EFFECT OF POULTRY LITTER-YARD WASTE COMPOST APPLICATION ON PHOSPHORUS AVAILABILITY IN DIVERSE SOILS

by
Regine N. Mankolo

Dissertation to the faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY
in
Crop and Soil Environmental Sciences

APPROVED:

David C. Martens
Co-Chairman

James R. McKenna
Co-Chairman

James C. Baker

Julian D. Brake

Ronald D. Morse

December, 1997
Blacksburg, Virginia
EFFECT OF POULTRY LITTER-YARD WASTE COMPOST APPLICATION ON PHOSPHORUS AVAILABILITY IN DIVERSE SOILS

by

Regine N. Mankolo

Dr. David C. Martens, Co-chair

Dr. James R. McKenna, Co-chair

(ABSTRACT)

Land application of poultry litter has been successfully practiced for centuries to maintain and improve soil fertility, although over application may promote loss of nutrients through runoff or leaching. To decrease the potential for adverse environmental impacts of N and P in groundwater, a new approach developed in this research was to use a composted mixture of poultry litter (PL) and yard waste (YW) as a soil amendment for corn (Zea mays L.) production. Objectives of this research were to evaluate effects of pre-compost C:N substrate ratios for poultry litter-yard waste compost (PYC) on the availability of soil P, to determine the P response of corn plants to inorganic P, PL and PYC application, and to study relationships between P availability and both inorganic P and PYC application.

Langmuir isotherms were used in this research to select soils with relatively high P fixation capacities. Phosphorus sorption maximum for soils evaluated were as follows: 304 and 449 μg P g⁻¹ for A horizon Coastal Plain soils (Series: Kempsville and Myatt, respectively); 487 μg P g⁻¹ for an A horizon Ridge and Valley soil (Series: Frederick); 918 and 603 μg P g⁻¹ for A horizon Piedmont soils (Series: Elioak and Vance, respectively); 1099 μg P g⁻¹ for mine tailings (Series: Emporia located in the Coastal Plain); and 1524 μg P g⁻¹ for A and upper mixed horizon soil (Series: Starr from Piedmont region). Based on intermediate to high P sorption maxima, soil from
the Vance and Starr series and mine tailing from Emporia series were selected for greenhouse research to evaluate P availability of PYC.

Treatments applied to the soil in the greenhouse and field studies consisted of various levels of P as \( \text{Ca}(\text{H}_2\text{PO}_4)_2\cdot\text{H}_2\text{O} \), PL and PYC from 15:1, 20:1, and 25:1 C:N ratio substrates. Each P source increased dry weight of corn plants grown in the greenhouse by alleviation of P deficiency. Phosphorus uptake from PYC and PL application was either equal to or higher than P uptake from an equal level of P application as \( \text{Ca}(\text{H}_2\text{PO}_4)_2\cdot\text{H}_2\text{O} \). Application of 87.2 kg P ha\(^{-1}\) increased corn grain yields in a field experiment on Vance sandy loam from 6340 kg ha\(^{-1}\) on the control to a range of 10,170 to 11,350 kg ha\(^{-1}\) for PYC digested from the three C:N ratio substrates.

The yields on PYC treatments were attributed to a combination of factors including slow mineralization of P with less fixation during the growing season. The low P fixing capacity results from the blockage of \( \text{H}_2\text{PO}_4^- \) sorption by competition of negative charge from organic material and from the displacement of \( \text{H}_2\text{PO}_4^- \) in soil solution by \( \text{OH}^- \) from application of the alkaline composts. It would be desirable from the standpoint of more PL utilization to prepare composts from low substrate ratio substrates. Hence, in this research composts were prepared from 15:1, 20:1, and 25:1 C:N substrates, which consisted of PL and YW. The composting process was complete after only four months for the PYC from the 20:1 and 25:1 C:N ratio substrates. Yard waste compost without PL may require somewhere between two to three years for complete composting as opposed to four months with PL addition. The composting was incomplete in four months (presence of undigested leaves and \( \text{NH}_3 \)) for the PYC from the 15:1 C:N ratio substrate. The latter compost resembled poultry manure rather than a high quality compost after the 4-month composting period.
ACKNOWLEDGMENTS

Working with great people has made my graduate experience worthwhile. This dissertation would not have been completed without their support and guidance.

