PLANT AND SOIL EFFECTS FROM THE SURFACE APPLICATION OF
POULTRY LITTER TO UNMANAGED PASTURE

by

Daniel William Lucero

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Master of Science
in
Crop and Soil Environmental Sciences
with a Specialization in
International Development

APPROVED

David C. Martens, Co-Chairman
James R. McKenna, Co-Chairman

Surajit K. De Datta, Director OIRD and
Associate Dean, International Agriculture

February 3, 1994
Blacksburg, Virginia
LD
5655
V855
1994
L834
c.2
Plant and Soil Effects from the Surface Application of Poultry Litter to Unmanaged Pasture

by

Daniel W. Lucero

Committee Co-chair: Dr. D. C. Martens
Committee Co-chair: Dr. J. R. McKenna

(ABSTRACT)

The poultry industry, a vital economic force in Virginia, must dispose of vast amounts of waste, mainly litter (PL), generated during production processes. This study was conducted to investigate the short-term effects of various rates of PL application, i.e., cumulative 2-year totals of 9.8, 19.5, 29.3, 39.0, and 48.8 mt ha\(^{-1}\), to unimproved pasture. Dry matter yield, N recovery and use efficiency, P recovery and use efficiency, and changes in botanical composition were measured on a mixed species, tall fescue (*Festuca arundinacea*) and bluegrass (*Poa pratensis*) pasture. Additionally, the accumulation and movement of P was measured in a Starr clay loam (fine-loamy mixed thermic Fluventic Dystrochrepts) by the Mehlich 3 (M3) and Bray 1 (B1) soil tests. Dry matter yields increased curvilinearly with rate of PL application. This yield increase was attributed to correction of N deficiency in pasture by the PL application. Lower levels of PL increased forage yields in 1992 compared with 1991, due to residual effect of unmineralized N from PL applied in 1991. The PL application rate of 11.4 mt ha\(^{-1}\) in 1991, followed by 8.1 mt ha\(^{-1}\) in 1992 was the most environmentally and economically recommendable rate when compared with inorganic N and P recommended fertilizer rates. Forage yields in this treatment were 21.5 mt ha\(^{-1}\) versus 21.7 mt ha\(^{-1}\) for the inorganic N and P fertilizer treatment. All rates of applied PL increased the percentage of tall fescue (from approximately 50 percent to > 80 percent) and decreased the percentage of bluegrass in this mixed pasture. Phosphorus from both PL and inorganic sources accumulated in the zone of application. In 1992, the highest rates of PL application had increased M3-extractable P levels by 20 fold over the control (192 mg P kg\(^{-1}\) versus 11 mg P kg\(^{-1}\)) and caused movement of P into the 10 to 15 cm soil depth. Levels of P extracted by the M3 and B1 soil tests were highly correlated for both years ($r^2 = 0.96$ in 1991 and $r^2 = 0.99$ in 1992) but the M3 extracted substantially more P from the surface 0 to 5 cm depth (21 percent in 1991 and 23 percent 1992) while the B1 soil test extracted more P from the 5 to 30 cm soil depth (50 to 66 percent more in 1991 and 20 to 57 percent in 1992). Differences in total acidity and F concentrations account for differences of P extracted by the two procedures. Poultry litter is a suitable source of fertilizer for pasture renovation and production in the Piedmont Region of Virginia.
Acknowledgements

First and foremost, I desire to acknowledge and thank God for the love, encouragement and abilities He has given me that have enabled me to accomplish this work. I pray that in some small way this thesis will bring glory to His name and to His Son Jesus Christ.

I next want to thank my wife, Martina and children, Jeremiah, Melissa and Julia, who have been constant companions in my labors. They have brought immeasurable joy to my life. No man could be given a better wife than I have and her support, love, commitment, encouragement and advice, invested in my life, is ever present in this work.

I want to especially acknowledge my parents, C. Herbert and Joan Marie Lucero, whom I deeply love and respect. Their example of hard work and commitment, to both each other and the projects they undertake, has done much to make me the person that I am. A special thanks is as well due to my spiritual father in the Faith, Daniel DelVecchio, whose faithful obedience to God’s call in his life has enabled me to be where I am today.

I wish to deeply extend my appreciation to Dr. David C. Martens whose tireless commitment to me, as seen in numerous hours of instructive and insightful critique of my writing, has done much to allow me to professionally finish this thesis. I also wish to extend thanks to Dr. James R. McKenna and his wife Deb for both answering my telephone call from France and for securing me a place to do my studies for this thesis here at Virginia Tech. In this regard thanks are as well extended to Dr. Robert Q. Cannell as Department Head and to Dr. S. K. De Datta for his participation on my committee.

All the graduate students, and other faculty and staff, who have helped me are too numerous to be thanked personally by name, but two who I wish to personally mention are Hubert Walker who was always there to guide me through procedures in the laboratory and without whose help I could not have
hoped to finish this work, and Hans Willems who as well assisted me in many areas of both scientific thought and in the use of many computer programs.

Special thanks are due to David Starner and Robert Shoemaker and all the workers at the Northern Piedmont Research Station in Orange, Virginia who are the true catalysts of this investigation. I also wish to acknowledge the Poultry Industry of Virginia who funded this project during the summer of 1993. This allowed me to concentrate on this work and care for my family at the same time.

Last but not least I must make mention of one dear friend, Fred Fortune, without who I could never have begun or finished this project. The many hours of support he extended to me are deeply appreciated and eternally stored in my heart. May God bless you Fred and cause you to prosper in all your endeavors!
# Table of Contents

CHAPTER 1 ............................................................................................................ 1

Introduction .......................................................................................................... 2

CHAPTER 2 ............................................................................................................ 5

Literature Review ................................................................................................. 6

The Poultry Industry ............................................................................................... 6

Poultry Litter as a Fertilizer ................................................................................. 7

Environmental Impacts ......................................................................................... 12

Tall Fescue ............................................................................................................. 17

Nitrogen and Plant Yield ....................................................................................... 18

Nitrogen and Plant Recovery ................................................................................. 20

Negative Effects of Poultry Litter on Plants ....................................................... 22

Botanical Composition .......................................................................................... 23

Phosphorus and Plant Growth .............................................................................. 23

Phosphorus and Soil ............................................................................................. 26

Literature Cited ...................................................................................................... 32
CHAPTER 3 .................................................................................43

Effects of Applied Poultry Litter on Yield, Botanical Composition and Nitrogen and Phosphorus Recovery and Use Efficiency on a Starr Clay Loam ........................................ 43

Introduction ........................................................................ 44

Materials and Methods .............................................................. 46
Soil and Location ................................................................. 46
Field Experimentation ......................................................... 46
Yield Analyses .................................................................... 48
Tissue Analyses .................................................................. 48
Nitrogen and Phosphorus Recovery and Use Efficiency ................ 48
Botanical Composition Determination .................................. 49
Statistical Analyses ............................................................. 49

Results and Discussion .......................................................... 50
Dry Matter Yield .................................................................. 52
Nitrogen Recovery and Use Efficiency ................................. 57
Phosphorus Recovery and Use Efficiency ............................... 62
Botanical Composition ........................................................ 66
Summary .............................................................................. 68
Literature Cited .................................................................... 70
CHAPTER 4

Movement and Accumulation of Phosphorus in a Starr Clay Loam from Poultry Litter

Application .............................................................................................................73

Introduction .........................................................................................................74

Materials and Methods ......................................................................................76

Soil Sampling and Analyses .............................................................................76

Results and Discussion .....................................................................................77

Summary ............................................................................................................81

Literature Cited .................................................................................................82

CHAPTER 5

Comparison of Mehlich 3 and Bray 1 Extractable Phosphorus Levels on a Starr Clay Loam Amended with Poultry Litter .................................................................85

Introduction .....................................................................................................86

Methods and Materials ....................................................................................89

Results and Discussion ..................................................................................89

Conclusion ......................................................................................................105

vii
# List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Forage Yield versus level of N application as PL during year 1</td>
<td>54</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Forage Yield versus level of N application as PL during year 2</td>
<td>54</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Forage Yield versus level of P application as PL during year 1</td>
<td>56</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Forage Yield versus level of P application as PL during year 2</td>
<td>56</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Nitrogen uptake from applied PL in year 1</td>
<td>61</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Nitrogen uptake from applied PL in year 2</td>
<td>61</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Phosphorus uptake from applied PL in year 1</td>
<td>63</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Phosphorus uptake from applied PL in year 2</td>
<td>64</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Relationship between M3 and B1 extractable P in the 0 to 5 cm depth in year 1</td>
<td>91</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Relationship between M3 and B1 extractable P in the 0 to 5 cm depth in year 2</td>
<td>92</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Relationship between M3 and B1 extractable P in the 5 to 30 cm depth in year 1</td>
<td>93</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Relationship between M3 and B1 extractable P in the 5 to 30 cm depth in year 2</td>
<td>93</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Relationship between P uptake by pasture in 1991 and M3 extractable P</td>
<td>96</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Relationship between P uptake by pasture in 1991 and B1 extractable P</td>
<td>96</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Relationship between P uptake by pasture in 1991 and M3 extractable P</td>
<td>97</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Relationship between P uptake by pasture in 1991 and B1 extractable P</td>
<td>97</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Relationship between P uptake by pasture in 1992 and M3 extractable P</td>
<td>98</td>
</tr>
<tr>
<td>Figure 18</td>
<td>Relationship between P uptake by pasture in 1992 and B1 extractable P</td>
<td>98</td>
</tr>
<tr>
<td>Figure 19</td>
<td>Relationship between P uptake by pasture in 1992 and M3 extractable P</td>
<td>99</td>
</tr>
<tr>
<td>Figure 20</td>
<td>Relationship between P uptake by pasture in 1992 and B1 extractable P</td>
<td>99</td>
</tr>
<tr>
<td>Figure 21</td>
<td>Relationship between M3 extractable P and forage yield in 1991</td>
<td>101</td>
</tr>
</tbody>
</table>
List of Tables

Table 1. Elemental composition of PL used in a field experiment on a Starr clay loam in 1991 and 1992 .................................................................50

Table 2. Levels of PL applications on a Starr clay loam in 1991 and 1992 ... 51

Table 3. Amount of N and P applied in a field experiment on a Starr clay loam in 1991 and 1992.... 51

Table 4. Total forage dry matter yield in a field experiment on a Starr clay loam treated with synthetic and PL fertilizer in 1991 and 1992 ................. 53

Table 5. Nitrogen and P tissue concentrations in a field experiment on a Starr clay loam treated with synthetic and PL fertilizer in 1991 and 1992 ......................... 58

Table 6. Percent N and P recovery from synthetic and poultry litter applications sources used in a field experiment on a Starr clay loam in 1991 and 1992 .................. 59

Table 7. Nitrogen and P use efficiency from synthetic and PL application sources used in a field experiment on a Starr clay loam in 1991 and 1992 ................. 60

Table 8. Phosphorus in forage dry matter recovered in a field experiment on a Starr clay loam treated with synthetic and PL fertilizer in 1991 and 1992 ......................... 65

Table 9. Botanical composition of unmanaged pasture treated with synthetic and PL application rates in a field experiment on a Starr clay loam measured in 1993 ..................... 67

Table 10. Mehlich 3-extractable P in soil samples taken in April 1992 in a field experiment on a Starr clay loam treated with synthetic and PL fertilizer ...................... 78

Table 11. Mehlich 3-extractable P in soil samples taken in April 1993 in a field experiment on a Starr clay loam treated with synthetic and PL fertilizer ...................... 79

Table 12. Regression parameters of the M3 soil test with the B1 method on a Starr clay loam treated with synthetic and PL fertilizer in 1991 ............................................ 90

Table 13. Regression parameters of the M3 soil test with the B1 method on a Starr clay loam treated with synthetic and PL fertilizer in 1992 ............................................ 91

Table A1. Forage dry matter yield in a field experiment on a Starr clay loam on an individual cutting basis by treatment for 1991 and 1992 ........................................ 112

Table A2. Rainfall and departure from long-term means for 1991 and 1992, Orange, VA. .......... 113
Chapter 1
INTRODUCTION

The poultry industry, once a backyard enterprise, has today achieved a level of unprecedented scientific sophistication. In the developing nations of the world this transformation has begun to take place over the past 15 years, but because of large capital constraints, progress is being made at a much slower rate (Panda, 1989). With protein remaining today the most limiting dietary component in the developing nations and with the ever increasing demand by the American public for a steady increase in the supply of inexpensive, low cholesterol, high protein meat, the poultry industry will continue to grow in its important contributions to human dietary needs.

The poultry industry, along with all other animal agriculture in the United States, faces tremendous challenges as it enters the 21st century. With little dispute, the number one concern confronting the poultry industry today is the economically sound and environmentally safe disposal of its waste products. As it has been historically in the past, land application of poultry wastes will most likely continue to be the most practical, feasible, and economic disposal method.

Poultry litter (PL), a combination of excreta, feathers, wasted feed and bedding material (Malone, 1992a), is probably the most valuable waste by-product produced on the poultry farm. A flock of 1,000 laying hens produces approximately 11,340 kilograms of waste per day (Moreng and Avens, 1985). A metric dry ton of litter, on average, is produced per 1,000 broilers per flock (Malone, 1992b). A broiler complex that produces 1.0 million birds a week, a relatively common practice, will produce approximately 60,000 metric tons of PL annually (Weaver and Souder, 1990).

It is common for poultry growers in the southeastern United States to accomplish this on only a few hectares of land. The logistics of manure handling often dictate that it be spread relatively close to its source of production even if the resultant high rates of application do not make optimum use of the plant nutrients in the manure. A consequence of PL mismanagement is that these high rates of
application can lead to severe environmental hazards, such as contamination of ground water and pollution of waterways and lakes.

In the summer of 1991, the United States Department of Agriculture Research Service, United States Soil Conservation Service, United States Environmental Protection Agency and the Tennessee Valley Authority sponsored a National Livestock, Poultry and Agriculture Waste Management Workshop in Kansas City, Missouri. The purpose of this workshop was to specifically address and develop national consensus on the impacts of animal wastes on the environment. In the poultry priorities work group the issue identified as the number one concern facing the poultry industry at the present time was to determine if phosphorus (P), rather than nitrogen (N), should be used as the limiting factor in the development and implementation of nutrient management plans (Schwartz, 1991).

Because P requirements for crops other than legumes are much less than N requirements, a large over application of P results from the use of animal manures as a source for supplying crop N needs (Simpson, 1991). Chemical composition rates analyzed in PL vary widely, but various scientific sources show a 1:1 relationship between total N and P expressed as $P_2O_5$ (Parker et al., 1959; Ranske et al., 1987; Simpson 1991). Therefore when PL is applied according to crop N recommendations a large over supply of P typically increases available P levels in both acid or alkaline soils (Perkins et al., 1964; Singh and Jones, 1976). This is a well documented phenomena for PL amended soils (Perkins et al., 1964; Shorthall and Liebhardt, 1975; Mitchell et al., 1992; Kingerly et al., 1993; Sharpley et al., 1993).

Some studies have shown significant amounts of P movement within the soil profile (Spencer, 1957; Hannapel et al., 1964; Gilman, 1973; Rolston et al., 1975; Sommers et al., 1979). Movement of P in the soil profiles depends on integrated factors such as, the rate of P application, the P reactions with soil, and the consistency and type of the applied waste. Researchers have been able to detect a decrease in P sorption by soils in the presence of organic residues (Struthers and Seiling, 1950; Dalton
et al., 1952; Vyas, 1964; Gaur, 1969). These studies on organic residue effects indicated that formation of stable organic acid complexes with iron (Fe) and aluminum (Al) subsequently blocked P retention. But the increased retention of P due to inorganic residue application has also been observed (Taylor, 1946; Jackman, 1955; Rennie and McKercher, 1958; Larsen et al., 1959; Fokin and Chistova, 1964; Harter, 1969).

The purpose of this research was to determine the short term effects of various rates of PL application on unimproved pasture and to evaluate the suitability of PL applications for pasture grass renovation. Specific objectives addressed while completing this research were as follows: 1) to study plant utilization of N and P from PL application; 2) to evaluate the effect of PL application on botanical composition of pasture canopy; and 3) to characterize the effect of PL application on surface accumulation and downward movement of P. A further purpose of this research was to compare the efficacy of the Mehlich 3 (M3) and Bray 1 (B1) soil tests for the extraction of available P from PL applications.
Chapter 2
LITERATURE REVIEW

The Poultry Industry

The United States Department of Agriculture (USDA Statistics, 1992) reported that the combined value from the production of poultry in fiscal year 1991 was approximately 14.7 billion dollars. This included 6.4 billion broilers (5.5 billion of these in just 15 States located primarily in the southeast) valued at 8.39 billion dollars, 69.0 billion eggs valued at 3.89 billion dollars, and 285 million turkeys (weighing over 3.0 billion kg) valued at 2.34 billion dollars.

