Drying/rewetting cycles in southern Australian agricultural soils: effects on turnover of soil phosphorus, carbon and the microbial biomass.

A thesis submitted in fulfilment of the degree of Doctor of Philosophy
Soil and Land Systems, School of Earth and Environmental Sciences
The University of Adelaide

Clayton Robert Butterly
B.Sc. (Hons) Murdoch University

January, 2008
Dedicated to my parents, Robert and Betty Butterly
Table of Contents

Table of Contents........................................................................................................ iii
List of Figures................................................................................................................ vii
List of Tables.................................................................................................................. x
List of Appendices.......................................................................................................... xii
Abstract........................................................................................................................ xiii
Declaration...................................................................................................................... xvi
Acknowledgements....................................................................................................... xvii

Chapter 1. Introduction & Review of Literature........................................................... 1
  1.1 PHOSPHORUS IN AGRICULTURE ......................................................................... 1
  1.2 FORMS OF PHOSPHORUS IN SOIL ...................................................................... 2
      1.2.1 Inorganic phosphorus .................................................................................... 2
      1.2.2 Organic phosphorus ...................................................................................... 3
  1.3 THE PHOSPHORUS CYCLE .................................................................................. 4
      1.3.1 Processes decreasing phosphorus in soil solution .............................................. 6
      1.3.2 Processes increasing phosphorus in the soil solution ........................................ 9
  1.4 DRY-REWET CYCLES AND FLUSH EFFECTS ...................................................... 10
      1.4.1 Biological effects ............................................................................................ 12
      1.4.2 Physical/chemical effects ............................................................................... 14
  1.5 FACTORS INFLUENCING FLUSH DYNAMICS ................................................... 15
  1.6 AIMS ..................................................................................................................... 18

Chapter 2. General Methods....................................................................................... 21
  2.1 INCUBATION SYSTEM .......................................................................................... 21
  2.2 WATER-FILLED PORE SPACE ............................................................................. 21
  2.3 MICROBIAL BIOMASS CARBON AND NITROGEN ............................................ 21
  2.4 RESIN/MICROBIAL BIOMASS PHOSPHORUS .................................................... 22
  2.5 EXTRACTABLE ORGANIC CARBON .................................................................. 22
  2.6 TOTAL DISSOLVED NITROGEN ......................................................................... 22
  2.7 DISSOLVED INORGANIC PHOSPHORUS ............................................................ 23
  2.8 TOTAL DISSOLVED PHOSPHORUS, DISSOLVED ORGANIC PHOSPHORUS ........ 23
  2.9 DISSOLVED INORGANIC NITROGEN ................................................................. 23
  2.10 AROMATICITY OF EXTRACTABLE ORGANIC CARBON ................................ 23
  2.11 pH ..................................................................................................................... 24
  2.12 TOTAL CARBON AND NITROGEN ................................................................... 24
  2.13 TOTAL PHOSPHORUS ....................................................................................... 24

Chapter 3. Rewetting CO2 flushes in Australian agricultural soils and the influence of soil properties ................................................................. 26
  3.1 INTRODUCTION .................................................................................................. 26
  3.2 METHODS ........................................................................................................... 27
      3.2.1 Overview ........................................................................................................ 27
      3.2.2 Soil collection and physiochemical properties ............................................... 28
      3.2.3 Soil incubations ............................................................................................. 30
      3.2.4 Drying and rewetting ..................................................................................... 30
      3.2.5 Quantifying respiration flush ....................................................................... 30
Chapter 4. Repeated drying/rewetting of soils with different microbial biomass size and community composition

4.1 INTRODUCTION

4.2 METHODS

4.2.1 Overview

4.2.2 Soil sampling

4.2.3 Carbon sources and nutrient solution

4.2.4 Carbon amendment procedures

4.2.5 Sample preparation

4.2.6 Soil Incubation

4.2.7 Soil respiration

4.2.8 Microbial biomass and nutrient analyses

4.2.9 Microbial community composition by fatty acid methyl ester analysis

4.2.10 Statistical analyses

4.3 RESULTS

4.3.1 Respiration rate

4.3.2 Carbon availability

4.3.3 Phosphorus availability

4.3.4 Microbial biomass size and composition

4.4 DISCUSSION

4.4.1 Carbon mineralisation

4.4.2 Phosphorus availability

4.4.3 Microbial biomass size and community composition

4.5 CONCLUSIONS

Chapter 5. Short-term fluctuations in respiration activity and phosphorus, nitrogen and carbon immediately after rewetting
| Chapter 6 | Long-term effects of drying/rewetting on nutrient pools and the size and composition of the microbial biomass | 102 |
| Chapter 7 | Determining the changes in phosphorus availability after long-term drying and rewetting using a plant bio-assay | 139 |
| Chapter 8 | General Discussion | 157 |