First, I would like to express a very special appreciation to my co-advisors Dr. Dave Martens and Dr. James McKenna, for their guidance, encouragement and to support my intellectual endeavors at Virginia Tech since 1991 when I started my Master degree. By various arrangements they have provided me with financial support and field assistance to complete my doctoral program. Dr. Martens has always been there when needed with patience, unselfish, and sharing of time to review this manuscript.

I would also like to individually thank other members of my committee, Drs. James Baker, Julian Brake, and Donald Morse for their wisdom and suggestions. I greatly appreciate the time and effort they have put forth.

Thanks are also extended to other members of the faculty, Dr Hall III head of the Department, Drs Lucian Zelazny, Duane Berry, Ozzie Abaye, and Naraine Persaud for their guidance and cooperation.

Appreciation is expressed to the funding support of Virginia Agricultural Council throughout this research program.

Special thanks to Wonae Pong-Fike from her friendship and support. I am grateful to Hubert Walker, who have showed great kindness and help with the laboratory work, and to Wesley Atkinson assistance for all aspects of field and greenhouse works. Assistance and suggestions are appreciated from Dr. Ma Guorong who provided frequent help on statistics. I also wish to thank my fellow graduate students for their support.

I owe so much to the kindness of my friend Dr. Enyong Laetitia who made my life enjoyable when I arrived at Virginia Tech. Laetitia Enyong and my lovely friend Chrissie Chawanje will always be close to my heart, without them to help me get through the rough time
and to share the good time, I would not have made it.

Appreciation is expressed to Dr. Ayuk Takem and Dr. Atayi for their advice and encouragement during my program of study.

My parents Samuel and Alice Mankollo cannot be thanked enough for all they have done. Without their unending love, support, and encouragements throughout my life, I would not have achieved this goal in my life. I would also like to thank my brothers Jean-Martin, Guillaume, David, Remi, Alain and my sisters Henriette, Olga, Florine, and Celine for their constant support faith in my abilities.

And finally, thank to my son Michael Felix Banen for his love, patience, and understanding of a mommy who spent such a long time far from him.
DEDICATION

This dissertation is dedicated to my lovely son Michael Banen who has always been very supportive.

To my parents Samuel and Alice Mankollo whose love, encouragement, and unending support have brought me the happiness I now enjoy.
# TABLE OF CONTENTS

ABSTRACT .......................................................... i  
ACKNOWLEDGMENTS ................................................ ii  
DEDICATION ...................................................... v  
LIST OF TABLES .................................................. x  
LIST OF FIGURES ................................................. xi  

CHAPTER I. INTRODUCTION ....................................... 1  
CHAPTER 2. LITERATURE REVIEW .................................. 4  
CHAPTER 3. PHOSPHORUS ADSORPTION BY DIVERSE SOILS ........ 23  

3-1 INTRODUCTION ............................................. 24  
3-1.1 Adsorption Isotherm ....................................... 25  
3-1.1.1 Langmuir equation ..................................... 25  
3-1.1.2 BET .................................................... 28  
3-1.1.3 Freundlich Isotherm .................................... 28  
3-1.2 Chemical and Physical soil factors affecting P adsorption . 29  
3-1.2.1 Clay content ........................................... 29  
3-1.2.2 pH effects ............................................. 29  
3-1.2.3 Organic matter ........................................ 30  
3-1.2.4 Iron and Aluminum oxides .............................. 30  

3-2 MATERIALS AND METHODS ................................... 31  
3-2.2 Soil analysis ............................................... 31  
3-2.3 Soil test P analysis ....................................... 32  
3-2.4 Phosphorus adsorption isotherms .......................... 32  
3-2.5 Statistic analysis ......................................... 35  

3-3 RESULTS AND DISCUSSION ................................. 36
3-3.1 Phosphorus adsorption characteristics ...................... 36
3-3.2 Soil properties affecting P adsorption ...................... 43
3-3.3 Phosphorus requirement ................................ 44
3-4 CONCLUSION ........................................... 46
3-5 REFERENCES ........................................... 47