To minimize feed and transportation costs, poultry is produced in spatially concentrated areas. While this might be economically advisable, it places a tremendous burden on small land areas for the disposal of waste generated during poultry production. The floors of poultry "houses" are generally covered with a non-toxic absorbent material, referred to as litter. Though litter is necessary to grow healthy poultry products, it also increases the amount of waste generated. Waste from poultry production is therefore referred to as PL and is a combination of excreta, feathers, wasted feed, and bedding material (Malone, 1992a).

A flock of 1,000 laying hens produces approximately 11,340 kilograms of waste per day (Moreng and Avens, 1985). A metric dry ton of litter, on average, is produced per 1,000 broilers per flock (Malone, 1992b). A broiler complex that produces 1.0 million birds a week, a rather common practice, will produce approximately 60,000 metric tons of PL annually (Weaver and Souder, 1990). It is common for poultry growers in the southeastern United States to accomplish this on only a few hectares of land. These spatial restrictions heighten the difficulty of proper disposal of the waste generated by these facilities.
Poultry Litter as a Fertilizer

The chemical composition of PL varies considerably depending on numerous factors. These factors include the type of food consumed, the quantity and kind of litter, the number of flocks between cleanings and the state of decomposition (Hileman, 1967). Factors affecting the nutrient content of PL include moisture, temperature, and such management practices as the amount of soil picked up in cleaning a house and the amount of time and conditions under which the litter was allowed to accumulate, i.e., protected versus unprotected storage areas (Parker et al., 1959; Ranske et al., 1987). Even the site of sample collection for analysis (location within a house and a house versus a stockpile sample), method of collection and analytical procedures of nutrient determination add to PL nutrient variability (Malone, 1992b).

Of all the materials presently available for use as a bedding material, wood shavings from soft wood species (primarily pine) have been the predominant material used in poultry production (Malone, 1992b). Softwood species, particularly pine, tend to be more absorbent and preferred over hardwood. This preference is in part due to the perception that softwood species have a more appealing odor/color and fewer mold problems than do hardwood products. Reed and McCartney (1970) rated pine shavings the most desirable of eight materials evaluated based on seven different physical characteristics. The two most important physical characteristics evaluated were water holding capacity and bulk density. Bulk density is a function of the type of material, particle size and texture, moisture content, and the extent of compaction (Malone, 1992a).

Overall, the relative contribution of any bedding source on the value and composition of the litter upon removal after multiple flocks is minimal (Malone, 1992a). Malone (1992a) in comparing 16 sources of litter material on a dry weight basis by their potential contribution of nutrients as a fertilizer, found nutrient supplying potentials ranged from 2 to 20 kg for N, 1 to 13 kg for P, and 1 to 13 kg for
potassium (K) mt\(^{-1}\) on a dry matter basis. Malone found that the nutrient content of PL was affected as much or more by the moisture content of bedding than by the actual type of litter material.

Nutrient composition of PL on a dry matter basis for 147 broiler houses sampled in Alabama between 1977 and 1987 were as follows (Ranske et al., 1987):

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Average Analysis</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>19.7</td>
<td>15.0 - 39.0</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>3.9</td>
<td>2.2 - 6.0</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>1.6</td>
<td>0.6 - 3.9</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>2.1</td>
<td>0.7 - 5.1</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>2.2</td>
<td>0.8 - 6.1</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>0.5</td>
<td>0.2 - 2.1</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>0.4</td>
<td>0.01 - 0.8</td>
</tr>
</tbody>
</table>

Though there is a large range of variability, average nutrient content of PL reported from different states were very similar.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>kg mt(^{-1}) ton dry weight basis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maryland</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>29</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>13</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>15</td>
</tr>
</tbody>
</table>

Data from Virginia showed no real difference between broiler and turkey litter and indicated that approximately 30 kg of N, 13 kg of P and 13 kg of K are present mt\(^{-1}\) of dry litter (Simpson, 1991). There has been little change in the N, P, and K concentrations in PL based on analyses reported by Kroontje et al. (1958), and by Parker et al. (1959).
In and of itself, PL is neither a resource nor a pollutant. It does have the potential of being a valuable resource, though, in that it can be utilized as a fertilizer, soil amendment, bedding material, energy source, or feed (Boyd, 1990). Though much research has and continues to be done on the use of PL as a livestock feed and human energy source, land application is still the most common, and generally, most practical disposal method of this organic waste.

Land application of animal wastes is an age-old and world-wide agricultural practice. It is well documented that animal manure application improves the tilth and physical condition of soils. These beneficial physical effects include improved water holding capacity of soils for plant use, increased pH buffering capacity of soils, increased activity of soil microorganisms, and improved aeration of soil for more rapid seed germination (Clap et al., 1986; Hileman, 1967).

The land application of animal waste not only improves the physical condition of soil, it can also be an effective way to dispose of a waste product that, at the same time, recycles valuable nutrients into the soil-plant ecosystem. Animal waste can supply a large proportion of the plant nutrients needed by crops. During the decomposition of animal wastes applied to soil, such nutrients as carbon (C), N and P are increased, as is soil cation exchange capacity (Clap et al., 1986). Broiler litter is generally considered the most valuable of animal wastes for use as a fertilizer owing to its relatively high nutrient and low moisture content (Wilkinson, 1979).

At the mid-part of the present century, livestock and poultry waste applied at disposal rates seemed to be a common practice. Today agriculture is returning to the philosophy of waste application to the land for its effect on soil physical, chemical, and biological systems. The goals of any fertilizer nutrient management plan on the farm level is to achieve maximum economic benefits from the applied nutrients while having, at the same time, a minimal impact on the environment (Collins et al., 1988).

Nitrogen is the most limiting nutrient for crop production, and inorganic N represents the single largest energy input into crop production systems (Wilkinson, 1979). Application of PL as a
fertilizer source is therefore usually regulated according to N requirements of crops. This practice results in the simultaneous addition of large amounts of P to the soil.

Nitrogen can be present in the environment in many molecular forms and in a solid, liquid or gaseous states (Zublena, 1992). Nitrogen in the form of nitrate (NO$_3$-N) is highly soluble and is easily carried in solution in surface water and leached into groundwater. Phosphorus on the other hand moves as a passenger bound to sediment, much of which is eroded from fields (Smith et al., 1987).

In PL, about 65 to 75 percent of the N is organically bound and the remaining 25 to 35 percent is in an inorganic form, essentially all ammonia (Allred and Ohlrogge, 1964; Blanchar, 1967; Sims, 1986; Simpson, 1991). The amount of N available for plant growth is determined by the rate at which organic N mineralizes and the fraction of ammonia that is not lost by volatilization (Simpson, 1991). Mineralization is the conversion of organic N to plant available inorganic forms of N, mainly NO$_3$-N and ammonium (NH$_4$-N).

In calculating fertility and nutrient management programs, the Virginia Cooperative Extension Service suggests that approximately 50 percent of the organic N is released during the first year following application, 12 percent the second, 5 percent the third and 2 percent the fourth (Collins, 1990). Bitzer and Sims (1988), in measuring the mineralization rates from 20 litter sources, showed great variability between sources but found mineralization to be a rapid process. When combining the inorganic N with the mineralized organic N, they determined large amounts of N to be available for plant use within two weeks of incorporation into soil. They suggested the following formula for determining the amount of available N in PL:

$$\text{PAN} = 0.80 \, N_i + 0.60 \, N_o$$

where PAN = predicted available nitrogen - kg mt$^{-1}$
$N_i$ = inorganic nitrogen - kg mt$^{-1}$
$N_o$ = organic nitrogen - kg mt$^{-1}$
Bitzer and Sims (1988) determined available N by measuring NO$_3$-N and NH$_4$-N after periods of aerobic incubation. Their study indicated that two mineralizable fractions of N were present in PL, one rapidly available and the other more slowly available. The first fraction was mineralized between 0 and 14 days, and the second between 14 and 140 days. Available N decreased from days 80 to 140. This relationship suggested that there was simultaneous microbial immobilization of available N during the mineralization process. The mean average amount of organic N mineralized in the 20 PL was 66 percent.

The potential for the volatilization losses of surface applied N from PL is great and is a function of time between application and incorporation into the soil. Graves (1986) determined that 60 percent of available N in PL may be lost within the first 7 days if surface applied and not incorporated into the soil. Collins (1990) suggested that decomposition of unincorporated manure may result in the loss of as much as 75 percent of the inorganic portion within this same period of time. Typically, the N lost to volatilization ranges from 15 to 50 percent (Simpson, 1991).

Seeing that the mineralization rates of poultry waste is such a variable process and that only crude estimates can be made of the plant available N from PL, it is accepted that the actual fraction of N recovered from PL during a single growing season is generally less than that recovered from inorganic fertilizers (Sims, 1987; Cooper et al., 1984). Therefore N application rates based on total N may need to be greater for PL than for inorganic N sources. The P and K fractions of PL are considered to be about 75 percent as effective as in commercial fertilizers during the first year, with the remainder being gradually released during subsequent years of PL decomposition (Ranske et al., 1987).

The economics and logistics of manure handling often dictate that it be spread relatively close to its source of production even if the resultant high rates of application do not provide optimum use of the plant nutrients in the manure. But the land application of PL in the small quantities often recommended for certain crops is difficult. Some newer, very expensive spinner spreaders can be adjusted
to apply 2 to 3 mt ha\(^{-1}\), but the typical box spreaders currently in the hands of farmers are only well calibrated in the 12 to 22 mt ha\(^{-1}\) range (Carr, 1988). Poultry litter contains a wide range of particle sizes, shapes of particles and moisture contents which add to the difficulty in calibrating machinery to apply small, uniformly distributed application rates (Zublena, 1992). Unused nutrients, by crops from the land application of poultry waste, represent a loss to the poultry grower. They as well pose a possible environmental hazard through the increased potential for surface and ground water contamination through runoff and leaching.

**Environmental Impacts**

Historically in the south, broiler production has been concentrated in upland areas such as the Ozark Mountain area of Arkansas (the number one poultry producing state in the U.S.) and in the Sand Mountain region of Alabama (the number two broiler producing state in the U.S.) (Wood, 1992). The inability to use this land for row crop production and cheap labor costs, rather than any climatic benefits, are the major reasons for this high broiler production. These soils tend to be sloping, shallow to bedrock and permeable to dissolved substrates such as NO\(_3\)-N, and are similar to conditions in the poultry producing regions of the Shenandoah Valley of Virginia. In the Coastal Plain region, the sandy soils of the Delmarva (Delaware, Maryland and Virginia) peninsula possess a highly concentrated poultry industry, which generates an estimated 580,000 mt of poultry manure per year (Sims, 1987). The sandy soils of Delmarva can be susceptible to leaching losses of applied nutrients.

Water pollution is probably the most damaging widespread environmental effect of agricultural production (NRC, 1989). Agriculture is the largest non-point source of water pollution, accounting for approximately half of all water pollution in the United States (Chesters and Schierow, 1985; Myers *et al.*, 1985). It is estimated that between 50 and 70 percent of all nutrients reaching surface waterways,
principally N and P, originate in the form of fertilizer or animal waste (Phipps and Crosson, 1986; USDA, 1987).

Prior to 1972, each state was required to establish and regulate its own water quality standards. This changed in 1972 when Congress passed the Water Pollution Control Act, commonly referred to as Public Law (P.L.) 92-500. Congress renamed this law the Clean Water Act in 1977. Public Law 92-500 was originally only concerned with the environmental impact of point sources of animal waste (such as livestock waste in large feedlots), not in monitoring the acceptable agricultural practice of the disposal of animal wastes on cropland. This changed in 1983 when the Environmental Protection Agency released its Chesapeake Bay Study which identified non-point source contributions of pollutants as one of the major reasons for the general decline in the water quality of the Chesapeake Bay (Magette, 1988).

The National Council on Agriculture (NRC, 1989) estimated that the surface water damage from agriculture is between 2 and 16 billion dollars per year. This, they concluded, may be an underestimate, as it did not account for the possible long term costs of pollution. The passage of the Water Quality Act of 1987, which emphasized the control of non-point sources of pollution, brought the agricultural practice of spreading animal waste on cropland under greater scrutiny than ever before.

It is estimated that 27 million kg of N and 4 million kilograms of P entered the Chesapeake Bay from cropland in Virginia in 1985 (Kintzer, 1990). Rockingham County, Virginia, located in the heart of the Shenandoah Valley, is the largest poultry-producing county in Virginia (Bosch and Napit, 1992). Using 1987 census data, Napit (1990), in calculating the N needs of all crops in Rockingham County and the satisfying of these needs with the locally produced poultry waste, estimated an annual surplus of 57,600 mt of PL. Even when considering the total potential of PL consumption by all beef cattle in the county, he still calculated a surplus of 26,600 mt of PL on an annual basis. These figures are today probably underestimates as trends at the time of this study showed poultry production expanding while beef production was declining. Unfortunately the total use of animal waste to meet
plant N needs is not feasible either practically or economically in today’s agriculture production schemes.

In July of 1988, Rockingham County enacted an ordinance which requires poultry growers to develop a plan for litter disposal (Rockingham Co., 1988). The ordinance states "the plan should provide for safe disposal or use of 100 percent of the animal waste produced by each poultry facility". All poultry producers applying for a production permit after 1988 must have an approved nutrient management plan for the disposal of their wastes at the time of application, and all existing producers are to have a similar plan approved by 1994. If land-applied, the land application rates of PL must be accomplished according to agronomic rates as established by the Virginia Cooperative Extension Service and other appropriate agencies (Bosch and Napit, 1992).

This is a hefty challenge with the ever-decreasing profit margin per unit of production and the likelihood of rising gasoline prices further increasing the transportation costs of shipping supplies into, or PL out of, a poultry complex. Aho (1989), using 1989 economic data, estimated that a poultry producer forced to increase its radius of operation from 40 to 80 kilometers from its hatchery, feed mill and processing plant would experience a one cent increase per pound of broiler produced. He therefore estimated that a typical broiler complex would experience a 2 million dollar increase in its cost of operations on an annual basis.

Nitrate can be a major source of ground water contamination, especially in these heavily concentrated areas of poultry production. In southern Delaware, where poultry operations are prevalent, 41 of 95 wells sampled had NO$_3$-N concentrations above the United States Environmental Agency’s 10 mg L$^{-1}$ standard for NO$_3$-N in drinking water (Robertson, 1977). Ritter and Chirnside (1984), who also sampled wells in Delaware, found that the majority of wells had above 10 mg L$^{-1}$ NO$_3$-N, and that NO$_3$-N levels decreased with an increasing distance from poultry houses. Liebhardt et al. (1979) found that, as PL rates increased from 0 to 179 mt ha$^{-1}$ on an Eversboro loamy sand (mesic, coated,
Typic Quartzipsamment), NO₃-N levels in ground water increased from 7 to 15 mg L⁻¹ to 65 to 175 mg L⁻¹ at the 3 meter depth. Prolonged exposures to NO₃-N levels exceeding 10 ppm in drinking water can lead to methemoglobinemia (oxygen deficiency in the blood), a serious health risk to humans, especially to infants less than 6 months of age whose digestive systems have a higher pH and different microorganisms than adults (Zublena, 1992).

When NO₃-N enters the digestive tract, it is quickly converted to nitrite (NO₂-N) (Zublena, 1992). Nitrite is extremely reactive and combines with the oxygen carrying hemoglobin in the body's blood stream forming a compound called methemoglobin. This compound decreases the oxygen available to the system of an individual, especially a baby. When this happens, the individual will begin to suffocate due to lack of oxygen (Zublena, 1992). Thus, the common name for methemoglobinemia, blue baby syndrome, is derived. Though recorded cases are rare in the United States, one must still be concerned. Death occurs when 70 percent of the body's hemoglobin converts to methemoglobin (Zublena, 1992).

Other major human health problems associated with the ingestion of high NO₃-N containing waters include cancer and respiratory illnesses (Stevenson, 1986). In addition to the same problems confronted in humans, there is also an increase in the number of fetal abortions when NO₃-N levels are elevated in the drinking water of livestock (Stevenson, 1986).