5.4.1 DRW and carbon mineralisation .................................................................96
5.4.2 DRW and nutrient availability ...................................................................98
5.5 CONCLUSIONS .........................................................................................99

6.1 INTRODUCTION ......................................................................................102
6.2 METHODS ...............................................................................................104
  6.2.1 Overview ............................................................................................104
  6.2.2 Field sampling and processing ............................................................104
  6.2.3 Determination of field capacity ...........................................................105
  6.2.4 Pre-treatment soil water regimes .........................................................105
  6.2.5 Experimental drying and rewetting ......................................................107
  6.2.6 Respiration rate ..................................................................................108
  6.2.7 Microbial biomass and nutrient analyses ............................................108
  6.2.8 Phosphomonoesterase activity ...........................................................109
  6.2.9 Microbial community composition ....................................................109
  6.2.10 Statistical analyses ...........................................................................111
6.3 RESULTS ..................................................................................................111
  6.3.1 Soil respiration ....................................................................................111
  6.3.2 Modelling of microbial respiration data ..............................................114
  6.3.3 Carbon availability .............................................................................116
  6.3.4 Phosphorus availability .......................................................................118
  6.3.5 Microbial biomass size and community composition ........................125
6.4 DISCUSSION .............................................................................................131
  6.4.1 Effect of pre-treatment water regime ..................................................131
  6.4.2 Effect of DRW and the influence of pre-treatment soil water regime ....133
  6.4.3 Changes in microbial community composition ....................................135
6.5 CONCLUSIONS .......................................................................................137

7.1 INTRODUCTION ......................................................................................139
7.2 METHODS ...............................................................................................140
  7.2.1 Overview ............................................................................................140
  7.2.2 Field sampling and processing ............................................................140
  7.2.3 Pre-treatment soil water regimes .........................................................140
  7.2.4 Experimental drying and rewetting ......................................................141
  7.2.5 Preparation and growth of wheat seedlings ..........................................142
  7.2.6 Harvesting wheat seedlings .................................................................142
  7.2.7 Microbial biomass and nutrient analyses ............................................143
  7.2.8 Tissue phosphorus determination .......................................................143
  7.2.9 Phosphorus budget .............................................................................143
  7.2.10 Statistical analyses ...........................................................................143
7.3 RESULTS ..................................................................................................144
  7.3.1 Plant growth .......................................................................................144
  7.3.2 Nutrient availability and phosphorus budget .......................................149
7.4 DISCUSSION .............................................................................................153
  7.4.1 Plant growth .......................................................................................153
  7.4.2 Nutrient availability and phosphorus budget .......................................154
7.5 CONCLUSIONS .......................................................................................154

8.1 CONCLUSIONS .......................................................................................162
8.2 FURTHER RESEARCH .............................................................................162
Chapter 9. References ................................................................................................... 165
Chapter 10. Appendices ................................................................................................. 177
List of Figures