CHAPTER 4. MINERALIZATION OF PHOSPHORUS FROM VANCE SOIL WITH POULTRY LITTER-YARD WASTE COMPOST
ABSTRACT ................................................. 54
4-1 INTRODUCTION ........................................ 55
4-2 MATERIALS AND METHODS ................................ 55
  4-2.1 Compost process ...................................... 55
  4-2.2 Sampling procedures ................................... 56
  4-2.3 Soil description ....................................... 56
  4-2.4 Laboratory incubation .................................. 58
  4-2.5 Soil P analysis ........................................ 58
  4-2.6 Statistics ............................................ 59
4-3 RESULTS AND DISCUSSION ................................ 59
  4-3.1 Soil incubation experiment ............................... 59
  4-3.2 Sand incubation experiment .............................. 63
4.4 CONCLUSION ........................................... 66
4-5 REFERENCES ........................................... 68

CHAPTER 5. EFFECT OF YARD WASTE-POULTRY LITTER COMPOST ON CORN GROWTH AND PHOSPHORUS UPTAKE IN A GREENHOUSE STUDY
ABSTRACT ..................................................... 71
5-1 INTRODUCTION .......................................... 73
5-2 MATERIALS AND METHODS ................................. 73
5-2-1 Soils characteristics ................................. 73
5-2.2 Greenhouse investigation ............................... 74
  5-2.2.1 Greenhouse Study 1 .............................. 74
  5-2.2.2 Greenhouse Study 2 .............................. 76
5-2.3 Laboratory analysis ...................................... 78
  5-2.3.1 Plant tissue P analysis ............................ 78
  5-2.3.2 Compost analysis ................................. 78
  5-2.3.3 Soil analysis ..................................... 79
5-2.4 Statistics analysis ..................................... 79
5-3 RESULTS AND DISCUSSION ............................. 81
  5-3.1 Dry matter production of corn ....................... 81
    5-3.1.1 Greenhouse Study 1-dry weights of corn plants .... 81
    5-3.1.2 Greenhouse Study 2-dry weights of corn plants .... 86
  5-3.2 Phosphorus uptake by corn plants ...................... 91
    5-3.2.1 Greenhouse Study 1-Phosphorus uptake by corn plants ... 92
    5-3.2.2 Greenhouse Study 2-Phosphorus uptake by corn plants ... 96
  5-3.3 Nitrogen concentration and uptake by corn plant ........ 101
  5-3.4 Zinc and Cu concentration in the corn plant tissue ..... 108
  5-3.5 Soil pH ........................................... 111
5-4 REFERENCES ........................................... 113

CHAPTER 6. EFFECT OF POULTRY LITTER-YARD WASTE COMPOST ON
CORN GROWTH IN A FIELD STUDY

ABSTRACT ..................................................... 116
6-1 INTRODUCTION ........................................... 117
6-2 MATERIALS AND METHODS ............................... 117
  6-2.1 Field experiment .................................... 117
    6-2.1.1 Treatment and experimental design .................. 118
6-2.2 Laboratory Analysis ........................................ 118
   6-2.2.1 Plant tissue sampling and analysis ................. 121
   6-2.2.2 Soil sampling and analysis ........................ 121
6-2.3 Statistics analysis ....................................... 121
6-3 RESULTS AND DISCUSSION ................................ 122
   6-3.1 Dry matter production and plant height ............. 122
   6-3.2 Phosphorus uptake in young corn and soil extractable P .... 124
   6-3.3 Crop yield, P uptake and soil extractable P .......... 126
   6-3.4 Nitrogen concentration and uptake by corn plant ....... 127
   6-3.5 Zinc and Cu concentration in corn plant tissue ...... 131
6-4 REFERENCES .................................................. 133
CHAPTER 7 SUMMARY AND RECOMMENDATIONS .................. 135
APPENDICES ...................................................... 138
VITA .......................................................... 155
LIST OF TABLES