Phosphorus is indispensable for life because of the role it plays in energy transfers as a constituent of adenosine triphosphate. Phosphorus usually is low in availability in ecosystems which therefore often makes it the most life-limiting element (Ozanne, 1980). The low availability of soil P to plants is frequently assured by formation of highly insoluble Al, Fe and Ca precipitates and by adsorption reactions with oxides. Of the P in the plant-soil-animal system, commonly 90 percent is in the soil, and of this, less than 10 percent enters the plant-animal life cycle (Ozanne, 1980).

Within the soil, P can be considered to exist in three fractions; organic matter P, insoluble inorganic P and soluble inorganic P. The organic matter P becomes available through mineralization
like N and can be up to 50 percent of total soil P. The soluble inorganic portion is very variable and is usually quite small (Ozanne, 1980). These fractions are often referred to as labile, non-labile and solution P. Phosphorus, unlike many other elements, is not commonly recycled in rainfall and once removed from the soil by the crop or by erosion runoff or leaching, its replenishment must come from external sources (Sanyal and De Datta, 1991).

Although P is not toxic, the continued application and accumulation of P, in both organic and inorganic forms, can lead to environmental problems (Sharpley and Menzel, 1987). Phosphorus enters water supplies primarily through surface runoff. Phosphorus losses by leaching or erosion causes eutrophication in rivers and estuaries (Berkheiser et al., 1980; Enfield and Ellis, 1983). This relationship has been documented in Finland (Kauppi, 1985), the southwestern U.S. (Sharpley et al., 1987), and Australia (Birch, 1982). Eutrophication of surface waters creates problems with the use of water for fisheries, recreation, industry, or drinking due to the increase in growth of undesirable algae and weeds (Sharpley and Menzel, 1987; Sharpley et al., 1985). Nitrogen and C also are a cause of eutrophication, but because of the difficulty in controlling the atmospheric sources of N and C, P is often considered the key element for limiting eutrophication (Lee, 1973; Lee et al., 1978, Sharpley et al., 1987).

Phosphorus is transported from farmlands into streams and lakes in solution and in association with sediments, but erosion, transport and deposition processes are selective. Fine soil components, including organic matter, are eroded preferentially (Schriever, 1988). Much of the research on the effects of P on eutrophication is based on total P, i.e., the sediment P plus the solution-phase P. Various studies (Taylor and Kunishi, 1971; Schreiber et al., 1977; Huettl et al., 1979; Johson et al., 1979) have indicated that from only 5 to 40 percent of eroded sediment P is labile, that is, it has the capacity to enter into solution and thus be available for biological activity; the rest is thermodynamically stable and therefore not biologically available to support the growth of algae and larger plants.
On the other hand, measurement of only soluble P may underestimate the total P available for algae growth (Schreiber, 1988).

Sawyer (1952) and Hutchinson (1957) proposed critical soluble and total P concentrations of 10 to 30 ug L⁻¹ (0.01-0.03 mg L⁻¹), respectively, which, if exceeded, may accelerate the eutrophication of lakes and waterways by increasing undesirable algae blooms. Sharpley et al. (1985), in studying the long term effects of soluble P and total P levels associated with agricultural surface runoff, groundwater, stream flow, impoundments and rainfall, strongly suggested that it was unrealistic to attain or maintain P in surface waters below these critical levels. In their studies unfertilized natural soil had fertility levels high enough to result in soluble and total P concentrations consistently greater than these critical levels associated with accelerated eutrophication. They advocated tackling the P eutrophication problem on the basis of the physical characteristics of the water body and site specific recognizable needs.

**Tall Fescue**

Forages are of varying importance for livestock use on a world-wide basis. The agricultural economies of some countries such as Australia, New Zealand and Argentina, revolve almost exclusively around livestock forage systems, while some of the highly populated countries of Asia do not produce a substantive amount of forage. Grasslands occupy more than 400 million ha of land in the United States of which approximately 60 million of this is in hay and cropland or improved pasture (Mays et al., 1980). Tall fescue (*Festuca arundinacea* Schreb.) is grown on approximately 17 million of this 60 million ha and is the predominant cool season perennial grass species produced in the southeast (Belesky et al., 1984).
Tall fescue is adapted to a wide range of climatic conditions. It was introduced to North America from Europe. Though western Europe is considered by some to be the main center of variation of the tribe *Festuca* (Borrill, 1976), tall fescue is considered too coarse and unpalatable to be first-class pasture and is seldom sown there (Whyte *et al.*, 1959). Adapted and grown from Canada to Florida in North America, tall fescue grows best in the transition zone between the two.

Tall fescue grows well on soils that vary from strongly acid (pH 4.7) to alkaline (pH 9.5) (Cowan, 1956). It thrives and conserves soil on thin, droughty slopes, yet forms dense sods and produces excellent growth on poorly drained soils where few other cool season grasses survive (Bucken*ner et al.*, 1979). In Virginia, a 4-year study showed that tall fescue was more productive than orchardgrass or bromegrass under good fertilization (Wolf, 1973). Tall fescue is generally much more yield-responsive to N fertilizer than is bluegrass (Wells *et al.*, 1982).

**Nitrogen and Plant Yield**

Nitrogen is most often the limiting nutrient for forage grass production (Woodhouse and Griffith, 1974) and N application is a major factor affecting the efficient use of fertilizer by forage grasses (Power, 1972). Nitrogen is with little doubt the single fertility component that most often limits the growth of tall fescue. While one can not always be sure of the response of grasses to other nutrients, the response to a certain application rate of N can be fairly well predicted for a given grass species and environmental situation (Mays *et al.*, 1980).

Numerous research reports clearly demonstrate that application of N increases the forage dry matter yield and crude protein content of most grasses, tall fescue included (Whitehead, 1970). A synopsis by Matches (1979) of research on the effect of N application on tall fescue showed that, up to
a certain point, additions of N increased dry matter yield. The magnitude of response to different rates of N appeared to be highly associated with the geographic region in which tall fescue was grown.

Without N application, annual yields of tall fescue ranged from 360 kg ha\(^{-1}\) under non-irrigated conditions in Georgia to a high of 8,160 kg ha\(^{-1}\) under irrigation in southern Oregon. Under irrigated conditions, yields of 15,490 kg ha\(^{-1}\) were obtained with the addition of 353 kg ha\(^{-1}\) N in southern Oregon and 14,120 kg ha\(^{-1}\) with the addition of 896 kg ha\(^{-1}\) N addition in Nevada. Without irrigation and with 448 kg ha\(^{-1}\) N additions, tall fescue yielded 12,486 kg ha\(^{-1}\) in West Virginia. To explain this relatively high yield Belesky et al. (1984) reported increasing N levels in tall fescue significantly increased leaf area and leaf number, and was inversely related to the number of senesced leaves. In Matches’ (1979) synopsis, growth response per unit of N diminished as rate of N increased. Increments of N less than 112 kg ha\(^{-1}\) generally resulted in the greatest increase in dry matter production per unit N.

Though not as common, studies determining the yield response of tall fescue and other forages from PL derived N show similar results to synthetic fertilizer sources. A comparison of PL derived N and synthetically derived N on a long established pasture by Papanos and Brown (1950) indicated that N applied at equal rates produced the same yields. But Kroontje et al. (1958), on two silt loam soils of the Shenandoah valley of Virginia, found that PL alone produced significantly lower corn, wheat and clover yields than did PL supplemented with commercial fertilizer. Hileman (1965) noted that broiler rates in excess of 26 mt ha\(^{-1}\) depressed pasture grass yields and that higher rates temporarily depressed plant growth.

On a study in Alabama, Wood et al. (1992) showed that broiler litter on an equal N basis increased yields and improved quality of bermudagrass equal to or higher than that fertilized with ammonium nitrate. Preliminary data from the first year of a two year study in North Carolina on an Appling sandy loam showed that, at comparable N rates, grain and dry matter yield of winter wheat
was lower from PL than from synthetic fertilizer application (Crouse et al., 1992). This relationship was attributed to a slower mineralization rate of organic N from PL due to lower soil temperatures when applied in the fall.

Kee et al. (1992), showed that fertilizer N increased yield of tall fescue over PL derived N on sandy soils when moisture levels were below normal. But with normal moisture levels, in the same study, higher fescue yields were obtained with PL derived N than with inorganic N, at comparable rates. This relationship reflected the slow release of organically bound N over the growing season. On clayey soils, regardless of moisture levels, fescue yields were higher from inorganic N sources than from PL derived N sources.

In the southern Piedmont region of Georgia, tall fescue yields plateaued at broiler manure application rates above 27 mt ha\(^{-1}\) when plots were cut at a 5.0 to 8.0 cm height three to five times per year. When the same plots were cut six times per year at a 2.5 to 4.0 cm height, yields were appreciable higher and an increased yield response occurred at application rates above 27 mt ha\(^{-1}\) (Wilkinson and Mays, 1979). Various other studies documented the ability of PL derived N to replace inorganic sources of N for corn (Carr, 1983; Sims, 1987; Flynn and Wood, 1992), vegetables (Bandel et al., 1972; Giardini et al., 1992) and cotton. (Burmester et al., 1992).

**Nitrogen and Plant Recovery**

The recovery by plants of fertilizer N is dependant upon many factors. These include, the rate and time of N application; the N source; the availability of existing soil N; the forage species; the ambient and soil temperatures; moisture levels; and the interval between the N application and crop harvest (Dougherty and Rhykerd, 1985). Matches (1979), in a synopsis of studies done on tall fescue throughout the United States, concluded that the efficiency of N conversion to dry matter was depen-
dant on the soil fertility status and on the growing season conditions. Efficiency ratios varied from 6.1 to 52.6 kg of forage kg⁻¹ of N fertilizer application. In nearly all cases, growth response of N diminished with increased rate of N application. Lower increments of N, especially rates of 112 kg ha⁻¹ or less, generally caused the greatest increase in dry matter production per unit of applied N. Phillips et al. (1992) indicated that though fertilizer N increased tall fescue yields, rates above 340 kg N ha⁻¹ yr⁻¹ resulted in very inefficient N use.

Studies have been conducted to determine the N recovery by tall fescue from non fertilizer sources of N. Devitt et al. (1990) measured the response of tall fescue to applied sewage sludge in a pot study on three desert soils (loamy sand, sandy loam, and clay) and reported that the percent N in the tissue increased as sludge loading rate increased for each soil (loamy sand r=0.87, p=0.001; sandy loam, r=0.93, p=0.001; and clay, r=0.90, p=0.001). Relatively high correlations occurred between final harvest dry weight (r=0.93, p=0.001) and percent N in the tissue (r=0.90, p=0.05). Nitrogen concentration in the clippings decreased from the beginning of the experiment (3.5 to 5.5 percent) to the end of the experiment (0.6 to 2.7 percent). This finding was attributed to the reduced N release of the sludge with time, and to the greater presence of dead and senescent tissue in the final harvest. Both N concentration and content of all treatments were highly correlated with the P content in the final harvest (r=0.98, p=0.001).

Tester et al. (1982), also studied the agronomic value of sewage sludge amendments to tall fescue and found that the addition of a fertilizer P source caused a substantial increase in fescue N content for all the used rates of compost addition. They noted that the rate of mineralization of organic N limited plant N uptake and attributed this slow N release to the excess C present in the woody material of the sewage sludge. Warman (1986a) assessed the N recovery of timothy (Phleum pratense) from pig manure and sewage sludge amended soils determined N efficiency rates to range from 16 to
26 percent on a sandy loam and from 22 to 49 percent on a clay loam. These figures were similar to data reported by King (1981).

**Negative Effects of Poultry Litter on Plants**

Negative effects of animal waste application on plant growth, especially the effects of excess PL on corn germination and growth, have been discussed in the literature. Adriano et al. (1971), stated that chlorides are the major constituents of salts in dairy cattle waste and that there is a potential hazard for a salinity build up in heavily manured soils. Unlike other animal manures poultry manure can excrete up to 61 percent of its N in the form of uric acid (Eno, 1966).

Weil et al. (1979), in studying the effects of 5 years of heavy PL applications (up to 100 mt ha⁻¹ year⁻¹) on a Davidson clay loam (clayey, kaolinitic, thermic, Rhodic Paleudult), found salt levels between 3,136 and 4,064 mg kg⁻¹ in the upper 8 cm (where litter was disked in), and residual salt levels in excess of 1,400 mg kg⁻¹ down to 36 cm, on the highest treated PL plots. These levels of salt from PL applications of 56 mt ha⁻¹ and above, increased water stress, decreased leaf area index and decreased yield on corn (Shorthall and Liebhardt, 1975). Weil et al. (1979), determined that the water stress at higher rates of PL could have been caused from the low matrix moisture tension and the high rate of organic composition, possibly inducing oxygen deficiency. Germination rates were reduced by greater than 50 percent and grain yields by 60 percent as compared with the lower treatments of PL application rates. Considerable seedling mortality occurred at the 3 and 4 leaf stage. Seedlings that did not die, exhibited general chlorosis, burned leaf tips and margins, and stunted root growth. High levels of nitrites and ammonia were felt to contribute to this.

High amounts of ammonia have been shown to inhibit seed germination of corn (Allred and Ohrogge, 1964; Blancher, 1967). Ammonia above 10 mg kg⁻¹ soil was found to be lethal to cotton
seeds (Megie et al., 1967). Siegel et al. (1975) saw depressed germination rates and consequent yields of corn at PL rates of 3.0 percent or more (based on soil dry weight). They noted that root extension was retarded and that root hair and lateral development was inhibited. This repressed root growth was attributed to the release of ammonia from the decomposition of uric acid in fresh PL.

Liebhardt (1976b) identified a toxic build up of essential nutrients due to PL rates of greater than 22 mt ha\(^{-1}\). It was noted that the high levels of essential nutrients in the soil were reduced by winter rain and that subsequent corn yield and growth was unaffected by previous excessive applications of manure. On mixed swards of cool season forages, Bomke and Lowe (1991) saw no indications of toxicity problems, even at the highest rates of broiler litter application (40 mt ha\(^{-1}\)). Though this rate raised total soil levels of trace elements, this was found only to have beneficial implications for livestock mineral nutrition.

**Botanical Composition**

Studies looking at the ability of PL to affect the composition of mixed swards are very limited. Bomke and Lowe (1991), evaluating yield response of an orchardgrass-ladino clover sward on a silty clay loam, saw substantial yield increases up to 20 mt ha\(^{-1}\). However, manure rates greater than 2.5 mt ha\(^{-1}\) completely inhibited the ladino clover component of the mixed sward.

**Phosphorus and Plant Growth**

It is well documented that low available soil P supply can be a major cause of low yields on N fertilized grasses. Soil P status changes almost on a field by field status due to past fertilizer practices. Though Beason (1945) was able to delineate wide areas of P deficiency in the United States almost 50
years ago, today, P deficiencies are rare, except in drastically disturbed areas such as strip mine spoils, highway cuts and other scalped areas where no topsoil is present. The reason P deficient soils are rare in the United States is mostly due to a massive and extensive federal cost share program begun in the 1940s and 1950s that allowed farmers to fertilize lands at economically feasible rates. Still, Beaton and Berger (1974) calculated that the total use of P fertilizer on forages was less than 25 percent of levels recommended for highest economic return.

Data from 31 years and 11 locations in North Dakota showed decreases in forage yields when soil P availability was low (Dodds, 1984). Studies have indicated that the application of only P fertilizer to forages has not generally resulted in increased forage production, especially when P soil levels are in the normal crop production range (Kilcher et al., 1965; Lorenz and Rogler, 1973). In rangeland studies, the addition of P alone, did not show yield increase, but increases in yields were seen with the application of N (Wright and Black, 1972; Lorenz and Rogler, 1973).

Mays et al. (1980), gave the following four reasons why historically, low rates of fertilizer, especially P have been used on forages in the United States:

1) Forages are considered to be low value crops and thus economics do not favor P application.
2) Reduced yields due to low P fertility are not always obvious, particularly under grazing.
3) It is difficult for the farmer to measure a P fertilizer response in terms of dollars of profit per area unit of land.
4) The level of management practiced by many farmers does not result in full utilization of the extra forage produced by P fertilization.

Phosphorus removal from a soil is a function of the yield level, P concentration in the harvested forage, and the form in which the crop is removed, i.e., hayed or grazed (Matches, 1979). A yield of 9,000 kg ha⁻¹ containing 0.30 percent P, would remove 27 kg P ha⁻¹ under a hay management system. Under grazing systems, at a forage consumption of 60 to 65 percent, a significant amount of
P would be returned to the soil through excreta. At these yield levels, removal of P would be less than 15 kg ha\(^{-1}\) (Ozanne, 1980).