Figure 1.1: The phosphorus cycle. Adapted from Stewart and Tiessen (1987)......................5
Figure 1.2: Nutrient cycling during drying and rewetting...................................................11
Figure 3.1: Cumulative C mineralisation (left) and soil C mineralisability (right) for measured (solid) and modelled (hollow) data in soil subjected to DRW (circles) and constantly moist (triangles) controls..........................................................35
Figure 3.2: Carbon mineralisation responses to DRW; (A) increase in $C_{90h}$ and $k$, (B) increase in $k$ and no change in $C_{90h}$, (C) no change in either $C_{90h}$ or $k$ and (D) decrease in $k$ with no change in $C_{90h}$.................................................................38
Figure 3.3: Extractable organic carbon (EOC) in soils immediately after rewetting (1 h) and at the end of the incubation period (90 h). Significant (*) differences ($P<0.05$) between sampling times..........................................................................................41
Figure 3.4: Total dissolved N (TDN) in soils immediately after rewetting (1 h) and at the end of the incubation period (90 h). Significant (*) differences ($P<0.05$) between sampling times..........................................................................................42
Figure 3.5: Dissolved inorganic N (DIN) in soils immediately after rewetting (1 h) and at the end of the incubation period (90 h). Significant (*) differences ($P<0.05$) between sampling times..........................................................................................42
Figure 3.6: Total dissolved P (TDP) in soils immediately after rewetting (1 h) and at the end of the incubation period (90 h). Significant (*) differences ($P<0.05$) between sampling times..........................................................................................43
Figure 3.7: Correlations between $\Delta C_{90h}$ (DRW $C_{90h}$ – Moist $C_{90h}$) and eight soil properties.................................................................................................................................49
Figure 4.1: Respiration rates in moist (M) and DRW (D) soils previously amended with glucose (G), starch (S), cellulose (C) and non-amended (N). Bars indicate standard errors of the mean. Arrows indicate rewetting events.............................................63
Figure 4.2: Cumulative respiration activity in moist (M) and DRW (D) soils previously amended with glucose (G), starch (S), cellulose (C) and non-amended (N). Error bars indicate standard error of the mean. Arrows indicate rewetting events..........64
Figure 4.3: Extractable organic C (EOC) in moist (M) and DRW (D) soils previously amended with glucose (G), starch (S), cellulose (C) and non-amended (N) for soil extractions at the end of pre-incubation (initial) and at 1 h and 7 d after each of 3 DRW cycles. Letters indicate significant differences ($P<0.05$) between DRW treatments for each amended soil.................................................................66
Figure 4.4: Resin extractable P ($P_{resin}$) in moist (M) and DRW (D) soils previously amended with glucose (G), starch (S), cellulose (C) and non-amended (N) for soil extractions at the end of pre-incubation (initial) and at 1 h and 7 d after each of 3 DRW cycles. Letters indicate significant differences ($P<0.05$) between DRW treatments for each amended soil.................................................................68
Figure 4.5: Total dissolved P (TDP) in moist (M) and DRW (D) soils previously amended with glucose (G), starch (S), cellulose (C) and non-amended (N) for soil extractions at the end of pre-incubation (initial) and at 1 h and 7 d after each of 3 DRW cycles. Letters indicate significant differences ($P<0.05$) between DRW treatments for each amended soil.................................................................69
Figure 4.6: Dissolved organic P (DOP) in moist (M) and DRW (D) soils previously amended with glucose (G), starch (S), cellulose (C) and non-amended (N) for soil extractions at the end of pre-incubation (initial) and at 1 h and 7 d after each of 3
Figure 4.7: Microbial biomass C (MBC) in moist (M) and DRW (D) soils previously amended with glucose (G), starch (S), cellulose (C) and non-amended (N) for soil extractions at the end of pre-incubation (initial) and at 1 h and 7 d after each of 3 DRW cycles. Letters indicate significant differences ($P<0.05$) between DRW treatments for each amended soil.

Figure 4.8: Microbial biomass P (MBP) in moist (M) and DRW (D) soils previously amended with glucose (G), starch (S), cellulose (C) and non-amended (N) for soil extractions at the end of pre-incubation (initial) and at 1 h and 7 d after each of 3 DRW cycles. Letters indicate significant differences ($P<0.05$) between DRW treatments for each amended soil.

Figure 4.9: Principal component analysis of fatty acid methyl ester (FAME) profiles as indicator of microbial community composition within moist (M) and DRW (D) soils previously amended with glucose (G), starch (S), cellulose (C) and non-amended (N) at the end of the study. Bars indicate stand error of the mean.

Figure 4.10: Vector plot of PCA showing signature fatty acid methyl ester (FAME) associated with fungi, gram positive (G+ve) and gram negative bacteria (G-ve).

Figure 5.1: Respiration rate in soils subject to DRW (black squares) and moist incubated controls (top) and without (bottom) glucose. LSD = 0.407 (n=3).

Figure 5.2: Cumulative respiration for measured (black) and modelled (white) data in soil subjected to DRW (circles) and constantly moist (triangles) controls and incubated with (top) and without (bottom) glucose. LSD = 0.007 (n=3).

Figure 5.3: Extractable organic C (EOC) in soils subject to DRW (black squares) and moist incubated controls (white squares) and incubated with (top) and without (bottom) glucose. Bars indicate standard error of the mean. LSD = 13.02 (n=3).

