental S sources PVA and LS resulted in a higher recovery than SW and HF up to week 17 with the reverse recorded after this time.

The release rate of S from the different sources and physical tests of the S-coated fertilisers were also undertaken. These tests included the physical strength against frictional forces and simulated raindrop impact. The strength of S-coated fertilisers (PVA, LS, SW and HF) against frictional forces was tested in a friabilator, whilst the strength against simulated rain drop impact was conducted in a leaching bed. When the fertilisers were tested in the friabilator the PVA, LS and SW showed stronger physical characteristics than those of HF. After 32 minutes rotation in the friabilator, 0.08, 0.09 and 0.07 % of the S coat was lost from the PVA, LS and SW granules respectively. These losses were lower than those from HF (0.70 %). In contrast, HF granules exhibited stronger physical characteristics than those of PVA and LS when these materials were tested in the leaching bed. After 3 hours of leaching 25.4 % and 29.3 % of elemental S were lost from the PVA and LS granules respectively. These were higher than those of HF (6.8 %).

A computer model of S release developed in an earlier study was used to predict the oxidation rate of elemental S applied at different times and with different particle sizes at two temperate and two tropical locations in Australia. The simulations showed that total oxidation over one calendar year to be 96.5 % at Armidale, 86.3 % at Dalwallinu, 99.9 % at Darwin and 100 % at Cairns. Generally, elemental S with fine particle size (<100 μm) was oxidized more quickly than the coarser soon after application both in temperate and tropical areas which resulted in an excessive S release compared to the S demand of pastures.

More field trials are required to test the agronomic and economic effectiveness of these materials in order to establish their potential as efficient S sources.

ACKNOWLEDGMENTS

I gratefully acknowledge the Department of Soil Science, Faculty of Agriculture, Udayana University of Indonesia for my leave of absence to undertake this study and the International Development Program (IDP), the Australian International Development Assistance Bureau (AIDAB) and the Australian Centre for International Agricultural Research (ACIAR) for financial support.

I would like to express my sincere appreciation to my supervisors A/Prof. Graeme Blair and Dr. Rod Lefroy for their continuous guidance, suggestions and encouragement during the conduct of this study and for their valuable comments on the preparation of this thesis. I wish to express my grateful thanks to Dr. A. R. Till for his supervision during the earlier stage of this study.

I am grateful for the guidance given by Dr. Jim Scott in the use of the seed-coating device used to make S-coated fertilisers.

I acknowledge Dr. Malcolm MacCaskill and Mr. Geoff Anderson for their valuable help and suggestions for the S model.

I received substantial assistance in taking soil samples, performing experiments, and conducting soil and plant analyses from Judy Gaudron, Leanne Lisle, Michael Faint, Ian Cowan, Matthew Monk, Gary Cluley, Greg Chamberlain and Nell Deane of the Department of Agronomy and Soil Science, the University of New England; I thank them very much for their assistance.

Other personnel at the University of New England I would like to thank include : Dr. Ian Davies for his statistical advice, Dr. David Evans for helping me in English and the staff of the Electron Microscope Unit and Media Resources for their generous assistance in making electron micrographs and taking the photographs, respectively.

I am also grateful to my postgraduate colleagues and many other members of the Department of Agronomy and Soil Science for their warm social relations, which encouraged me in various ways.

Finally, I wish to sincerely acknowledge my parents Ketut Karma and Ni Wayan Puri, my wife, Ria, along with my lovely son, Indra Pratama, for their understanding and support during the period of this study.