Weidin (1974) reported that P concentrations in cool season grasses range from 0.14 to 0.50 percent. Concentrations below 0.20 percent are usually an indication of a deficiency, while ranges from 0.30 to 0.35 percent are usually necessary for optimal yields. Martin and Matocha (1973) list the following P ranges for tall fescue cut at 4 to 5 weeks: less than 0.24 percent - deficient; 0.26 to 0.32 percent - critical; 0.34 to 0.40 percent adequate; more than 0.45 percent - high.

Christie and Moorby (1975) examined three grass species grown in culture with 5 levels of P from 0.003 to 30.00 mg P L\(^{-1}\) and observed large yield increases in all three grass species as P concentration of the culture increased. Total P uptake was related to yield rather than to the concentration in the tissue. Hillard et al. (1990) reported a linear increase in tissue P concentrations in both ryegrass and bermudagrass as fertilizer phosphate levels were increased from 0 to 1100 kg ha\(^{-1}\) on bermudagrass, and from 0 to 550 kg ha\(^{-1}\) on ryegrass. Sanders et al. (1991) showed that P application increased P uptake by wheat grown in greenhouses.

Jones et al. (1970) compared P response of Italian ryegrass, orchardgrass, tall oatgrass, hardinggrass and tall fescue, and found that tall fescue produced both the greatest yield without P, but also showed the greatest response to P fertilization. Lunt et al. (1965), who studied the response of fescue to applied P, showed an 80 percent yield increase to applications of 66 mg P kg\(^{-1}\) soil, which had an initial level of 2.8 mg kg\(^{-1}\) of NaCHO\(_2\)-extractable P. There was only a 19 percent increase for soils initially testing 8.2 ppm P or higher. They found that 66 mg P kg\(^{-1}\) applications increased tissue P by 50 percent on low P soils, but by only 31 percent on high P soils. Their estimations indicated that approximately 50 percent of maximum yield was obtained when tissue P levels were 0.19 percent; tissue P levels of 0.35 percent were needed for maximum yields.
Phosphorus and Soil

The effectiveness of surface applied P has been questioned, due to P relative immobility. Riley et al. (1975), in a review of literature on availability of surface applied P, concluded that surface applied P was readily absorbed by plants. Movement of P into the 2.5 to 5.0 cm layer by freezing and thawing, wetting and drying, and soil fauna, were reasons suggested for the movement of P into the root zone.

Loss of P from the root zone through upward or downward movement of P is not usually a problem in pastures. The dense network of fine fibrous roots produced by grasses, extensively explore soils and allow them to sorb P that other plants might not be able to. Black (1967) estimated that almost all the P supplied to plants comes from a soil layer approximately 1 mm in thickness around each root. Phosphorus adsorption and precipitation reactions also limit upward and downward movement. De Datta et al. (1963) found that three latosol soils, typical of warm and hot humid regions, immobilized over 98 percent of added fertilizer P.

That land application of animal manures have consistently increased soil P levels on all types of soils is well documented. Meek et al. (1982) showed that, after eight years, one application of 180 mt ha⁻¹ manure on a Holtville silty clay (Typic Torrifluvents) doubled the NaHCO₃-extractable P levels in the surface 30 cm of soil as compared with plots that did not receive manure. Other treatments that received higher manure rates, had as much as five times the extractable P levels as did the control. Eleven annual applications of cattle feedlot manure (Chang et al., 1991) increased both total and available P in the surface 30 cm depth. The "build up" of P has been documented by others in research with beef cattle manure (Herron and Erhart, 1965; Vitosh et al., 1973; Murphey et al., 1977), dairy cattle manure (Olsen and Barber, 1977), and swine manure (Perkins et al., 1964; Cummings et al., 1975; Collins et al., 1978; and King et al., 1990) on both alkaline and calcareous soils.
Phosphorus derived from poultry waste has, as well, been shown to increase P levels in soils (Perkins et al., 1964; Shorthall and Liebhardt, 1975; Mitchell et al., 1992; Kingerly et al., 1993; and Sharpley et al., 1993). Liebhardt (1976a) found that, when PL was applied at 168 mt ha\(^{-1}\) to an Elkton loamy sand under corn production, there was an eight fold increase over control plots in extractable P levels in the surface 15 cm. At 56 mt ha\(^{-1}\), there was still a four fold increase. Warman (1986b) showed that, where applied on an equivalent N basis, poultry manure treatments caused higher increases in Bray P\(_2\)-extractable P than dairy manure treatments on a Bearbrook clay (Typic Humaquept) planted to timothy. The poultry manure contained a higher percent P than the dairy manure.

Movement of P in the soil profile is dependent on such factors as the rate of P application; the P reactions with soil; and the consistency and type of the applied waste (Reddy et al., 1980). In most soils, P is retained close to the site of application, and the main mechanisms for loss from the soil system are physical erosion of topsoil and loss of solution P in surface runoff (Barrow, 1980). Leaching losses of P in soil are dependent upon soil properties (texture, adsorption capacity, amount and type of soil, etc.), environmental conditions (rainfall intensity and temporal distribution of rainfall), and management practices (solubility and rate of fertilization application, time of application relative to rainfall and type of crop) (Weaver et al., 1988).

Phosphorus tends to move very slowly in the soil. Slow movement accounts for the tendency of P, at normal application rates, to remain in the zone of application. Olsen et al. (1962) determined the diffusion coefficient of P in soil solution to be less than \(10^{-2}\) that in water. Barber et al. (1963) reported values for the diffusion of \(^{32}\)P in soil to be as low as \(4 \times 10^{-11}\) cm\(^2\) sec\(^{-1}\). Lewis and Quirk (1965) determined the mean velocity of phosphate ions to be only 0.04 mm day\(^{-1}\) at an applied P level of 100 mg kg\(^{-1}\) in Seddon soils.

The study of P immobilization (often referred to in the literature as phosphorus fixation or retention) at low pH in the presence of Fe and Al, and at higher pH in the presence of Ca and Mg
dates back to the mid 1800s (Way, 1850). Phosphorus is known to move downward in soil profiles by leaching. The wealth of information on this subject shows that the leaching of P, especially in light textured soils (sandy), can be rather extensive. The likelihood of P leaching increases in sandy soils low in concentrations of Fe and Al (Cogger and Duyburg, 1984; Diggle and Bell, 1984).

Spencer (1957) studied the movement of P applied as superphosphate to a Lakeland fine sand and found that considerable leaching of P occurred to a depth of over 2 meters. This data indicated that the greatest amount of P was retained in the 55 to 90 cm subsoil depth. Neller (1946) showed that practically all of the applied P, as superphosphate, was completely leached out of the surface 10 cm of two Coastal plain soils when pH was maintained at approximately 4.5, but that a retention of 60 percent of the P occurred when pH was raised to 5.7 by liming. Other studies (Hingston, 1959; Gilman, 1973) confirm that 90 percent of the P, applied in this form to sandy soils, can be lost from the surface soil by leaching.

Historically, the leaching of P from non-sandy soils has been reported to be extremely low or non detectable. Hubbard et al. (1989), in a study to assess P movement in two sandy soils and one clay soil under simulated rainfall, noted some P movement with percolation on only the sandy soils. On the clay soil movement of P was mostly measurable in the surface runoff. Olsen and Watanabe (1970), on the basis of diffusion studies, concluded that there was an eight times greater risk of P pollution of ground water from sands than from clays.

Sommers et al. (1979) observed that less than 30 percent of Bray-extractable P from application of municipal waste water had moved below the 0 to 15 cm layer of a Hublesbury clay loam (clayey, illitic mesic Typic Hapludults) after 12 years of irrigation. However on a Morrison sandy loam (fine loamy, mixed mesic Ultic Hapludults), 37 percent of the extractable P moved below 15 cm, and unlike the clay loam, some had moved to 60 cm, the limit of sampling. Numerous other studies show that in temperate humid regions, or under normal irrigation practices with associated wetting and
drying cycles, surface applied P is retained at a surface soil depth of from 5 to 15 cm (Hergert and Reuss, 1976; Sharpley, 1986; Lauer, 1988a,b).

The majority of studies on P movement in the soil profile have been completed with inorganic sources of P. Assessment of the effects of organic P applications on possible movement of P into the soil profile has detected more downward movement of P in the soil profile. Phosphorus derived from organic sources has more often shown a capacity to be leached from the soil surface, even on heavier soils (Hannapel et al., 1964; Rolston et al., 1975).

A number of researchers indicated that the presence of organic matter decreased P sorption in soil (Struthers and Seiling, 1950; Dalton et al., 1952; Vyas, 1964; Gaur, 1969). These studies indicated that formation of stable organic complexes with Fe and Al caused a blockage in P retention in the soil. In contrast, other studies have shown an increase in the retention of P for some soils in the presence of organic matter (Taylor, 1946; Jackman, 1955; Rennie and McRercher, 1958; Larsen et al., 1959; Fokin and Chistova, 1964; Harter, 1969). It was suggested that the increase in P retention was due possibly to the mineralization of P from the organic matter. Singh and Jones (1976) noted that the amount of P sorbed by soils decreased with added organic materials containing greater than 0.30 percent P, and that soil P adsorption capacity increased when organic residues contained less than 0.30 percent P.

Hannapel et al. (1964) found that the additions of organic matter increased P movement in calcareous soils, and attributed this relationship to downward movement of microbial cells and cellular debris from the organic matter. Rolston et al. (1975) also determined that organic bound P moved greater distances in soil than P from inorganic phosphate. Reddy et al. (1980) determined that increased loading rates of manure decreased the adsorption sites of a Norfolk loamy sand (fine loamy silicious thermic Typic Paleudults) and a Cecil sandy loam (clayey kalonitic thermic Typic Hapludult), though P did move deeper in the Norfolk soil than in the Cecil soil.
Meek et al. (1979) reported that NaHCO₃-extractable P levels were higher from the animal manure than the inorganic P source, when applications were on a P equivalent basis on a calcareous Holtville silty clay (Typic Torrifluvent). The highest rate of manure application increased the extractable P levels in the 0 to 30 cm surface soil depth by as much as 30 times over the control plot in some years (9 vs 297, and 9 vs 377 mg P kg⁻¹), while triple superphosphate sources of P only doubled the extractable P levels (14 vs 29, and 16 vs 31 mg P kg⁻¹) in this same soil depth. Only the manure increased extractable P levels over the control at the 30 to 60 cm soil depth. The highest level manure application increased the P level between the 30 and 150 cm depths. Meek et al. (1979) determined that the P moved in a soluble organic or inorganic form, and not as part of a complex organic carbon compound.

Data from other studies also indicated that manure increased the availability, persistence and movement of P. Abbott and Tucker (1973) found that the P concentration under manured cotton was higher than under either control or inorganic N treatments. Meek et al. (1982), in a continuation of previously discussed research (Meek et al., 1979), showed that after eight years, P (180 kg ha⁻¹) as manure applied once, had more than double the extractable P than the control in the surface 0 to 30 cm of soil. Other treatments with higher manure rates had as much as five times more soil extractable P than did the check. During the nine years of this study, the soil extractable P in the 30 to 60 cm soil depth remained higher than the control plot. The P that had moved to the 30 to 60 cm depth was suggested to be in the organic form.

Two recent studies were conducted in Alabama to determine the effects of long-term PL applications on soil and plant nutrient levels. One study was done in the north where the major portion of Alabama's 1.4 billion dollar poultry industry is concentrated (Kingerly et al., 1993), and the other in south Alabama (Mitchell et al., 1992). Both studies compared fields that had been subjected to long-term (15 to 25 years) applications of PL to adjacent fields in the same area that had not received PL
during the same period. In the mild climate of the north, where soils are typically sandy in texture, and sloping and shallow to bedrock, Kingerly et al. (1993) found that litter applications of between 4 and 20 mt ha\(^{-1}\) annually had dramatically increased P levels to depths of 45 cm. The average increase in P in this depth, over adjacent non littered fields, was 530 percent. Levels of nitrate nitrogen in excess of 40 ppm were also found at depths greater than 3 meters. In the south of Alabama, Mitchell et al. (1992) did not detect the high NO\(_3\)-N levels but they did detect movement of P into the soil profile. An Esto loamy sand (clayey, kaolinitic, thermic Typic Kandudults) that received between 4 and 84 mt of PL ha\(^{-1}\) annually for over 14 years had increased levels of P down to 60 cm (30 mg P kg\(^{-1}\) vs. barely detectable), compared with an adjacent field that did not receive PL additions during this same period. These authors concluded that long-term land applications of PL at disposal rates may indeed create a potential for harmful environmental effects, especially in the Sand Mountain region of northern Alabama.
Literature Cited


Robertson, F. N. 1977. The quality and potential problems of ground water in Sussex Co., Delaware. Waer Resources Center, University of Delaware, Newark, DE.

Rockingham County. 1988. Zoning Ordinance, Division 9, Section 17-178. Harrisonburg, VA.


Chapter 3

Effects of Applied Poultry Litter on Yield, Botanical Composition and Nitrogen and Phosphorus Recovery and Use Efficiency on a Starr Clay Loam
INTRODUCTION

The poultry industry is one of the largest agricultural industries in the world. A tremendous need for high protein foods in the developing nations and the ever increasing consumer demand for foods high in protein and low in cholesterol in the developed nations will assure that the poultry industry grows larger in the future. The combined value from the production of poultry in fiscal year 1991 in the United States was approximately 14.7 billion dollars and over 60 percent of this production occurred in the southeast (USDA Statistics, 1992). In 1992 in Virginia, broiler production cash receipts at the farm level exceeded 300 million dollars and was exceeded only by cattle and calf sales (Va. Agricultural Statistics, 1993).

The primary waste from poultry production is litter (PL), a mixture of bedding and manure. Approximately a metric dry ton of litter is annually produced per 1,000 broilers per flock (Moreng and Avens, 1985). Therefore the 6.14 billion broilers grown in the United States in 1991 (USDA Statistics, 1992) produced a total of 6.14 million metric tons of litter. Broiler production in Virginia in 1991 resulted in over 200,000 metric dry tons of litter. Land application of PL is the most practical, feasible and economic disposal method. Because poultry is produced in spatially concentrated areas in order to minimize feed and transportation costs, litter production often exceeds crop nutrient requirements of both poultry producing and adjacent farms.

Tall fescue (*Festuca Arundinacea* Schreb.) is the predominant cool season perennial grass species produced in the southeast (Belesky *et al.*, 1984). Hay production, predominately unimproved mixed species pastures of tall fescue, occupied approximately half a million ha in Virginia in 1992 (Va. Agricultural Statistics, 1993). Nitrogen is, with little question, the single fertility component that most often limits the growth of tall fescue (Mays *et al.*, 1980). Poultry litter, land applied as a fertilizer source for cool-season pasture species, is therefore usually regulated according to the N requirements of
the grass species. Chemical composition analyses of PL can vary widely, but various scientific sources show a 1:1 relationship between total N and P expressed as P₂O₅ (Ranske et al., 1987; Simpson, 1991). Except for legumes, pasture species P requirements are much lower than N requirements, for optimal growth. Therefore when PL is applied according to crop N needs a large oversupply of P occurs. This P in excess of crop requirements, from the land application of PL, represents a loss to the poultry grower. It can as well pose a possible environmental hazard through the increased potential for surface and ground water contamination through runoff and leaching.

The value of PL as a nutrient source for the production of agricultural crops has been recognized for a long time. Land applied PL has been shown to increase yields of tall fescue (Hileman, 1965; Vand eupopuliere et al., 1975; Quisenberry et al., 1980; Huneycutt et al., 1988; Kee et al., 1992). Studies on the ability of PL to affect the composition of mixed swards are very limited. Fertilizer N has changed the botanical composition of mixed species pastures (Rogler and Lorenz, 1974; Rauzi, 1979). Poultry litter rates greater than 2.5 mt ha⁻¹ increased the orchardgrass component while completely inhibiting the ladino clover component of a mixed orchardgrass-ladino clover sward (Bomke and Lowe, 1991).