Figure 5.4: Dissolved organic N (DON) in soils subject to DRW (black squares) and moist incubated controls (white squares) and incubated with (top) and without (bottom) glucose. Bars indicate standard error of the mean. LSD = 11.14 (n=3).

Figure 5.5: Resin extractable P ($P_{\text{resin}}$) in soils subject to DRW (black squares) and moist incubated controls (white squares) and incubated with (top) and without (bottom) glucose. Bars indicate standard error of the mean. LSD = 1.10 (n=3).

Figure 5.6: Dissolved inorganic P (DIP) in soils subject to DRW (black squares) and moist incubated controls (white squares) and incubated with (top) and without (bottom) glucose. Bars indicate standard error of the mean. LSD = 0.25 (n=3).

Figure 6.1: Extractable organic C (EOC) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d; Table 6.3) and either subjected to experimental DRW ($\nu$) or moist incubated ($\square$). Arrows indicate the timing of rewetting events.

Figure 6.2: Extractable organic C (EOC) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d; Table 6.3) and either subjected to experimental DRW (solid line) or moist incubated (dotted line). Arrows indicate the timing of rewetting events. Letters show significant differences ($P<0.05$) between water regimes and DRW for each soil.

Figure 6.3: Resin extractable P ($P_{\text{resin}}$) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d; Table 6.3) and either subjected to experimental DRW (solid line) or moist incubated (dotted line). Arrows indicate the timing of rewetting events.
indicate the timing of rewetting events. Letters show significant differences $(P<0.05)$ between water regimes and DRW for each soil. ........................................120

Figure 6.4: Total dissolved P (TDP) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d; Table 6.3) and either subjected to experimental DRW (solid line) or moist incubated (dotted line). Arrows indicate the timing of rewetting events. Letters show significant differences $(P<0.05)$ between water regimes and DRW for each soil. ........................................121

Figure 6.5: Dissolved organic P (DOP) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d; Table 6.3) and either subjected to experimental DRW (solid line) or moist incubated (dotted line). Arrows indicate the timing of rewetting events. Letters show significant differences $(P<0.05)$ between water regimes and DRW for each soil. ........................................123

Figure 6.6: Acid phosphatase activity in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d; Table 6.3) and either subjected to experimental DRW (solid line) or moist incubated (dotted line). Arrows indicate the timing of rewetting events. Letters show significant differences $(P<0.05)$ between water regimes and DRW for each soil. ........................................124

Figure 6.7: Microbial biomass C (MBC) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d; Table 6.3) and either subjected to experimental DRW (solid line) or moist incubated (dotted line). Arrows indicate the timing of rewetting events. Letters show significant differences $(P<0.05)$ between water regimes and DRW for each soil. ........................................127

Figure 6.8: Microbial biomass P (MBP) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d; Table 6.3) and either subjected to experimental DRW (solid line) or moist incubated (dotted line). Arrows indicate the timing of rewetting events. Letters show significant differences $(P<0.05)$ between water regimes and DRW for each soil. ........................................128

Figure 6.9: Principal component analysis of phospholipid fatty acid profiles within Hamilton (H) soil before pre-treatment (initial) or with four pre-treatment water regimes (m, int, fb, and d; Table 6.3) and subjected to either experimental DRW (black symbols) or moist incubated (white symbols) (A). Bars indicate standard errors of the mean. Vector plots of associated signature PLFA (B). .........................................................130

Figure 6.10: Principal component analysis of PLFA profiles within Crystal Brook (C) soil before pre-treatment (initial) or with four pre-treatment water regimes (m, int, fb, and d; Table 6.3) and subjected to either experimental DRW (black symbols) or moist incubated (white symbols) (A). Bars indicate standard error of the mean. Vector plots of associated signature PLFA (B). .........................................................130

Figure 7.1: Shoot (above) and root (below) dry matter (g) of wheat seedlings planted in Hamilton (top) and Crystal Brook (bottom) soils at 1 h and 14 d after the first DRW with four pre-treatment soil water regimes (m, int, fb and d; Table 7.1). Bars indicate standard error of the mean (n=4). Significant differences (*) between treatments and moist controls $(P<0.05)$. .....................................................................145

Figure 7.2: Shoot (above) and root (below) dry matter (g) of wheat seedlings planted in Hamilton (top) and Crystal Brook (bottom) soils at 1 h and 14 d after the second DRW or moist controls with four pre-treatment soil water regimes (m, int, fb and d; Table 7.1). Bars indicate standard error of the mean (n=4). .............................................146
List of Tables