TABLE OF CONTENTS

	Page
PREFACE	ii
ABSTRACT	iii
ACKNOWLEDGMENT	vi
TABLE OF CONTENTS	vii
LIST OF TABLES	ix
LIST OF FIGURES	xi
LIST OF APPENDICES	xiii
CHAPTER 1	
INTRODUCTION	1
CHAPTER 2	
REVIEW OF LITERATURE	4
2.1 Introduction	4
2.2 Global sulfur cycle	5
2.3 The agricultural sulfur cycle	7
2.3.1 Atmospheric sulfur	9
2.3.2 Hydrospheric sulfur	9
2.4 Roles and requirement of sulfur in plant nutrition	10
2.4.1 Role of sulfur in plant nutrition	10
2.4.2 Sulfur requirement of plants	11
2.5 Form and transformation of organic and inorganic sulfur in soil	12
2.5.1 Forms of organic sulfur in soil	12
2.5.2 Distribution of organic sulfur in soil	13
2.5.3 Transformation of organic S in soil	14
2.6 Inorganic sulfur	14
2.6.1 Adsorption and desorption of sulfate	15
2.6.2 Oxidation of elemental sulfur	17
2.6.3 Sulfur from fertilisers	22
CHAPTER 3	
SULFUR SOURCES FOR FLOODED AND NON-FLOODED RICE	25
3.1 Introduction	25
3.2 Materials and methods	26
3.2.1 Soil and pot preparations	26
3.2.2 Treatment, experimental design and statistical analysis	27
3.2.3 Basal nutrients and ^{35}S labelling	28
3.2.4 Crop management	30
3.3 Results - first flooded crop	32
3.3.1 Response to gypsum	32
3.3.2 Comparison of S sources	35
3.4 Results - second flooded crop	42
3.4.1 Response to gypsum	42
3.4.2 Comparison of S sources	44
3.5 Results - first non-flooded crop	48

3.5.1 Response to gypsum 48
3.5.2 Comparison of S sources 51
3.6 Results - second non-flooded crop 58
3.6.1 Response to gypsum 58
3.6.2 Comparison of S sources 60
3.7 Discussion 64

CHAPTER 4
SULFUR AND PHOSPHORUS SOURCES FOR PASTURES 73
4.1 Introduction 73
4.2 Materials and methods 74
4.3 Results - S and P sources experiment 78
4.3.1 Yield 78
4.3.2 S content 83
4.3.3 P content 86
4.3.4 Percentage of S derived from the fertiliser 87
4.3.5 Recovery of the fertiliser S 88
4.3.6 S and P loss through leaching 90
4.3.7 Soil S pools 91
4.4 Results - S sources experiment 92
4.4.1 Yield 92
4.4.2 S content 92
4.4.3 P content 92
4.4.4 Percentage of S derived from the fertiliser 93
4.4.5 Recovery of the fertiliser S 94
4.4.6 Soil S pools 94
4.5 Discussion 95

CHAPTER 5
PHYSICAL TESTS OF S COATED FERTILISERS 102
5.1 Introduction 102
5.2 Experiment 1 - Mechanical test 102
5.2.1 Materials and methods 102
5.2.2 Results and discussion 103
5.3 Experiment 2 - Leaching experiment 105
5.3.1 Materials and methods 105
5.3.2 Results and discussion 106

CHAPTER 6
INTEGRATING DISCUSSION AND THE MATCHING OF ELEMENTAL S RELEASE TO PLANT DEMAND 111
6.1 Effectiveness of S to crops as affected by agricultural management 111
6.2 The use of computer simulation to develop coatings to match S release rate to plant demand 113
6.2.1 Introduction 113
6.2.2 S release from different particle sizes 114
6.3 Future research and development required 119

BIBLIOGRAPHY 121

APPENDICES 138

LIST OF TABLES

Table 2.1	Sulfur content of selected crops at harvest.	11
Table 2.2	The S content of fertiliser S sources available.	24
Table 3.1	Soil characteristics.	26
Table 3.2	Source and rate of applied fertiliser.	28
Table 3.3	Basal nutrient application rate.	30
Table 3.4	Amount of N and P added to balance the nutrients in each pot.	30
Table 3.5	The effect of S-application rate on dry matter yield of plant components at different growth stages under flooded conditions.	32
Table 3.6	The effect of S-application rate on S content of rice at different growth stages under flooded conditions.	33
Table 3.7	The effect of S-application rate on the percentage of fertiliser S incorporated into the extractable S and organic S at different growth stages under flooded conditions.	34
Table 3.8	The effects of different S sources on relative yield of the whole plant and grain at different growth stages under flooded conditions.	36
Table 3.9	The effect of different S sources on relative S content of the whole plant at different growth stages under flooded conditions.	37
Table 3.10	The effect of different S sources on percentage of S derived from the fertiliser in the whole plant at different growth stages under flooded conditions.	38
Table 3.11	Rate and total of fertiliser S uptake by rice at different growth stages as affected by different sources of S under flooded conditions.	39
Table 3.12	The effect of different sources of S on percentage of fertiliser S incorporated into the extractable S and organic S at different growth stages under flooded conditions.	41
Table 3.13	Total oxidation and oxidation rate of elemental S as affected by different sources of S at different growth stages under flooded conditions.	42
Table 3.14	The residual effect of S-application rate on dry matter yield of plant components under flooded conditions.	42
Table 3.15	The residual effect of S-application rate on S content of plant components under flooded conditions.	43
Table 3.16	The residual effect of different sources of S on relative dry matter yield of plant components under flooded conditions.	45
Table 3.17	The residual effect of different sources of S on relative S content of plant components under flooded conditions.	46
Table 3.18	The residual effect of different S sources on percentage of S derived from the fertiliser in plant components under flooded conditions.	46
Table 3.19	The residual effect of different S sources on recovery of the fertiliser S in different plant parts under flooded conditions.	47
Table 3.20	The residual effects of different sources of S on the percentage of fertiliser S incorporated into extractable S and organic S under flooded conditions.	48
Table 3.21	The effect of S-application rate on dry matter yield of plant components at different growth stages under non-flooded conditions.	49
Table 3.22	The effect of S-application rate on S content of plant components at different growth stages under non-flooded conditions.	49
Table 3.23	The effects of S application rate on the percentage of fertiliser S incorporated into the extractable S and organic S at different growth stages under non-flooded conditions.	51