The purpose of this research was to determine the short term effects of various rates of land applied PL on unimproved pasture and to evaluate the suitability of PL applications for pasture grass renovation. Areas specifically addressed in this portion of the study were 1) the dry matter yield response of an unimproved pasture to PL application and 2) the N and P recovery and use efficiency by unimproved pasture as related to PL application. Changes to canopy composition from the PL application also were evaluated during this investigation.
MATERIALS AND METHODS

Soil and Location

A field experiment was conducted in 1991 and 1992 on unimproved pasture on a Starr clay loam (fine-loamy mixed thermic Flueventic Dystrochrepts) at the Northern Piedmont Research Station in Orange, Virginia (38°13' north latitude, 78°07' west longitude, elevation 158 m). The nearly level (< 2 percent slope) experimental area, 14 by 31 m, was mowed and raked in February of 1991. Thirty-two plots were laid out in rectangles of 3.0 by 3.65 m, with a 1.0 m buffer zone between each plot and a 1.5 m alley between blocks. Prior to initiating the research, the experimental area had been in unmanaged pasture for at least 20 years. The pasture was a mixture of native tall fescue (Festuca arundinacea), bluegrass (Poa pratensis), and broad-leaf weeds.

Field Experimentation

Eight treatments were applied to the experimental area in a randomized complete block design with four replications. The eight treatments were as follows: 1) a control; 2) 33 kg of P ha\(^{-1}\) as triple superphosphate applied each spring; 3) a recommended fertilizer regime for tall fescue pasture in the Piedmont region (Simpson et al., 1993), i.e., 33 kg of P ha\(^{-1}\) applied as triple superphosphate in the spring of each year and 138 kg N ha\(^{-1}\) as NH\(_4\)NO\(_3\) applied in two split applications of 92 kg N ha\(^{-1}\) in March and 46 kg N ha\(^{-1}\) in May (additionally this treatment received 26 kg N ha\(^{-1}\) as urea in August of 1991 and 46 kg N ha\(^{-1}\) as NH\(_4\)NO\(_3\) in August of 1992); and 4) five rates of PL based on N content (Simpson et al., 1993). In 1991 PL was applied at rates of approximately 5.7, 11.4, 17.1, 22.9, and 28.6 mt ha\(^{-1}\) on a dry weight basis. In 1992 rates were approximately 4.0, 8.1, 12.1, 16.1, and 20.2 mt
ha\textsuperscript{-1}. In 1991, half of the litter was applied in spring (March) and the other half in the fall (August), and in 1992, two-thirds was applied in spring (March) and the remaining one-third in the fall (August). In 1991, K was surfaced applied as (KCl) in March and May at the rate of 93 kg ha\textsuperscript{-1} to all treatments. Based on calibration data for the Mehlich 3 test (Mehlich, 1978), K soil levels were in the high range in 1991 and 1992. Poultry litter was acquired from a locally operated poultry farm each spring. Bedding material used for litter was wood shavings from soft wood species.

Percent moisture and concentrations of NH\textsubscript{4}-N, Ca, K, Mg, Total N, and P in the PL samples were determined prior to application. Percent moisture was measured gravimetrically after a 24-hour period at 85\degree C. Ammonium was extracted from the PL with 2 M KCl and determined calorimetrically by an indophenol-blue procedure (USEPA, 1979). Total N in PL was determined by a steam distillation procedure following Kjeldahl digestion (Bremer and Mulvaney, 1982). Poultry litter was digested in a HNO\textsubscript{3}-HClO\textsubscript{4} mixture in preparation for Ca, K, Mg, and P analyses. The Ca, K, Mg, and P in the digests were then determined by inductively coupled plasma emission spectrometry.

The soil of the experimental area had a pH of 6.3 prior to initiation of the research. Hence, dolomitic limestone (CCE of 104\%) was surface applied to the experimental area in 1991 at a rate of 5.6 mt ha\textsuperscript{-1}. Application of dolomitic limestone increased soil pH to 6.7 in the fall of 1991 and 1992. A herbicidal agent, 2,4-D, (2,4-dichlorophenoxy acetic acid) was applied at a rate of 2.25 kg ha\textsuperscript{-1} in April and July of 1991 and at a rate of 3.36 kg ha\textsuperscript{-1} in April of 1992 to control clover (Trifolium repens), crown vetch (Coronilla varia), and broad-leaf weeds. Banvel D (3,6-dichloro-2-methobenzoic acid) was applied at a rate of 4.5 kg ha\textsuperscript{-1} once in July of 1991 for additional weed control.
Yield Analyses

Forage was harvested and measured four times in 1991 (2 May, 20 June, 13 Aug, and 35 Oct) and five times in 1992 (6 May, 19 June, 14 Aug, 23 Sept, and 6 Nov). Average height of forage at harvest across all treatments for both years was approximately 62 cm. Areas of 0.75 by 3.65 m were cut to a height of 3 cm with a sickle bar mower and raked for yield measurements. Forage yield of each plot was adjusted to dry weight after drying a subsample at 65°C for 72 hours. Forage yields represent bulk sward yields and are reported on a dry weight basis herein.

Tissue Analysis

A plant tissue sample was taken from all plots from each harvest. The tissue was ground to pass a 0.833 mm sieve in preparation for N and P analyses. Total N in the ground plant tissue was determined by a steam distillation process following Kjeldahl digestion (Bremer and Mulvaney, 1982). Plant tissue was digested in a HNO₃-HClO₄ mixture in preparation for P analyses. Phosphorus in the digests were determined by inductively coupled plasma emission spectrometry.

Nitrogen and Phosphorus Recovery and Use Efficiency

Nitrogen recovery was calculated by determining the N uptake (yield x concentration in tissue) for each treatment. The N uptake for the control was subtracted from the N uptake of the other treatments. The net N uptake was than divided by the corresponding annual total N applied per treatment to determine N recovery. Phosphorus recovery was calculated in the same manner as N recovery. Nitrogen efficiency was calculated by subtracting dry matter yield of control from each treatment and
then dividing by the corresponding annual total N applied per treatment. Phosphorus efficiency was calculated in the same way as N efficiency.

**Botanical Composition Determination**

In July of 1993, a 0.5 by 0.5 m quadrant was randomly thrown into each plot and clipped to a height of 2 cm above the soil surface. Forage species were separated into groups according to individual grass species. The three major grass species groupings were tall fescue, bluegrass, and miscellaneous weeds. Separated samples were then dried at 65°C for 72 hours and weighed. Percent species composition was determined on a dry weight basis by calculating the weight of each species as a percentage of the total weight of harvested forage.

**Statistical Analyses**

All data were evaluated separately for 1991 and 1992. Dry matter forage yield, P and N concentrations in forage tissue were evaluated statistically by analyses of variance. Mean separations were performed by a LSD procedure where the F-values were significant at the 0.05 probability level (SAS, 1982). Relationships between dry matter yield and P or N uptake in tissue versus P and N applied in PL were evaluated by linear and curvilinear regression analyses.
Results and Discussion

Poultry litter used over the two-year period (Table 1) varied widely in nutrient concentrations but fell within ranges reported by other researches (Ranske et al., 1987; Simpson, 1991). Year 2 (Y2) PL had higher N levels than year 1 (Y1) PL. Hence, Y1 required higher application rates of PL than Y2 in order to obtain similar N application rates between years (Table 2). Though less total PL was applied per treatment (treatment 4 through 8) in Y2, more N was applied in Y2 than in Y1 (Table 3). Poultry litter was applied at rates that provided total N at increments of approximately 80 kg ha\(^{-1}\) in Y1 and 120 kg ha\(^{-1}\) in Y2. Poultry litter treatments 7 and 8 (i.e., 22.9 and 28.6 mt ha\(^{-1}\), respectively) temporarily depressed plant growth in Y1. This depression was likely due to a smothering effect of these higher rate levels of PL or possibly to the release of high amounts of ammonia from the decomposition of uric acid in freshly applied PL (Siegel et al., 1975). Recovery of pasture occurred within two weeks after application of PL. Total P applied for each treatment was relatively similar between years (Table 3).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Total N</th>
<th>NH(_4)-N</th>
<th>Ca</th>
<th>P</th>
<th>Mg</th>
<th>K</th>
<th>D M(^{2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring '91</td>
<td>13.4</td>
<td>6.4</td>
<td>8.6</td>
<td>6.0</td>
<td>1.3</td>
<td>7.0</td>
<td>66.3</td>
</tr>
<tr>
<td>Fall '91</td>
<td>15.3</td>
<td>6.9</td>
<td>17.4</td>
<td>14.1</td>
<td>2.7</td>
<td>12.4</td>
<td>61.3</td>
</tr>
<tr>
<td>Spring '92</td>
<td>32.6</td>
<td>4.5</td>
<td>17.3</td>
<td>11.4</td>
<td>3.6</td>
<td>4.7</td>
<td>74.6</td>
</tr>
<tr>
<td>Fall '92</td>
<td>24.8</td>
<td>4.5</td>
<td>22.6</td>
<td>13.4</td>
<td>4.6</td>
<td>5.0</td>
<td>74.2</td>
</tr>
</tbody>
</table>

* on a dry matter basis.

\(^{2}\) dry matter.

---

50
Table 2. Levels of poultry litter applications in a field experiment on a Starr clay loam in 1991 and 1992.

<table>
<thead>
<tr>
<th>no.</th>
<th>1991</th>
<th>1992</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spring</td>
<td>Fall</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>3.0</td>
<td>2.8</td>
<td>5.7</td>
</tr>
<tr>
<td>5</td>
<td>5.9</td>
<td>5.5</td>
<td>11.4</td>
</tr>
<tr>
<td>6</td>
<td>8.9</td>
<td>8.3</td>
<td>17.2</td>
</tr>
<tr>
<td>7</td>
<td>11.9</td>
<td>11.0</td>
<td>22.9</td>
</tr>
<tr>
<td>8</td>
<td>14.9</td>
<td>13.8</td>
<td>28.6</td>
</tr>
</tbody>
</table>

*on a dry matter basis.


<table>
<thead>
<tr>
<th>no.</th>
<th>1991</th>
<th>1992</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>164</td>
<td>33</td>
<td>184</td>
</tr>
<tr>
<td>4</td>
<td>82</td>
<td>57</td>
<td>119</td>
</tr>
<tr>
<td>5</td>
<td>164</td>
<td>113</td>
<td>237</td>
</tr>
<tr>
<td>6</td>
<td>246</td>
<td>170</td>
<td>355</td>
</tr>
<tr>
<td>7</td>
<td>327</td>
<td>226</td>
<td>474</td>
</tr>
<tr>
<td>8</td>
<td>408</td>
<td>283</td>
<td>592</td>
</tr>
</tbody>
</table>

*on a dry matter basis.
Dry Matter Yield

Dry matter yields increased curvilinearly \((r^2 = 0.99)\) with levels of PL application in Y1 and Y2 (Figs. 1 and 2). Critical maximum yields (90 percent Ymax) occurred at a PL application rate of 22.9 mt ha\(^{-1}\) (treatment 7) in Y1 and 12.1 mt ha\(^{-1}\) in Y2. The lower level of PL application to achieve the critical maximum yield in Y2 probably reflects residual nutrient availability from PL applied in Y1. The experimental data was evaluated to determine if PL application was as effective as inorganic N and P sources in obtaining dry matter yield. At similar rates of N application (treatment 5 vs treatment 3), PL was 89 percent as effective as inorganic N in 1991 and 112 percent as effective in 1992 in obtaining dry matter yield (Table 4). In both years all PL application rates, with the exception of the lowest rate (5.7 mt ha\(^{-1}\) in Y1 and 4.0 mt ha\(^{-1}\) in Y2), equalled or exceeded the dry matter yields obtained by the inorganic N and P treatment (treatment 3). Treatment 2 (inorganic P only) had the lowest cumulative dry matter yields for the experiment for all treatments except the control.
Table 4. Total forage dry matter yield in a field experiment on a Starr clay loam treated with synthetic and poultry litter fertilizer in 1991 and 1992.

<table>
<thead>
<tr>
<th></th>
<th>1991</th>
<th>1992</th>
<th>2 Year Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg ha⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (Control)</td>
<td>4,720 cd</td>
<td>3,410 e</td>
<td>8,130 d</td>
</tr>
<tr>
<td>2 (Inorganic P)</td>
<td>3,660 d</td>
<td>3,420 e</td>
<td>7,080 d</td>
</tr>
<tr>
<td>3 (Inorganic N &amp; P)</td>
<td>10,510 ab</td>
<td>10,980 c</td>
<td>21,490 b</td>
</tr>
<tr>
<td>4 (1x level of PL)</td>
<td>6,860 c</td>
<td>7,490 d</td>
<td>14,350 c</td>
</tr>
<tr>
<td>5 (2x level of PL)</td>
<td>9,310 b</td>
<td>12,350 bc</td>
<td>21,660 b</td>
</tr>
<tr>
<td>6 (3x level of PL)</td>
<td>10,050 ab</td>
<td>14,400 abc</td>
<td>24,450 ab</td>
</tr>
<tr>
<td>7 (4x level of PL)</td>
<td>11,160 ab</td>
<td>15,620 ab</td>
<td>26,780 a</td>
</tr>
<tr>
<td>8 (5x level of PL)</td>
<td>12,020 a</td>
<td>16,460 a</td>
<td>28,480 a</td>
</tr>
</tbody>
</table>

* LSD column means followed by different letters are significantly different (P≤0.05).

' * x = 5.7 mt ha⁻¹ in Year 1 and 4.0 mt ha⁻¹ in Year 2.
Fig. 1. Forage yield versus level of N application as PL during year 1.

\[ y = 4727.6 + 30.4 x - 0.031 x^2 \]
\[ r^2 = 0.992 \]

Fig. 2. Forage yield versus level of N application as PL during year 2.

\[ y = 3260.2 + 45.2 x - 0.039 x^2 \]
\[ r^2 = 0.994 \]
Dry matter yields (Table 4) were higher in Y2 than in Y1 for all treatments except treatments 1 (control) and 2 (inorganic P only). Forage grew more rapidly in Y2 and needed to be cut more frequently. This higher dry matter yield in Y2 is attributable to the higher levels of N supplied from PL in Y2 and to the higher levels of precipitation in Y2 than in Y1 (Appendix A2). Excluding the month of July (in which Y1 received 9.1 cm more precipitation than Y2), total precipitation between April and September was 20.1 cm more in Y2 than in Y1. Dry matter yield for fertilizer treatment 3 was similar between years. That treatments 1 (control) and 2 (inorganic P only) had lower dry matter yields in Y2 might be a reflection of the depletion of soil N from harvest removal in Y1. Higher yields in Y2 among PL treatments probably reflect increased soil H₂O holding capacity and increased soil N levels in Y2 from the residual effect of unmineralized PL carried over from Y1. Collins (1990) suggested that approximately 50 percent of the organic N from PL is released during the first year of application and that 12 percent will not be available until the second year. Increased cutting frequency has been reported to increase annual tall fescue yields (Wilkinson and Mays, 1979). In Y2 plots were cut 5 times versus only 4 times in Y1.

Phosphorus in the PL was as well highly related to yield (Figs. 3 and 4). Dry matter yields increased curvilinearly as P in PL applications increased in Y1 and Y2. As will be shown later, N in forage tissue was below the critical level in both Y1 and Y2. Phosphorus levels in forage tissue, with the exception of forage that received inorganic N and P (treatment 3) in Y1, were above the critical range for both years. Hence, the P relationship with dry matter yield reflects the high correlation between rate of N and P applied with the PL in both years.
Fig. 3. Forage yield versus level of P application as PL during year 1.

Fig. 4. Forage yield versus level of applied P application as PL during year 2.
Approximately 55 percent of dry matter yield occurred during the months of May and June for the 5 levels of PL application (Appendix A1). Approximately 63 percent of the dry matter yield for treatment 3 (inorganic N and P) was obtained during this same period. These results correspond to experimental data which indicate that two-thirds or more of the total annual yield of cool-season grasses occurs during these cooler months of May and June in the temperate regions of the United States (Wedin, 1974).