3-1 Series and Taxonomic Class of soils used in the study ................. 33
3-2 Selected soil characteristics bearing on P adsorption by 
the soil under study ............................................. 34
3-3 Phosphorus adsorption parameters as estimated by curvilinear 
Langmuir adsorption model ..................................... 37
3-4 Residual sums of squares of one site and two sites Langmuir .......... 42
3-5 Phosphorus adsorbed by soils at 0.2 ppm and phosphorus 
requirement in each group of soil ................................ 45
4-1 Elemental composition of organic amendments used in the 
mineralization study .................................................. 57
5-1 Selected physical and chemical properties of three soils used in 
the greenhouse studies ............................................. 75
5-2 Compost rates and inorganic sources used in the greenhouse study ... 77
5-3 Composition of Compost used in the greenhouse studies .............. 80
5-4 Measurement of soil pH on Vance subsoil and mine tailing soil 
after corn harvesting .................................................. 112
6-1 Elemental composition of compost used in the field study ............ 119
6-2 Rates of poultry-yard waste compost and poultry litter application 
for field investigation ................................................ 120
LIST OF FIGURES

3-1 Phosphorus adsorption isotherms for five surface soils ................. 38
3-2 Phosphorus adsorption isotherms for five subsoils .................... 38
3-3 Langmuir isotherm for phosphate adsorption by Starr and
    Mine tailings .............................................. 39
3-4 Two site Langmuir isotherms for phosphate adsorption by Starr
    and Mine tailings ........................................ 39
3-5 Two site Langmuir isotherms for phosphorus adsorption by
    five surface soils ........................................... 41
3-6 Two site Langmuir isotherms for phosphorus adsorption by
    five subsoils .............................................. 41
4-1 Extractable P at 26.2 mg P kg⁻¹ rate of application in relation with the
    time of incubation on Vance soil .................................. 60
4-2 Rates of P mineralization in relation with time of incubation on sand .... 65
4-3 Extractable P at 17.5 mg P kg⁻¹ rate of application in relation with the
    time of incubation on Vance soil .................................. 61
4-4 Extractable P at 17.5 mg P kg⁻¹ rate of application in relation with the
    time of incubation on sand ........................................ 67
5-1 Dry matter yield of corn plant as affected by the rate of P applied
    as PYC and TSP on Vance topsoil .................................. 82
5-2 Dry matter yield of corn plant as affected by the rate of P applied
    as PYC and TSP on Starr soil ..................................... 83
5-3 Percent P in corn tissue as affected by PYC and TSP on Vance topsoil ... 84
5-4 Percent P in corn tissue as affected by rate of applied P as PYC
    and TSP on Starr mixed horizon soil ................................ 85
5-5 Dry matter of corn plant as affected by rate of applied P as PYC, TSP and PL on Vance subsoil ................................................................. 87
5-6 Dry matter of corn plant as affected by rate of applied P as PYC, TSP and PL on mine tailings ................................................................. 88
5-7 Percent P in corn tissue as affected by rate of applied P as PYC and TSP on Vance subsoil ................................................................. 90
5-8 Percent P in corn tissue as affected by rate of applied P as PYC, TSP and PL on mine tailings ................................................................. 91
5-9 Relationship between dry weight and P uptake by corn plant on Vance topsoil ..................................................................................... 93
5-10 Relationship between dry weight and P uptake by corn plant on Starr soil ......................................................................................... 94
5-11 Phosphorus uptake by corn plant as affected by rate of applied P as TSP and PYC on Vance topsoil ............................................................ 95
5-12 Phosphorus uptake by corn plant as affected by rate of applied P as TSP and PYC on Starr soil .............................................................. 97
5-13 Relationship between dry weight and P uptake by corn plant on Vance subsoil ..................................................................................... 98
5-14 Relationship between dry weight and P uptake by corn plant on the mine tailings ............................................................................... 99
5-15 Phosphorus uptake by corn plant as affected by rate of applied P as TSP and PYC on Vance subsoil ............................................................ 100
5-16 Phosphorus uptake by corn plant as affected by rate of applied P as TSP and PYC on mine tailings .............................................................. 102
5-17 Percent N in corn tissue as affected by rate of applied P as PYC and TSP on Vance subsoil ................................................................. 103