Table 3.24 The effect of S source on relative plant yield at different growth stages under non-flooded conditions. 53
Table 3.25 The effect of S source on relative S content of plant at different growth stages under non-flooded conditions. 54
Table 3.26 The effect of S source on percentage of S derived from the fertiliser in the whole plant and grain at different growth stages under non-flooded conditions. 55
Table 3.27 Rate and total fertiliser-S uptake at different growth stages as affected by different sources of S under non-flooded conditions. 56
Table 3.28 The effect of different S sources on percentage of fertiliser S incorporated into the extractable S and organic S at different growth stages under non-flooded conditions. 57
Table 3.29 Total oxidation and oxidation rate of elemental S as affected by source of S at different growth stages under non-flooded conditions. 58
Table 3.30 The residual effect of S-application rate on dry matter yields of plant components under non-flooded conditions. 58
Table 3.31 The residual effect of S-application rate on S content of plant under non-flooded conditions. 59
Table 3.32 The residual effect of different S sources on relative dry matter yield of plant components under non-flooded conditions. 61
Table 3.33 The residual effect of S source on relative S content of plant components under non-flooded conditions. 62
Table 3.34 The residual effect of different S sources on percentage of plant S derived from the fertiliser under non-flooded conditions. 62
Table 3.35 The residual effect of different S sources on total fertiliser-S uptake by plants under non-flooded conditions. 63
Table 3.36 The residual effects of different sources of S on the percentage of fertiliser S incorporated into the extractable S and organic S under non-flooded conditions. 64
Table 4.1 Basal nutrient application rates. 75
Table 4.2 Treatments and treatment codes for pasture experiment. 76
Table 4.3 Source and rate of S and P applied under non-leached conditions. 77
Table 4.4 The effects of S and P sources on P content of pastures under leached and non-leached conditions. 86
Table 4.5 The effect of S and P sources on percentage of S in the tops derived from the fertiliser under leached and non-leached conditions. 87
Table 4.6 The effect of S and P sources on percentage of S in leachate derived from the fertiliser. 90
Table 4.7 The effect of S source on dry weight, S and P content of plant tops at different harvest times. 93
Table 4.8 The effect of S source on the percentage of S in pastures derived from the fertiliser at different harvest times. 94
Table 4.9 The effect of S source on the recovery of fertiliser S in pastures at different harvest times. 94
Table 6.1 Dry matter yield, S content and rate of fertiliser S uptake by flooded and non-flooded rice fertilised with gypsum at 5 mg S kg^{-1} soil. 111
Table 6.2 Effect of different particle sizes on the annual oxidation of elemental S at four locations in Australia. 115