**Nitrogen Recovery and Use Efficiency**

In both years N concentration in tissue increased with an increase in PL application rate (Table 5). This relationship agreed with findings of Devitt et al. (1990) who noted that percent N in tall fescue tissue increased with increases in sludge loading rates. Concentration of forage tissue N from the higher PL application rates (28.6 mt ha\(^{-1}\) in Y1 and >12 mt ha\(^{-1}\) in Y2) were higher than in the treatment that received inorganic N and P (treatment 3). That lower rates of PL caused this increase in tissue N concentration in Y2 can be attributed to the unmineralized residual organic N carried over in the soil from PL applied in Y1. Mineralization of the organic N would enlarge the pool of available N above that which was supplied from the PL application rates in Y2.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year 1</th>
<th></th>
<th>Year 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>1 (Control)</td>
<td>1.8 a *</td>
<td>0.37 a</td>
<td>2.1 e</td>
<td>0.37 c</td>
</tr>
<tr>
<td>2 (Inorganic P)</td>
<td>1.8 a</td>
<td>0.36 a</td>
<td>2.1 e</td>
<td>0.38 c</td>
</tr>
<tr>
<td>3 (Inorganic N &amp; P)</td>
<td>2.1 b</td>
<td>0.31 b</td>
<td>2.4 cd</td>
<td>0.36 c</td>
</tr>
<tr>
<td>4 (1x level of PL)'</td>
<td>1.8 cd</td>
<td>0.36 a</td>
<td>2.3 de</td>
<td>0.43 ab</td>
</tr>
<tr>
<td>5 (2x level of PL)</td>
<td>2.1 bc</td>
<td>0.38 a</td>
<td>2.5 bc</td>
<td>0.44 a</td>
</tr>
<tr>
<td>6 (3x level of PL)</td>
<td>2.2 b</td>
<td>0.37 a</td>
<td>2.7 b</td>
<td>0.46 a</td>
</tr>
<tr>
<td>7 (4x level of PL)</td>
<td>2.4 ab</td>
<td>0.37 a</td>
<td>3.0 a</td>
<td>0.43 ab</td>
</tr>
<tr>
<td>8 (5x level of PL)</td>
<td>2.5 a</td>
<td>0.37 a</td>
<td>3.0 a</td>
<td>0.40 bc</td>
</tr>
</tbody>
</table>

* LSD column means followed by different letters are significantly different (P ≤ 0.05).

' x = 5.7 mt ha⁻¹ in Year 1 and 4.0 mt ha⁻¹ in Year 2.

Total N in foliage can range from less than 1.5 percent in mature tall fescue to greater than 5 percent in highly fertilized and frequently clipped immature tall fescue (Wilkinson and Mays, 1979). According to Martin and Matocha (1973), N tissue contents of less than 2.5 percent are deficient for tall fescue harvested at 5 to 6 week intervals. They suggested that adequate N ranges were from 3.4 to 3.8 percent. In both years N tissue concentrations from all treatments were below this range. Hence, application of N would be expected to increase yield as occurred on this soil (Figures 1 and 2, Table 4).

Nitrogen recovery (Table 6) and use efficiency (Table 7) from the PL applications were higher in Y2 than in Y1. This greater N recovery and use efficiency again can be attributed to the enlarged pool of soil N available for plant uptake in Y2. The greater N recovery and use efficiency observed in harvested forage for treatment 3 (inorganic N and P) in Y2 compared with Y1 can be attributed to the higher amounts of precipitation received in Y2 than Y1. Harvested forage that received inorganic N
and P (treatment 3) had the highest N recovery and use efficiency in both years due to the applied N from this treatment being in a much more immediately available form than the N supplied from the PL application treatments. Inorganic sources of N are essentially 100 percent available for immediate plant uptake upon application. Nitrogen from PL must first undergo mineralization before becoming available for plant uptake (Bitzer and Simms, 1988; Simms 1986). In PL, about 65 to 75 percent of the total N is organically bound and the remaining 25 to 35 percent is in an inorganic form, essentially all ammonia (Allred and Ohlrogge, 1964; Blancher, 1967; Sims, 1986; Simpson, 1991). Bitzer and Simms (1988) study measured mineralization rates from 20 PL sources and suggested the following formula for determining the amount of available N in PL:

$$\text{PAN} = 0.80 \, N_i + 0.60 \, N_o$$

where $\text{PAN} =$ predicted available nitrogen - kg mt$^{-1}$.
$N_i =$ inorganic nitrogen - kg mt$^{-1}$.
$N_o =$ organic nitrogen - kg mt$^{-1}$.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year 1</th>
<th></th>
<th>Year 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------</td>
<td>----------</td>
<td>--------</td>
<td>----------</td>
</tr>
<tr>
<td>3 (Inorganic N &amp; P)</td>
<td>91.0</td>
<td>48.3</td>
<td></td>
<td>103.0</td>
</tr>
<tr>
<td>4 (1x level of PL)$^1$</td>
<td>54.6</td>
<td>12.9</td>
<td></td>
<td>82.0</td>
</tr>
<tr>
<td>5 (2x level of PL)</td>
<td>72.2</td>
<td>15.4</td>
<td></td>
<td>101.0</td>
</tr>
<tr>
<td>6 (3x level of PL)</td>
<td>56.8</td>
<td>11.5</td>
<td></td>
<td>88.6</td>
</tr>
<tr>
<td>7 (4x level of PL)</td>
<td>58.8</td>
<td>10.5</td>
<td></td>
<td>83.0</td>
</tr>
<tr>
<td>8 (5x level of PL)</td>
<td>55.8</td>
<td>9.8</td>
<td></td>
<td>72.0</td>
</tr>
</tbody>
</table>

$^1$ x = 5.7 mt ha$^{-1}$ in Year 1 and 4.0 mt ha$^{-1}$ in Year 2.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year 1</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>3 (Inorganic N &amp; P)</td>
<td>35.3</td>
<td>175.6</td>
</tr>
<tr>
<td>4 (1x level of PL)</td>
<td>26.2</td>
<td>37.9</td>
</tr>
<tr>
<td>5 (2x level of PL)</td>
<td>28.0</td>
<td>40.5</td>
</tr>
<tr>
<td>6 (3x level of PL)</td>
<td>21.7</td>
<td>31.4</td>
</tr>
<tr>
<td>7 (4x level of PL)</td>
<td>19.7</td>
<td>28.5</td>
</tr>
<tr>
<td>8 (5x level of PL)</td>
<td>17.9</td>
<td>25.8</td>
</tr>
</tbody>
</table>

' x = 5.7 mt ha\(^{-1}\) in Year 1 and 4.0 mt ha\(^{-1}\) in Year 2.

Nitrogen uptake increased curvilinearly with levels of N applied in PL for both years (Figs. 5 and 6). That this relationship was almost linear in Y1 reflects the low soil N levels at the initiation of experiment. The N uptake in Y2 being more curvilinear again reflects the larger pool of N available in Y2 than Y1 from the residual effect of PL applied in Y1.
Fig. 5. Nitrogen uptake from applied PL in year 1.

Fig. 6. Nitrogen uptake from applied PL in year 2.
Harvested forage from treatment 5 (11.4 and 8.1 mt ha\(^{-1}\) PL in Y1 and Y2, respectively) recovered a greater amount of N and had a higher N use efficiency than did the harvested forage from other PL application rates for both years (Tables 6 and 7). In both years, the harvested forage from treatment 5 (11.4 and 8.1 mt ha\(^{-1}\) PL in Y1 and Y2, respectively) most closely approximated the N recovery and use efficiency of that for the forage harvested from the inorganic N and P (treatment 3). In both years, with the exception of harvested forage from treatment 5, growth response per unit N diminished as rate of N increased from PL applications (Table 7). The N recovered by harvested forage per unit of N applied for both years and for all treatments (Table 7) fell within ranges (6 to 53 kg forage (kg N)\(^{-1}\) applied) reported by Matches (1979) for tall fescue grown under various management schemes.

**Phosphorus Recovery and Use Efficiency**

Phosphorus concentration in harvested forage did not increase in either year with an increase in P fertilizer rate as occurred with N (Table 5). Forage that received inorganic N and P (treatment 3) had the lowest tissue P concentration of all treatments in both years. According to determinations by Martin and Matocha (1973), P concentration relationship with optimal yields of cool-season grasses are as follows: <0.24 percent = deficient; 0.26 to 0.32 percent = critical; 0.34 to 0.40 percent = adequate; more than 0.45 percent = high. The tissue P concentration for treatment 3 was in the critical range during Y1. Forage plants with P levels in this critical range are more susceptible to poorer growth and reduced yields due to nutrient imbalances than when in the adequate range. The low forage tissue P concentration observed in forage that received inorganic N and P (treatment 3) in Y1 can be attributed to more rapid fixation of the inorganically supplied P into nonavailable P than P supplied from PL. That inorganic P can be quickly immobilized when applied to soils, and especially in soils of low P.
and pH and high in Al and Fe is well documented. De Datta et al. (1963) observed that three latosols (oxisols), typical of warm and hot humid regions in Hawaii, immobilized over 98 percent of added P fertilizer. The higher tissue P concentrations observed in Y2 probably are caused by uptake of residual P from Y1. In Y2 all forage tissue P concentrations were within the adequate to high range.

Phosphorus uptake increased curvilinearly with levels of P applied in PL for Y1 and Y2 (Figs. 7 and 8). That the uptake response curve was much more curvilinear in Y2 than Y1 is probably a reflection of the high correlation between rate of N and P on dry matter yield. The more linear response of P uptake in Y1 reflects the low soil P levels of the experimental site at the initiation of experiment.

![Graph showing phosphorus uptake from applied PL in year 1.](image)

Fig. 7. Phosphorus uptake from applied PL in year 1.
Phosphorus recovery (Table 6) and use efficiency (Table 7) of harvested forage were about twice as high in Y2 than Y1 in the PL treatments (treatment 4 through 8). This increase can be attributed to greater root exploration resulting in increased forage yield due to higher amounts of precipitation in Y2 than Y1. Black (1967) estimated that almost all the P in plants is sorbed from a soil layer approximately 1 mm in thickness around each root. The denser network of fine fibrous roots produced by pasture grasses with higher levels of moisture promotes greater soil exploration for P. The more extensive root growth in Y2, due to higher levels of precipitation, accounts for the higher P recovery and use efficiency seen in Y2. The higher P recovery and use efficiency observed in Y2 can also be attributed to the residual organic P carried over in the unmineralized PL from Y1 and mineralized into a plant available form in Y2.

Except for PL treatment 5, P recovery and use efficiency decreased as P application rates increased for PL treatments (Tables 6 and 7). Among the PL treatments, harvested forage from treatment 5 had the highest P use efficiency in both years. This high P recovery (Table 6) and use efficien-
cy (Table 7) in harvested forage that received treatment 5 (11.4 and 8.1 mt ha\(^{-1}\) in Y1 and Y2, respectively) led to removal of as much P from the soil as the higher rates of PL application in both years (Table 8). The environmental implications of this low phosphorus recovery from PL could be significant as the forage yields produced from rates of PL applied by treatment 5 will leave less P in the soil ecosystem. Although P is not toxic, the continued application and accumulation of P can lead to environmental problems. Phosphorus entering surface waters and estuaries through surface runoff and erosion is documented as a cause of eutrophication (Birch, 1982; Kauppi, 1985; Sharpley et al., 1987).


<table>
<thead>
<tr>
<th>Treatment Description</th>
<th>1991</th>
<th>1992</th>
<th>2-Year Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg ha(^{-1})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (Control)</td>
<td>18.0 de</td>
<td>13.3 d</td>
<td>31.3 e</td>
</tr>
<tr>
<td>2 (Inorganic P)</td>
<td>13.2 e</td>
<td>13.8 d</td>
<td>27.0 e</td>
</tr>
<tr>
<td>3 (Inorganic N &amp; P)</td>
<td>33.9 bc</td>
<td>39.5 bc</td>
<td>77.4 cd</td>
</tr>
<tr>
<td>4 (1x level of PL)(^\dagger)</td>
<td>25.3 cd</td>
<td>31.8 c</td>
<td>57.1 d</td>
</tr>
<tr>
<td>5 (2x level of PL)</td>
<td>35.4 b</td>
<td>54.2 ab</td>
<td>89.6 bc</td>
</tr>
<tr>
<td>6 (3x level of PL)</td>
<td>37.5 ab</td>
<td>66.3 a</td>
<td>103.8 ab</td>
</tr>
<tr>
<td>7 (4x level of PL)</td>
<td>41.7 ab</td>
<td>67.7 a</td>
<td>109.4 a</td>
</tr>
<tr>
<td>8 (5x level of PL)</td>
<td>45.7 a</td>
<td>68.4 a</td>
<td>114.1 a</td>
</tr>
</tbody>
</table>

\(^\dagger\) LSD column means followed by different letters are significantly different (P≤0.05).
\(^\dagger\) \(x = 5.7\) mt ha\(^{-1}\) in Year 1 and 4.0 mt ha\(^{-1}\) in Year 2.

Phosphorus recovery and use efficiency for treatment 3 (inorganic N and P) were also higher in Y2 than Y1 (Tables 6 and 7). Harvested forage from treatment 3 as well had the highest P recovery
and use efficiency of all treatments. Higher P recovery and use efficiency observed in the inorganic N and P treatment 3 can be attributed to the inorganic P being in a more readily available plant form than the PL source.

**Botanical Composition**

Botanical composition (i.e., the mixture of plant species) measurements of the experimental site were made in July of 1993. Botanical composition of the pasture was changed by the PL treatments (treatments 4 through 8) and by the inorganic fertilizer treatment 3 (inorganic N and P) when compared with the control (treatment 1) (Table 9). Tall fescue increased, while bluegrass and weeds decreased as a percentage of the botanical composition. Tall fescue generally is much more yield-responsive to N fertilization than is bluegrass (Wells et al., 1982). Bomke and Lowe (1991) reported that poultry manure rates greater than 2.5 mt ha\(^{-1}\) completely inhibited the ladino clover (*Trifolium repens*) component of a mixed orchardgrass-ladino clover sward on a silty clay loam even though there were substantial yield increases up to 20 mt ha\(^{-1}\) of applied PL. Treatment 2 (inorganic P only) did not change the botanical composition of the bluegrass species and as well had the highest percentage of weeds. The high percentage of weeds may be attributed to the applied P enhanced the competitiveness of weeds from P application on this normally P deficient soil.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Tall Fescue</th>
<th>Bluegrass</th>
<th>Weeds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>------------</td>
<td>-----------</td>
<td>-------</td>
</tr>
<tr>
<td>1 (Control)</td>
<td>50 b</td>
<td>43 a</td>
<td>8 b</td>
</tr>
<tr>
<td>2 (Inorganic P)</td>
<td>53 b</td>
<td>19 b</td>
<td>29 a</td>
</tr>
<tr>
<td>3 (Inorganic N &amp; P)</td>
<td>82 a</td>
<td>18 b</td>
<td>T</td>
</tr>
<tr>
<td>4 (1x level of PL)</td>
<td>77 a</td>
<td>19 b</td>
<td>3 b</td>
</tr>
<tr>
<td>5 (2x level of PL)</td>
<td>81 a</td>
<td>19 b</td>
<td>T</td>
</tr>
<tr>
<td>6 (3x level of PL)</td>
<td>91 a</td>
<td>10 b</td>
<td>T</td>
</tr>
<tr>
<td>7 (4x level of PL)</td>
<td>94 a</td>
<td>6 b</td>
<td>T</td>
</tr>
<tr>
<td>8 (5x level of PL)</td>
<td>95 a</td>
<td>5 b</td>
<td>T</td>
</tr>
</tbody>
</table>

* LSD column means followed by different letters are significantly different (P≤0.05).
* x = 5.7 mt ha\(^{-1}\) in Year 1 and 4.0 mt ha\(^{-1}\) in Year 2.
\(^{2}\) T = trace amounts.
Summary

The results from this study show that dry matter yield increased with rate of PL application. The yield response to applied PL mainly reflects correction of N deficiency of the pasture from N in applied PL. The higher increase in dry matter yields in Y2 are a reflection of the residual N carried over from Y1 in the applied PL treatments. Increased yields in Y2 are also a reflection of the beneficial effects of organic matter additions to the soil (i.e., increased H₂O capacity). This later relationship is evidenced in increased yields for only the PL treatments in Y2. Poultry litter application rates of 11.4 mt ha⁻¹ in Y1 followed by 8.1 mt ha⁻¹ in Y2 were as suitable as the currently recommended inorganic N and P fertilizer recommendations for pasture in the Piedmont Region. Dry matter yields at these rates equalled those produced from recommended N and P application rates.

The results from this study show that surface applied PL is as suitable as presently recommended inorganic N and P rates for pasture grass renovation in the Piedmont region of Virginia. The lowest PL application rate in this study (5.7 and 4.0 mt ha⁻¹ in Y1 and Y2, respectively) changed the botanical composition of the previously unmanaged pasture from a tall fescue-bluegrass-weeds mixture to predominately tall fescue. Poultry litter rates of at least 11.4 mt ha⁻¹ in Y1 and 8.1 mt ha⁻¹ in Y2 were required to obtain an 80 percent tall fescue sward composition, i.e., the composition obtained by application of recommended rates of inorganic N and P.