Table 3.1: Soil sampling locations, soil classifications and land-use details..........................29
Table 3.2: Soil physiochemical properties ............................................................................31
Table 3.3: Mineralisable C fraction (Co90h) and proportional mineralisation rate constant (k) from one-pool C mineralisation model fitting (mg CO2-C g soil-1) in soils subjected to DRW and constantly moist controls. Significant differences (P<0.05) between DRW treatments using Tukey pairwise comparisons are indicated with ***.................................................................................................................................37
Table 3.4: C mineralisability (Co90h) determined by one-pool C mineralisation model fitting (mg CO2-C g soil C-1) in soils subjected to DRW and constantly moist controls. Significant differences (P<0.05) between DRW treatments using Tukey pairwise comparisons are indicated with ***.................................................................................................................................40
Table 4.1: Summary of abbreviations used ..........................................................................56
Table 4.2: Extractable organic C (EOC) degradability as indicated by specific UV absorbance (SUVA A250 nm/mg C ml-1) in moist (M) and DRW (D) soils previously amended with glucose (G), starch (S), cellulose (C) and non-amended (N). .....................................................................................................................................66
Table 4.3: Richness and evenness of signature fatty acid methyl ester (FAME). Letters indicate significant differences for each parameter (P<0.05).....................................75
Table 5.1: Predicted mineralisable C fraction (Co49h) and proportional mineralisation rate constant (k) of one-pool C mineralisation model fitting (mg CO2-C g soil-1) in soil subjected to DRW and constantly moist and incubated with and without glucose. Letters indicate significant differences (P<0.05) for each parameter. .......91
Table 6.1: Initial physiochemical properties of soils from Hamilton and Crystal Brook. ..........................................................105
Table 6.2: Pre-treatment soil water regimes.......................................................................106
Table 6.3: Summary of abbreviations used. .......................................................................106
Table 6.4: Experimental DRW for Hamilton (H) and Crystal Brook (C) soils . Sampling occurred at 1 h and 14 d after the two DRW events (weeks 16 and 19).........................108
Table 6.5: Predicted mineralisable C fraction (Co14d) and proportional mineralisation rate constant (k) of one-pool C mineralisation model fitting (mg CO2-C g soil-1) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d; Table 6.3) and either subjected to experimental DRW or moist incubated. Letters indicate significant differences (P<0.05) between treatments for each parameter and DRW event..................................................................................115
Table 6.6: Predicted C mineralisability (Co14d) of one-pool C mineralisation model fitting (mg CO2-C g soil C-1) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d; Table 6.3) and either subjected to experimental DRW or moist incubated. Letters indicate significant differences (P<0.05) between treatments for each DRW event.................................................................116
Table 7.1: Pre-treatment water regimes and abbreviations .............................................141
Table 7.2: Experimental DRW for Hamilton (H) and Crystal Brook (C) soils. Seedlings were planted at 1 h and 14 d after the two DRW events (weeks 16 and 19) ............142
Table 7.3: Shoot and root P concentrations (mg g-1) of wheat seedlings planted in Hamilton (H) and Crystal Brook (C) soils at 1 h and 14 d after the first DRW with four pre-treatment soil water regimes (m, int, fb and d; Table 7.1)..........................147
controls with four pre-treatment soil water regimes (m, int, fb and d; Table 7.1).

Table 7.5: Allocation of P within soil (MBP, P_{resin} and TDP) and plant (P_{shoot} and P_{root}) pools at harvest, determined as a percent (%) of the labile P at planting and calculated for Hamilton (H) and Crystal Brook (C) soils with four pre-treatment soil water regimes (m, int, fb and d; Table 7.1)..........................150

Table 7.6: Allocation of P within soil (MBP, P_{resin} and TDP) and plant (P_{shoot} and P_{root}) pools at harvest, determined as a percent (%) of the labile P at planting and calculated for Hamilton (H) soil with four pre-treatment soil water regimes (m, int, fb and d; Table 7.1) either DRW or moist incubated and planted with wheat seedlings at 1 h or 14 d after DRW .................................................................151

Table 7.7: Allocation of P within soil (MBP, P_{resin} and TDP) and plant (P_{shoot} and P_{root}) pools at harvest, determined as a percent (%) of the labile P at planting and calculated for Crystal Brook (C) soil with four pre-treatment soil water regimes (m, int, fb and d; Table 7.1) either DRW or moist incubated and planted with wheat seedlings at 1 h or 14 d after DRW .................................................................152
List of Appendices