LIST OF FIGURES

Figure 2.1 The major natural and anthropogenic pool sizes and fluxes of the global biogeochemical S cycle. 6
Figure 2.2 S utilisation in crop and animal production. 7
Figure 2.3 S pools and fluxes simulated by a computer model and calculated annual S fluxes over a 10-year period for pasture system to which no S is added, and one receiving 43 kg S ha^{-1} yr^{-1}. 8
Figure 2.4 Change in particle radius, surface area, S release for a constant unit release rate using the spherical particle model. 21
Figure 3.1 The effect of S application rate on percentage of S derived from the fertiliser in different plant parts at different growth stages under flooded conditions. 33
Figure 3.2 The effect of S application rate on the percentage of fertiliser S incorporated into the plant components at different growth stages under flooded conditions. 34
Figure 3.3 The effect of different S sources on number of tillers at different growth stages under flooded conditions. 36
Figure 3.4 The residual effect of S-application rate on percentage of S derived from the fertiliser in different parts of plant under flooded conditions. 43
Figure 3.5 The residual effect of S-application rate on the percentage of fertiliser S incorporated into the plant components under flooded conditions. 44
Figure 3.6 The effect of S application rate on percentage of S derived from the fertiliser in different parts of the plant at different growth stages under non-flooded conditions. 50
Figure 3.7 The effect of S-application rate on the percentage of fertiliser S incorporated into the plant components at different growth stages under non-flooded conditions. 50
Figure 3.8 The effect of different S sources on number of tillers at different growth stages under non-flooded conditions. 53
Figure 3.9 The residual effect of S-application rate on percentage of S derived from fertiliser by different plant parts under non-flooded conditions. 59
Figure 3.10 The residual effect of S-application rate on the percentage of fertiliser S incorporated into the plant components under non-flooded conditions. 60
Figure 3.11 The percentage of fertiliser S incorporated into the grain, stem + leaf, root, unoxidized elemental S, extractable S and organic S after the first crop under flooded and non-flooded conditions. 68
Figure 3.12 The initial and residual effects of different S sources on grain yield at the same rate of S application under flooded and non-flooded conditions. 70
Figure 3.13 Summary diagram showing the fate of fertiliser S applied into the two successive crops under flooded and non-flooded conditions. 71
Figure 3.14 Prediction of S oxidation of elemental S and correlation between predicted S oxidation and observed S oxidation under flooded and non-flooded conditions. 72
Figure 4.1 The effects of different S and P sources on dry weight of clover under leached and non-leached conditions. 79
Figure 4.2 The effect of different S and P sources on dry weight of grass under leached and non-leached conditions. 80
Figure 4.3 The effect of different S and P sources on total tops dry weight under leached and non-leached conditions. 82

Figure 4.4 The effect of different S and P sources on total tops S content under leached and non-leached conditions. 85
Figure 4.5 The effect of different S and P sources on the recovery of fertiliser S in plant tops under leached and non-leached conditions. 89
Figure 4.6 The effect of different S and P sources on the recovery of fertiliser S in leachates. 91
Figure 4.7 The effect of S and P sources on the percentage of fertiliser S incorporated into the plant and soil components under leached and non-leached conditions. 98
Figure 4.8 The effect of S source on the percentage of fertiliser S incorporated into the plant and soil component. 100
Figure 4.9 Prediction of elemental S oxidation and correlation between predicted S oxidation and recovery of S in plants from different S sources. 101
Figure 5.1 Effect of fertiliser source and rotation time on fertiliser loss during the rotating period. 104
Figure 5.2 Effect of fertiliser source and rotation time on elemental S loss during the rotating period. 104
Figure 5.3 Cross-section of S-coated fertiliser and areas where scanning microprobe was used. 105
Figure 5.4 Effect of fertiliser source and leaching time on percentage of elemental S lost through leaching. 106
Figure 5.5 Effect of fertiliser source and leaching time on loss of calcium and phosphorus through leaching. 107
Figure 5.6 Scanning micrograph of S-coated fertiliser prior and after 24 hours of leaching. 107
Figure 5.7 Electron micrographs of cross-section of coated fertilisers treated in leaching bed for 24 hours. 109
Figure 5.8 Coated fertiliser dispersion in distilled water at different observation times. 110
Figure 6.1 Prediction of S demand of pastures under non-limiting nutrient condition and oxidation of elemental S as affected by temperature, moisture, application times and particle sizes in two temperate locations in Australia. 117
Figure 6.2 Prediction of S demand of pastures under non-limiting nutrient condition and oxidation of elemental S as affected by temperature, moisture, application times and particle sizes in two tropical locations in Australia. 118