Harvested forage that received 11.4 mt ha⁻¹ followed by 8.1 mt ha⁻¹ the following year had the most efficient N and P recovery and use efficiency of all PL treatment rates. The implications from these data are important both economically and environmentally. Harvested forage that received these PL rates closely approximated the N recovery and use efficiency of that obtained by pasture fertilized with presently recommended inorganic rates of N and P.
Rates of PL application of 22.9 mt ha⁻¹ and above temporarily depressed plant growth. Hileman (1963) noted depressed pasture grass yields with PL rates in excess of 26 mt ha⁻¹. High rates (i.e., 22.9 mt ha⁻¹ and above) should therefore be avoided in order to avoid depressions in crop response to applied PL. Higher rates of PL application should also be avoided because N, and especially P, recovery and use efficiency dramatically decreased as PL application rates increased. From both an agronomic and environmental perspective, PL rates of 11.4 mt ha⁻¹ in Y1 followed by 8.1 mt ha⁻¹ in Y2 were the most environmentally favorable rates because the harvested forage that received these rates had the most efficient use and recovery of N and P. Hence, less N and P remained in the ecosystem. Nutrients supplied in excess of plant usage pose possible environmental pollution problems.

It must be remembered that the results from this study are applicable for the PL used in this study and would possibly differ for PL from different sources. In this study, the PL used was highly variable between years. Total N in PL was twice as high in Y2 compared with Y1. This difference, though very large, is consistent with nutrient concentrations of PL reported in the scientific literature. More research must be done to properly monitor that these rates determined in this study are environmentally prudent for long-term agriculture production of pasture in Virginia.
Literature Cited


Chapter 4

Movement and Accumulation of Phosphorus in a Starr Clay Loam from Poultry Litter Application
Introduction

Application of PL on pasture land is usually based on crop N requirements. Because P requirements for crops other than legumes are much less than N requirements, accumulation of P results from application of animal manures, especially PL applied at levels to supply crop N needs (Simpson, 1991). When PL is applied according to crop N recommendations a large over supply of P typically increases available P levels in both acid or alkaline soils (Perkins et al., 1964; Singh and Jones, 1976). This relationship is a well documented phenomena for PL amended soils (Perkins et al., 1964; Short-hall and Liebhardt, 1975; Mitchell et al., 1992; Kingerly et al., 1993; Sharpley et al., 1993).

Movement of P in the soil profile is dependent on the rate of P application, the P reactions with soil, and the consistency and type of the applied waste (Reddy et al., 1980). In most soils, P is retained close to the site of application, and the main mechanisms for loss from the soil system are physical erosion with topsoil and loss of solution P in surface runoff (Barrow, 1980). Leaching losses of P in soil are dependent upon soil properties (texture, adsorption capacity, amount and type of soil, etc.), environmental conditions (rainfall intensity and temporal distribution of rainfall), and management practices (solubility and rate of fertilization application, time of application relative to rainfall, and type of crop) (Weaver et al., 1988).

Some studies have shown significant amounts of downward movement of P in the soil profile (Spencer, 1957; Hannapel et al., 1964; Gilman, 1973; Rolston et al., 1975; Sommers et al., 1979). A wealth of information on this subject shows that leaching of P can be rather extensive, especially in sandy-textured soils. The likelihood of P leaching increases in sandy soils that are low in Fe and Al (Cogger and Duyburg, 1984, Diggle and Bell, 1984). Phosphorus movement in non-sandy soils has been reported to be extremely low or non detectable (Hubbard et al., 1989; Sommers et al., 1979).
Research has shown that downward movement of organic-bound P occurs in the soil profile. Phosphorus in organic sources leaches from the soil surface, even in heavier-textured soils (Hannapel et al., 1964; Rolston et al., 1975).

A number of researchers indicated that the presence of organic matter decreased P sorption in soil (Struthers and Seiling, 1950; Dalton et al., 1952; Vyas, 1964; Gaur, 1969). These studies indicated that formation of stable organic complexes with Fe and Al blocked P retention in soil. In contrast, other studies have shown an increase in the retention of P in the presence of organic matter (Taylor, 1946; Jackman, 1955; Rennie and McKeencher, 1958; Larsen et al., 1959; Fokin and Chistova, 1964; Harter, 1969). The increase in P retention was attributed to the mineralization of P from the organic matter.

The purpose of this research was to evaluate the effect of PL application rates on surface accumulation and downward movement of P in a Starr clay loam. High amounts of P as PL were applied to the soil over a two-year period (Table 3). The PL was surface applied to renovate a forage area on a Starr soil.
MATERIALS AND METHODS

The soil used in this study belongs to the Starr series. The Starr series, a soil common to the Piedmont region of Virginia, is a member of the fine-loamy mixed thermic family of Fluventic Dystrochrepts. The surface layer of the Starr soil is dark reddish brown clay loam about 45 cm thick. Soil tests made in March 1991 prior to application of the treatments for the field experiment described herein indicated that the soil at the experimental site had a pH of 6.3 and a Mehlich 3-extractable (Mehlich, 1984) P level of 8 mg P kg$^{-1}$. This Starr soil was selected based on its P fixation capacity and hence, the frequent incidence of P deficiencies in the soil. The experimental site, PL characteristics and field experimental procedures have been previously discussed in chapter 3.

Soil Sampling and Analysis

Prior to commencement of the experiment, ten cores plot$^{-1}$ were obtained from the 0 to 15 cm surface layer to establish baseline soil P level data. Thereafter, each spring (in April of 1992 and 1993), prior to the next year's PL treatment applications, soil samples consisting of 10 cores plot$^{-1}$ were taken from the 0 to 5 cm, 5 to 10 cm, and 10 to 15 cm layers of all plots and from the 15 to 30 cm layer of the control (treatment 1), the inorganic N and P treatment (treatment 3), and from two of the PL application treatments (treatments 6 and 8) (Table 2). Soil samples were air-dried and crushed to pass a 2-mm sieve prior to determination of extractable P. Extractable P was determined in all soil samples by the Mehlich 3 (Mehlich, 1984) extractable P procedure. Extractions were determined using a 1:10 (weight/volume) soil:solution ratio and samples were shaken 5 minutes at 200 4-cm reciprocations min$^{-1}$. Soil pH was measured by a glass electrode method after a 10 cm$^3$ soil sample using a 1 to 10 soil to water ratio was equilibrated for 0.5 hr (Plank, 1992). All data was evaluated separately for
1992 and 1993 statistically by the LSD mean separation procedure where the F values were significant at the 0.05 probability level.

Results and Discussion

The amount of P applied for each treatment was relatively similar between years (Table 3), though slightly more P was applied in 1991 than in 1992 due to higher rates of PL application in 1991 (Table 2). Phosphorus from PL was applied at increments of approximately 56.6 kg ha\(^{-1}\) in 1991 and 49.2 kg ha\(^{-1}\) in 1992 (Table 3). Pre-experimental Mehlich 3-extractable P levels for the 0 to 15 cm depth were determined to be in the very low range of 0 to 20 mg P kg\(^{-1}\) soil. Mehlich (1978) determined that P soil levels of < 20 mg P kg\(^{-1}\) are very low, 20 to 30 mg P kg\(^{-1}\) are low, 31 to 50 mg P kg\(^{-1}\) are medium and > 50 mg P kg\(^{-1}\) are high.

As expected, the application of PL caused large increases in Mehlich 3-extractable P in the 0 to 5 cm depth in both 1992 (Table 10) and 1993 (Table 11). In 1992, PL application rate levels of treatment 5 and above, (11.4 mt ha\(^{-1}\), i.e., 113.2 kg P ha\(^{-1}\)), increased Mehlich 3-extractable P levels in the 0 to 5 cm depth above that of both the control (treatment 1) and the inorganic N and P fertilizer treatment (treatment 3). Based on calibration data for the Mehlich 3 test (Mehlich, 1978), P levels in the 0 to 5 cm depth in 1992, from PL application rate levels of treatment 6 and above (17.2 mt ha\(^{-1}\), i.e., 169.8 kg P ha\(^{-1}\)), were in the high range. The highest PL treatment in 1992 (28.6 mt ha\(^{-1}\), i.e., 283 kg P ha\(^{-1}\)) increased Mehlich 3-extractable P levels in the 0 to 5 cm depth by 10 fold as compared with the control (treatment 1) and inorganic fertilizer N and P treatment (33 kg P ha\(^{-1}\)). Liebhardt (1976) noted that, when PL was applied at a rate of 56 mt ha\(^{-1}\), there was a 4 four fold increase in Mehlich-extractable P levels in the surface 15 cm of soil. Meek et al. (1982) determined that, after 8 years, one
application of 180 mt ha\(^{-1}\) manure on a Holtville silty clay (Typic Torriorthents) doubled the NaHCO\(_3\) extractable P levels in the surface 30 cm of soil as compared with plots that did not receive manure.

Table 10. Mehlich 3-extractable P in soil samples taken in April 1992 in a field experiment on a Starr clay loam treated with synthetic and poultry litter fertilizer.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>0 - 5</th>
<th>5 -10</th>
<th>10 - 15</th>
<th>15 -30</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Control)</td>
<td>9</td>
<td>6</td>
<td>6 b</td>
<td>1 b</td>
</tr>
<tr>
<td>2 (Inorganic P)</td>
<td>11 d</td>
<td>7 ab</td>
<td>6 bcd</td>
<td>---</td>
</tr>
<tr>
<td>3 (Inorganic N &amp; P)</td>
<td>8 d</td>
<td>3 c</td>
<td>5 d</td>
<td>4 ab</td>
</tr>
<tr>
<td>4 (1x level of PL)</td>
<td>18 cd</td>
<td>6 b</td>
<td>5 cd</td>
<td>---</td>
</tr>
<tr>
<td>5 (2x level of PL)</td>
<td>38 bc</td>
<td>6 b</td>
<td>6 bcd</td>
<td>---</td>
</tr>
<tr>
<td>6 (3x level of PL)</td>
<td>56 b</td>
<td>7 ab</td>
<td>7 ab</td>
<td>4 ab</td>
</tr>
<tr>
<td>7 (4x level of PL)</td>
<td>55 b</td>
<td>7 ab</td>
<td>6 abc</td>
<td>---</td>
</tr>
<tr>
<td>8 (5x level of PL)</td>
<td>85 a</td>
<td>9 a</td>
<td>8 a</td>
<td>6 a</td>
</tr>
</tbody>
</table>

* LSD column means followed by different letters are significantly different (P ≤ 0.05).
*\(^{1}\) x = 5.7 mt ha\(^{-1}\) in 1991.
*\(^{2}\) soil sample not taken.
Table 11. Mehlich 3-extractable P in soil samples taken in April 1993 in a field experiment on a Starr clay loam treated with synthetic and poultry litter fertilizer.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Depth (cm)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 - 5</td>
<td>5 - 10</td>
<td>10 - 15</td>
<td>15 - 30</td>
</tr>
<tr>
<td>--------------------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>1 (Control)</td>
<td>11 f</td>
<td>5 b</td>
<td>6 cd</td>
<td>2 a</td>
</tr>
<tr>
<td>2 (Inorganic P)</td>
<td>26 ef</td>
<td>5 b</td>
<td>6 cd</td>
<td>---^2</td>
</tr>
<tr>
<td>3 (Inorganic N &amp; P)</td>
<td>15 ef</td>
<td>3 b</td>
<td>5 d</td>
<td>6 a</td>
</tr>
<tr>
<td>4 (1x level of PL)'</td>
<td>34 e</td>
<td>6 b</td>
<td>6 cd</td>
<td>---</td>
</tr>
<tr>
<td>5 (2x level of PL)</td>
<td>81 d</td>
<td>10 b</td>
<td>7 cd</td>
<td>---</td>
</tr>
<tr>
<td>6 (3x level of PL)</td>
<td>102 c</td>
<td>9 b</td>
<td>7 bc</td>
<td>4 a</td>
</tr>
<tr>
<td>7 (4x level of PL)</td>
<td>149 b</td>
<td>23 ab</td>
<td>9 ab</td>
<td>---</td>
</tr>
<tr>
<td>8 (5x level of PL)</td>
<td>192 a</td>
<td>26 a</td>
<td>10 a</td>
<td>4 a</td>
</tr>
</tbody>
</table>

* LSD column means followed by different letters are significantly different (P≤0.05).
^ x = 5.7 mt ha^-1 in 1991 and 4.0 mt ha^-1 in 1992.
^ soil sample not taken.

In 1992 only the highest PL application rate of 28.6 mt ha^-1 (283 kg P ha^-1) had higher P levels than those observed in the control (treatment 1) and in the 5 to 10, 10 to 15 and 15 to 30 depths (Table 10). Much of the P that moved into the lower soil profiles from this highest rate of PL application likely would have been in an organically bound form. Rolston *et al.* (1975) studied movement of organic and inorganic bound P. They compared six organic P sources versus an inorganic P source (potassium phosphate) and noted that P from all the organic compounds moved to approximately the 12 cm depth in a Panoch clay loam soil, whereas inorganic phosphate moved to a depth of no more than 2 to 3 cm. The inorganic P compounds studied in this experiment were glycerophosphate, methyl ester phosphate, glycol phosphate, ethyl ester phosphate, glucose 1-phosphate and glucose 6-phosphate.

Mehlich 3-extractable P levels in the surface 0 to 5 cm soil depth were higher in 1993 (Table 11) than in 1992 (Table 10) for all treatments. Treatments with PL application rates of 8.1 mt ha^-1
(98.5 kg P ha\(^{-1}\)) and above had higher Mehlich 3-extractable P levels in the 0 to 5 cm depth than both the control (treatment 1) and the inorganic N and P treatment (treatment 3). In 1993, PL treatments 5 through 8 (8.1, 12.1, 16.1 and 20.2 mt ha\(^{-1}\) PL, respectively) increased the Mehlich 3-extractable P levels in the 0 to 5 cm depth by approximately 8, 10, 15 and 20 fold over the control (treatment 1). These Mehlich 3-extractable P levels in the 0 to 5 cm soil depth from PL application were in the high range according to calibration for the Mehlich P determination procedure (Mehlich, 1978). Mehlich 3-extractable P levels increased from 8 mg P kg\(^{-1}\) soil in 1992 to 15 mg P kg\(^{-1}\) soil in 1993 in the soil that received the inorganic N and P treatment (treatment 3).

Applications of 33 kg P ha\(^{-1}\) inorganic P (treatment 2) increased Mehlich 3-extractable P in the 0 to 5 cm depth from 11 mg P kg\(^{-1}\) soil in 1992 to 26 mg P kg\(^{-1}\) soil in 1993. Meek et al. (1979) found that, when inorganic P was applied annually at 490 kg ha\(^{-1}\) to Holtville silty clay (Typic Torri- fluvent) for two years, the NaHCO\(_3\)-extractable P was increased from 16 to 31 mg P kg\(^{-1}\) soil in the 0 to 30 cm depth. Meek et al. (1979) also reported that NaHCO\(_3\)-extractable P levels in the surface 0 to 30 cm were increased substantially more from manure sources than from inorganic sources when P was applied at similar rates. When 334 kg P ha\(^{-1}\) was applied in manure (45 mt ha\(^{-1}\) yr\(^{-1}\)) for 2 years, NaHCO\(_3\)-extractable P was increased by > 100 mg P kg\(^{-1}\) soil over the control. In contrast, application of 392 kg P ha\(^{-1}\) from inorganic P for 2 years increased the NaHCO\(_3\)-extractable P by only 11 mg P kg\(^{-1}\) soil over the control.

In 1993, downward movement of P occurred only at the exceptionally high rate of PL application (20.2 mt ha\(^{-1}\)). Downward movement occurred into the 5 to 10 and 10 to 15 cm depths. Phosphorus levels at the 5 to 10 cm depth were approximately 5 fold greater in soil that received this high rate of PL application than in the control. At the 10 to 15 cm depth, the soil amended with the highest rate of PL application had a two-fold higher amount of P than the control.
Summary

The results from this study substantiate the findings from other studies that application of PL causes accumulation of P in the zone of application. Most of the P applied from both PL sources and the inorganic source remained in the surface soil layer. Phosphorus movement only occurred into the 15 to 30 cm depth in 1992 from the treatment that received the highest rate of PL for this experiment (28.6 mt ha⁻¹ PL). In 1993, higher levels of P were not seen in this deepest zone of soil sampling but substantial increases of P movement were observed in the 5 to 10 and 10 to 15 cm depths. Over each of the two years the Mehlich 3-extractable P varied with rate of P application.