Appendix 3.1: Cumulative C mineralisation for measured (solid) and modelled (hollow) data in 32 soils subjected to DRW (circles) and constantly moist (triangles) controls........................................................................................................................................... 177

Appendix 3.2: Soil C mineralisability for measured (solid) and modelled (hollow) data in 32 soils subjected to DRW (circles) and constantly moist (triangles) controls............................................................................................................................................... 181

Appendix 5.1: Phosphorus extraction with increasing number of anion exchange resins using a single 1 h extraction as compared to the standard method (16 h shake with 1 resin strip). Letters indicate significant differences between means using post-hoc Tukey test (n=6)........................................................................................................................................... 185

Appendix 6.1: Cumulative C mineralisation in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d) for measured (black) and modelled (white) data........................................................................................................................................... 186

Appendix 6.2: Soil C mineralisability in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d) for measured (black) and modelled (white) data....................................................................................................................................... 187

Appendix 6.3: Cumulative respiration in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d) subjected to experimental DRW (circles) or incubated moist (triangles) for measured (black) and modelled (white) data........................................................................................................................................... 188

Appendix 6.4: Soil C mineralisability in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d) subjected to experimental DRW (circles) or incubated moist (triangles) for measured (black) and modelled (white) data....................................................................................................................................... 189

Appendix 7.1: Shoot (above) and root (below) P (mg) of wheat seedlings planted at 1 h and 14 d after DRW in Hamilton (top) and Crystal Brook (bottom) soils with four pre-treatment water regimes (m, int, fb and d). Bars indicate standard error of the mean (n=4)................................................................................................................................................ 190

Appendix 7.2: Shoot (above) and root (below) P (mg) of wheat seedlings planted at 1 h and 14 d after DRW in Hamilton (top) and Crystal Brook (bottom) soils with four simulated water regimes (m, int, fb and d). Bars indicate standard error of the mean (n=4)................................................................................................................................................ 191

Appendix 7.3: Microbial biomass P (MBP) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d) and either subjected to experimental DRW (solid line) or moist incubated (dotted line). Arrows indicate timing of rewetting events ........................................................................................................................................... 192

Appendix 7.4: Resin extractable P (P\text{resin}) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d) and either subjected to experimental DRW (solid line) or moist incubated (dotted line). Arrows indicate timing of rewetting events ........................................................................................................................................... 193

Appendix 7.5: Total dissolved P (TDP) in Hamilton (H) and Crystal Brook (C) soils with four pre-treatment water regimes (m, int, fb and d) and either subjected to experimental DRW (solid line) or moist incubated (dotted line). Arrows indicate timing of rewetting events ........................................................................................................................................... 194
Abstract

Phosphorus (P) limitations to agricultural productivity commonly occur in Australian soils and have largely been overcome by the use of inorganic fertilisers. However, studies have shown that most of the P taken up by plants is from native P pools. The turnover of P and native soil organic matter may be strongly affected by drying and rewetting (DRW). Rewetting dry soil results in a pulse of respiration activity and available nutrients. In Mediterranean-type climates surface soils naturally undergo recurrent DRW cycles. In southern Australia, soils experience DRW due to erratic rainfall within the growing season, and short, high intensity thunderstorms also during summer periods. The principal objective of this thesis was to determine the significance of dry-rewet events, for altering P availability and cycling in agricultural soils in Australia.

Soils representing a wide range of soil types and climatic zones of southern Australia, showed large flushes in carbon (C) mineralisation after a single DRW event. For some soils these were comparable with reported values, however large variability in flush size between soils was observed. Soils that commonly experience DRW did not appear to be more resilient to DRW than soils from areas with fewer DRW events. Even when soils had relatively small respiration flushes, as a result of low soil organic matter, a high proportion of the soil C was mineralised after rewetting. Soil physiochemical properties (total C, total N, organic C, humus, microbial biomass P, organic P, sand and silt) were correlated to the size of the flush, hence nutrient availability and soil texture appear to primarily determine flush size. Therefore, the influence of climate on DRW may relate to determining the quantity of organic matter and microbial biomass that is available for turnover.