LIST OF APPENDICES

3.1 Examples of variance analysis using NEVA computer program. 138
3.2 The effect of S-application rate on yield components at different growth stages under flooded conditions. 140
3.3 The effect of S application rate on extractable S and organic S at different growth stages under flooded conditions. 140
3.4 The effect of S sources on yield components at maturity under flooded conditions 141
3.5 The effect of S sources on relative yield of plant components at different growth stages under flooded conditions. 141
3.6 The effect of S sources on relative S content of plant parts at different growth stages under flooded conditions. 142
3.7 The effect of different S sources on extractable S at different growth stages under flooded conditions. 143
3.8 The effect of S sources on organic S at different growth stages under flooded conditions. 144
3.9 The residual effect of S application rate on yield components under flooded conditions. 144
3.10 The residual effect of S application rate on extractable S and organic S under flooded conditions. 144
3.11 The residual effect of S application rate on the percentage of fertiliser S incorporated into the extractable S and organic S fractions under flooded conditions. 145
3.12 The residual effect of S sources on yield components under flooded conditions. 145
3.13 The residual effect of different sources of S on extractable S, organic S and acetone-extractable elemental S under flooded conditions. 145
3.14 The effect of S application rate on yield components at different growth stages under non-flooded conditions. 146
3.15 The effect of S application rate on extractable S and organic S at different growth stages under non-flooded conditions. 146
3.16 The effect of S sources on yield components at maturity under non-flooded conditions. 146
3.17 The effect of S sources on relative yield of plant components at different growth stages under non-flooded conditions. 147
3.18 The effect of S sources on relative S content of plant components at different growth stages under flooded conditions. 148
3.19 The effect of S sources on extractable S at different growth stages under non-flooded conditions. 149
3.20 The effect of different sources of S on organic S at different growth stages under non-flooded conditions. 149
3.21 The residual effect of S application rate on yield components under non-flooded conditions. 149
3.22 The residual effect of S application rate on extractable S , organic S and recovery of fertiliser S in these fraction under non-flooded conditions. 150
3.23 The residual effect of different S sources on yield components under non-flooded conditions. 150
3.24 The residual effect of different sources of S on extractable S and organic S under non-flooded conditions. 150
4.1 Main effects and interaction terms for the clover yield occurring with C, S, P, and L factors when analysis was performed at each harvest. 151

4.2 Main effects and interaction terms for the grass yield occurring with C, S, P, and L factors when analysis was performed at each harvest. 151
4.3 Main effects and interaction terms for the pasture yield occurring with C, S, P, and L factors when analysis was performed at each harvest. 152
4.4 The effects of S and P sources on dry weight, S content, P content, percentage of S derived from the fertiliser and the recovery of fertiliser S in root under leached and non-leached conditions. 152
4.5 Main effects and interaction terms for the clover S content occurring with C, S, P, and L factors when analysis was performed at each harvest. 152
4.6 The effects of S and P sources on clover S content under leached and non-leached conditions. 153
4.7 Main effects and interaction terms for the grass S content occurring with C, S, P, and L factors when analysis was performed at each harvest. 154
4.8 The effects of S and P sources on grass S content under leached and non-leached conditions. 155
4.9 Main effects and interaction terms for the pasture S content occurring with C, S, P, and L factors when analysis was performed at each harvest. 156
4.10 Main effects and interaction terms for the pasture P content occurring with C, S, P, and L factors when analysis was performed at each harvest. 156
4.11 Main effects and interaction terms for the percentage of S in pastures derived from the fertiliser occurring with C, S, P, and L factors when analysis was performed at each harvest. 157
4.12 Main effects and interaction terms for the recovery of fertiliser S in pastures occurring with C, S, P, and L factors when analysis was performed at each harvest. 157
4.13 Main effects and interaction terms for the S content of leachate occurring with C, S and P factors when analysis was performed at each harvest. 158
4.14 The effects of S and P sources on the S content of leachate at each observation time. 158
4.15 Main effects and interaction terms for the P content of leachate occurring with C, S and P factors when analysis was performed at each harvest. 158
4.16 The effects of S and P sources on the P content of leachate at each observation time. 159
4.17 Main effects and interaction terms for the percentage of S in leachate derived from the fertiliser occurring with C, S and P factors when analysis was performed at each harvest. 159
4.18 Main effects and interaction terms for the recovery of fertiliser S in leachates occurring with C, S and P factors when analysis was performed at each harvest. 159
4.19 The effects of S and P sources on extractable S, organic S, percentage of S derived from the fertiliser and the recovery of fertiliser S in these fractions under leached and non-leached conditions. 160
4.20 The effects of S and P sources on total P content of soil under leached and non-leached conditions. 160
4.21 The effects of different S sources on extractable S, organic S, percentage of S derived from the fertiliser and recovery of the fertiliser S in these fractions. 161
4.22 The effect of different S sources on total P content of soil. 161