Different size and composition of the microbial biomass within the same soil matrix were achieved by adding three different C substrates (glucose, starch and cellulose at 2.5 g kg\(^{-1}\)) at 5 times over 25 weeks. The treatments showed disparate responses to DRW, due to greater biomass (larger flushes) and effects of community composition, highlighting the central role of the soil microbes in DRW processes. When subjected to multiple DRW events these soils showed smaller rewetting respiration flushes with subsequent rewetting events. In contrast, the amount of P released after rewetting was
the same. This study showed that increases in P after rewetting were transient and rapid immobilisation of P by microbes occurred, which may limit the availability to plants. The composition of the microbial community was changed by DRW with a reduction in fungi and gram negative bacteria, showing that certain species are more susceptible to DRW than others.

Closer investigation at 2 hourly intervals after rewetting confirmed the transient nature of P flushes. The response in microbial respiration after rewetting was immediate, with the highest activity occurring within the first 2 h. Phosphorus availability was increased by DRW but remained stable over the following 48 h incubation period. The study highlights the rapid nature of changes in available nutrients after rewetting. Furthermore, while potentially only a small component of the P flush that occurred, the DRW soil had higher levels of P than most incubated soil at 48 h, this would be potentially available for plant uptake or movement with the soil solution.

Long-term water regimes (continuously moist or air-dry, or DRW occurring at different times during incubation) that were imposed on two soils from different climatic regions over a 14 wk period, did not alter available nutrient (P and C) pools or the size of the microbial biomass. However, these long-term water regimes determined the respiration response of the soils to experimental DRW. The largest flushes occurred in the treatment with the longest dry period, and confirm findings of reported studies that the response of a soil at rewetting is determined by the length of the period that it is dried. Microbial biomass was little affected by experimental DRW, but showed large changes in C:P ratio. Thus, changes in physiological state or community composition may be more affected by DRW than the size of the microbial biomass. Microbial communities were altered by DRW irrespective of climatic history (warm wet summer and temperate Mediterranean), however these changes were not related to specific groups of organisms. In addition, the disparate respiration responses and inhibition of phosphatase by DRW, indicate that functional changes may be induced by DRW but can not be sufficiently explained by quantifying available nutrient pools or the microbial biomass.
The use of wheat seedlings bio-indicators of P availability after the long-term water regimes, confirmed that plant available P was altered by DRW, indicated by differences in growth, although the large variability in seedling growth made it difficult to quantify these differences. However, the distribution of labile P, available at planting, in soil and plant pools at harvest, showed that long-term water regimes increased P allocation in plant tissue in one soil and decreased it in another. Furthermore, only a small fraction of the labile P present at planting was taken up by plants, which confirms the superior ability of soil microbes to immobilise P that is released by DRW. Nevertheless, since the long-term water regimes increased P availability, this may be transported via surface water or leaching.

DRW is important for C and P turnover in soils of southern Australia. However, P flushes occur rapidly after rewetting and are transient. Therefore, DRW appears to have only minor consequences for P availability to plants.
Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

Clayton Robert Butterly
January 2008
Acknowledgements

I would like to thank my supervisors Dr Petra Marschner, Dr Ann McNeill and Dr Jeff Baldock for their invaluable guidance and support. I would also like to thank Dr Else Bünemann for her mentoring and friendship.

I wish to acknowledge the Grains Research and Development Corporation (GRDC) for funding of this work, which was a component of the ‘Biological cycling of P in farming systems’ project and also to the School of Earth & Environmental Sciences, The University of Adelaide for financial support via a divisional scholarship.

I am extremely grateful for the following awards; GRDC Travel Award, Alf Anderson Award from the Australian Plant Nutrition Trust, Research Abroad Scholarship from The University of Adelaide and also financial assistance from the Australian Society of Soil Science to; conduct a research project at The University of California, Berkeley, USA, attend the ‘3rd International Symposium - Phosphorus dynamics in the soil-plant continuum’, Brazil, the ‘18th World Congress of Soil Science’, USA and to visit Rothamsted Research, UK in 2006.

I would also like to acknowledge the support and friendship of colleagues within the Discipline of Soil and Land Systems at The University of Adelaide, in particular Dr Damien Adcock and Dr Kris Broos. I am indebted for the technical assistance of Rebecca Stonor and Carol Sigston.

I wish to thank my extended ‘Adelaide family’ who have made my PhD an enjoyable and memorable time, particularly Emily, Laurence and Jean-Patrick for encouragement and support during our PhD studies. Finally, I wish to thank Pete for his assistance, support and unconditional friendship.