Recent studies have documented the effects from long-term PL applications on pasture nutrient levels (Kingerley et al., 1992; Mitchell et al., 1992; Sharpley et al., 1993). Kingerley et al. (1992) concluded that long-term (15 to 25 years) PL applications on fescue pasture at disposal rates (5 to 20 mt ha⁻¹) may create adverse environmental effects and reduce pasture quality. They reported an increase of 530 percent in extractable P concentrations to a depth of 45 cm in littered versus non-littered pasture. These studies (Kingerley et al., 1992; Mitchell et al., 1992; Sharpley et al., 1993) have been done on sandy-textured soils, where downward movement of nutrients, especially P, is a more commonly accepted phenomena. That some downward movement of P was seen in this short-term experiment on a Starr clay loam indicates that caution must be taken when PL is applied to pasture land at disposal rates of > 20 mt ha⁻¹. Further studies should be done to substantiate these findings and monitor further possible downward P movement in this heavy textured soil.
Literature Cited


Chapter 5

Comparison of Mehlich 3 and Bray 1 Extractable Phosphorus Levels on a Starr Clay Loam Amended with Poultry Litter
Introduction

A soil test is a means by which nutrient elements are chemically extracted from the soil in an attempt to measure the plant availability of a nutrient. The selection of an appropriate soil test extractant is critical for any soil testing program. A soil test should meet the following three criteria: (1) the extractant should extract the total amount or a proportion of the available form or forms of a nutrient from soils with variable properties; (2) the amount of nutrients in the extract should be measured with reasonable accuracy and speed, and (3) the amounts extracted should depict the growth and response of each crop to the nutrient under various conditions (Bray, 1948). Additionally, the soil test should be easily performed by laboratory personnel.

Many methods exist to characterize the amount of P in the soil profile. Two of the most common tests used to characterize soil P levels in the southeast are the Bray P1 (B1) and Mehlich 3 (M3) procedures. The B1 soil extractant is a mild acid NH₄F solution and is one of the oldest standard soil test solutions in use today. It was developed in 1945 by Bray and Kurtz and has been most applicable to predict the levels of P in neutral to acid soils. The B1 soil test, while originally designed for P, has also been used for K determination (Peterson et al., 1971).

An ever increasing role and demand for routine soil tests, to more efficiently aid farmers to economically and environmentally manage their resources, necessitates the use of the most rapid and efficient procedure. The M3 has been proposed as a "universal " extractant because, unlike the B1 soil test, it simultaneously extracts labile P, K, Ca, Mg, Na, Mn, Zn, and Cu. Increasing use of multi-elemental analyzers, such as the inductively coupled plasma (ICP) emission spectrometer, gives the M3 a distinct advantage over the B1 soil test in laboratories that are up-grading for the 21st century.

The M3 soil test was introduced as a modification of the Mehlich 2 soil test (Mehlich, 1984). It was designed for nutrient extraction from acid and neutral soils but also has been quite effective for
alkaline soils. Many researchers have reported the amount of P extracted by the M3 soil test to be highly correlated with the P extracted by the B1 method, i.e., $r^2 > 0.96$ (Mehlich, 1984; Hanlon and Johnson, 1984; Wolf and Baker, 1985; Beegle and Oravec, 1990, Sen Tran et al., 1990). Relationships between the amount of P extracted by the two soil tests has varied with experiments and especially among soils. Wolf and Baker (1985) compared the results of 27 experimental sites from the southeastern, north central and northeastern states and reported similar amounts of P removed by the two tests. Mehlich (1984) evaluated soil test methodology for 105 soils from the southern and mid-Atlantic states and indicated that the M3 soil test extracted 3 to 4 percent more P than the B1 procedure. Michaelson et al. (1987) found significant variation between the amounts of P extracted on Alaskan soils. The M3 extracted on average 66 percent more P than B1 from volcanic ash soils and 12 percent more from loess soils. Sen Tran et al. (1990) reported that the high NH$_4$F concentration in the B1 soil test may overestimate the available P in some soils by extracting the strongly fixed Al-P and, hence, would extract more soil P than the M3 test.

Many laboratories are in the process of switching from the B1 to the M3 soil test because of its ability to simultaneously extract multi-elements. The B1 test for the determination of soil P levels is currently the most widely used and scientifically accepted soil test in the southeast. Additionally, there exists years of correlation data between B1 soil P levels and plant yield that have yet to be gathered for the M3 soil test. Usage of the M3 soil test is becoming widespread in the southeastern United States for soils that supply inadequate nutrients for plant growth. It would be advantageous to producers and scientists if the soil test procedure would indicate an inadequate and an over supply of nutrients. This research was directed to both low and high soil nutrient availability. The objective of this investigation was to compare the M3 and B1 soil test levels of extractable P determined on a soil amended with relatively low to high surface applications of PL. A Starr clay loam soil was selected
based on its high P fixing capabilities, and hence, frequent incidence of P deficiency. Additionally these two soil tests were compared with P uptake by harvested forage.
Methods and Materials

The experimental site, PL characteristics and experimental procedures have been previously discussed in chapter 3, and the soil characteristics and sampling methods in chapter 4. The procedures used to determine the M3 extractable P levels were those described by Mehlich (1984). Procedures followed for the B1 test were those outlined by Olson and Sommers (1982). For the M3 test procedure, extractions were determined with a 1:10 (weight/volume) soil-to-solution ratio and an extraction time of 5 minutes. For the B1 test procedure, extractants were determined with a 1:7 (weight/volume) soil-to-solution ratio and an extraction time of 1 minute. All extractions for both tests were performed in duplicate. A total of 112 PL amended soil samples were compared for both 1991 and 1992. Thirty-two soil samples were obtained from the 0 to 5 cm depth; 32 from the 5 to 10 cm depth; 32 from the 10 to 15 cm soil depth; and 16 from the 15 to 30 cm depth for each year.

Results and Discussion

The M3 and B1 soil P tests were highly correlated for both years (Tables 12 and 13) for all samples from all depths ($r^2 = 0.96$ in 1991 and $r^2 = 0.99$ in 1992). This relationship agrees with findings reported in the literature (Mehlich, 1984; Hanlon and Johnson, 1984; Wolf and Baker, 1985; Beegle and Oravec, 1990, Sen Tran et al., 1990). The regression slopes ranged from 0.55 to 1.53 in 1991 and from 0.72 to 1.40 in 1992 (Tables 12 and 13). The range in slope is similar in magnitude to those reported by Hanlon and Johnson (1984) for Oklahoma soils (0.64 to 1.52) and by Michaelson et al. (1987) for Alaskan soils (1.01 to 1.88).
Table 12. Regression parameters of the Mehlich 3 soil test (y) with the Bray 1 method (x) on a Starr clay loam treated with synthetic fertilizer and poultry litter in 1991.

<table>
<thead>
<tr>
<th>Soil Depth (cm)</th>
<th>Extractable P mean</th>
<th>Intercept</th>
<th>Slope</th>
<th>r²</th>
<th>sd²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 30</td>
<td>M3: 1 - 131 14</td>
<td>-6.82</td>
<td>1.46</td>
<td>0.96</td>
<td>4.16</td>
</tr>
<tr>
<td>(112)</td>
<td>B1: 1 - 85 14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - 5</td>
<td>M3: 4 - 131 35</td>
<td>-8.96</td>
<td>1.53</td>
<td>0.98</td>
<td>6.10</td>
</tr>
<tr>
<td>(32)</td>
<td>B1: 5 - 85 29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 10</td>
<td>M3: 1 - 10 6</td>
<td>+1.44</td>
<td>0.55</td>
<td>0.60</td>
<td>1.27</td>
</tr>
<tr>
<td>(32)</td>
<td>B1: 1 - 14 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 - 15</td>
<td>M3: 3 - 10 6</td>
<td>+0.30</td>
<td>0.57</td>
<td>0.65</td>
<td>0.79</td>
</tr>
<tr>
<td>(32)</td>
<td>B1: 5 - 14 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 - 30</td>
<td>M3: 1 - 10 3</td>
<td>+0.68</td>
<td>0.68</td>
<td>0.87</td>
<td>1.06</td>
</tr>
<tr>
<td>(16)</td>
<td>B1: 1 - 13 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 number of samples.
2 M3 = Mehlich 3, B1 = Bray 1.
3 All equations are significant at P = 0.001.
4 Standard deviation of the estimate for the slope of each regression.

Differences in the slope values for the regression of M3 with B1 soil test indicated that the two procedures did not extract P from precisely the same sources in the surface soil depth (0 to 5 cm) and the subsurface soil depth (5 to 30 cm). The M3 procedure extracted considerably higher levels of P in the 0 to 5 cm depth than the B1 for both years, i.e., 21 percent more in 1991, 35 mg P kg⁻¹ versus 29 mg P kg⁻¹; and 23 percent more in 1992, 76 mg P kg⁻¹ versus 62 mg P kg⁻¹ (Tables 12 and 13). The regression slopes for the 0 to 5 cm depth was much greater than 1.0 for both years (Figs. 9 and 10). This relationship shows M3 extractable P was considerable higher than B1 extractable P in the 0 to 5 cm soil depth.
Table 13. Regression parameters of the Mehlich 3 soil test (y) with the Bray 1 soil test (x) on a Starr clay loam treated with synthetic fertilizer and poultry litter in 1992.

<table>
<thead>
<tr>
<th>Soil Depth (cm)</th>
<th>Extractable P test range</th>
<th>Intercept</th>
<th>Slope</th>
<th>$r^2$</th>
<th>sd$^t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 30 (112)</td>
<td>M3 1 - 214 27</td>
<td>- 6.60</td>
<td>1.34</td>
<td>0.99</td>
<td>4.89</td>
</tr>
<tr>
<td></td>
<td>B1 1 - 157 25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - 5 (32)</td>
<td>M3 9 - 214 76</td>
<td>- 8.09</td>
<td>1.40</td>
<td>0.99</td>
<td>6.10</td>
</tr>
<tr>
<td></td>
<td>B1 10 - 157 62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 10 (32)</td>
<td>M3 2 - 52 11</td>
<td>- 3.10</td>
<td>1.02</td>
<td>0.96</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>B1 2 - 52 14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 - 15 (32)</td>
<td>M3 3 - 13 7</td>
<td>- 1.28</td>
<td>0.74</td>
<td>0.83</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>B1 5 - 17 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 - 30 (16)</td>
<td>M3 1 - 9 4</td>
<td>+0.21</td>
<td>0.72</td>
<td>0.93</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td>B1 1 - 13 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^t$ number of samples.

$^\dagger$ M3 = Mehlich 3, B1 = Bray 1.

$^\ddagger$ All equations are significant at $P = 0.001$.

$^\S$ Standard deviation of the estimate for the slope of each regression.

Fig. 9. Relationship between Mehlich 3 and Bray 1 extractable P in the 0 to 5 cm depth in year 1.
Fig. 10. Relationship between Mehlich 3 and Bray 1 extractable P in the 0 to 5 cm depth in year 2.

In contrast, the B1 soil test extracted considerable higher levels of P in the 5 to 30 cm soil depths than the M3 procedure in both years, i.e., from 50 to 66 percent more extracted P in 1991 and from 20 to 57 percent more in 1992 (Tables 12 and 13). The regression slopes for these depths of less than 1.0 indicate the higher levels of B1 extractable P in the subsurface soil layers (Figs. 11 and 12). But in 1992, at very low levels of B1 extractable P (less than or equal to 1.0 mg P kg⁻¹), the M3 levels of extracted P would be greater. Thus, this relationship of the B1 soil test extracting higher levels of P than the M3 procedure in the 5 to 30 cm depths is true in 1991 only where B1 extractable levels of P are greater than 1.0 mg P kg⁻¹. The levels of P determined by the two soil tests were more similar in 1992 (slope =0.96) than in 1991 (slope = 0.58) at this 5 to 30 cm soil depth (Figs. 11 and 12). The higher levels of B1 extractable P in the sub-surface soil layers in 1992 may be explained by the slight downward movement of organic P from the heavily manured soils (Chapter 4) and by complexation of Al and Fe from hydroxides by F with release of adsorbed P (Sen Tran et al., 1990).
Fig. 11. Relationship between Mehlich 3 and Bray 1 extractable P in the 5 to 30 cm depths in year 1.

Fig. 12. Relationship between Mehlich 3 and Bray 1 extractable P in the 5 to 30 cm depths in year 2.
Sen Tran et al. (1990) observed that, on acid soils with large amounts of amorphous Al, the M3 extractable P was about 15 to 30 percent less than the B1 extractable P. The higher levels of P extracted on acid soils high in amorphous Al by the B1 procedure was attributed to the high concentration of NH₄F in the B1 extract, which is double that of the M3 extractant. This higher level of NH₄F in the B1 extract causes extraction of more Al-P, and to a lesser extent Fe-P, than the M3. This relationship accounts for the higher levels of P determined by the B1 than the M3 soil test in the 5 to 30 cm soil depth in this study. The Starr soil was selected for this study based on its high P fixing capability. It is likely that much of the P extracted by the B1 in excess of M3 extractable P, in the sub surface layers was in Al-P and Fe-P complexes, relatively unavailable for plant uptake. Sen Tran et al. (1990) suggested that the ability of the B1 to extract Al-P complexes more readily than the M3 extractant might lead to an overestimate of plant available P in soils of this nature.

The higher levels of P extracted by the M3 soil test in the surface soil layer, where organic PL had been added, may be explained by a number of reasons. Cox et al. (1993) suggested that the greater tendency of the M3 extractant to remove P from soils, when compared with the B1 soil test, may be due to the greater amounts of anions in the solution that are available to solubilize P compounds. Sen Tran et al. (1990) attributed the higher levels of extractable P determined by the M3 soil test compared with the B1 soil test on high pH or calcareous soils to the partial neutralization of the B1 extract. At the initiation of this study dolomitic limestone had been added at a rate of 5.6 mt ha⁻¹. This addition of limestone changed the pH from 6.3 to 6.7. Hence, there was considerable basicity in the soil to neutralize hydrogen ions in the B1 soil test.

On volcanic ash soils of Alaska, Michaelson et al. (1987) observed 66 percent higher levels of P extraction by the M3 soil test compared with the B1 procedure. They concluded that the more strongly acidic extractant (M3) removed higher levels of P from volcanic ash soils relative to the weaker extractant (B1). In this study, the higher levels of P extracted by the M3 soil test in the surface
0 to 5 cm depth where PL was applied could also be due to the M3 extractant being more acidic than the B1 extractant. Hence, P extracted in this 0 to 5 cm depth, in an organically bound form from applied PL, was more easily solubilized by the M3 soil test than the B1 procedure. Watson (unpublished data) observed that on organic soils of Ohio, the M3 extracted 67 percent more P than the B1 soil extractant.

A curvilinear relationship described P uptake compared with the M3 and B1 levels of extracted P for both years (Figs. 13, 14, 17 and 18). The relationship between M3 and B1 soil P tests and P uptake were similar in 1991, \( r^2 = 0.575 \) for M3 and \( r^2 = 0.509 \) and 1992 \( r^2 = 0.806 \) for M3 and \( r^2 = 0.773 \) (Figs. 13, 14, 17 and 18). Relationships between soil test P and P uptake were improved by omitting the data from the inorganic fertilizer treatments in both 1991 and 1992 (Figs. 15, 16, 19 and 20). In 1992, when the inorganic fertilizer treatments were removed from the regression, the relationship of P uptake to P levels extracted by the M3 and B1 procedures were highly correlated \( r^2 = 0.925 \) for M3 and \( r^2 = 0.933 \) for the B1). Because of the high P fixing capacity of this soil, P supplied from the inorganic fertilizer source was not highly available for plant uptake. Phosphorus from the PL source, more slowly released from the organic to inorganic form, was a better reflection of plant P uptake.
Fig. 13. Relationship between P uptake by pasture in 1991 and Mehlich 3 extractable P. (Regression made using All treatments)

\[ y = 16.3 + 0.63x - 0.0033x^2 \]
\[ r^2 = 0.575 \]

Fig. 14. Relationship between P uptake by pasture in 1991 and Bray 1 extractable P. (Regression made using All treatments)

\[ y = 13.8 + 0.84x - 0.0056x^2 \]
\[ r^2 = 0.509 \]
Fig. 15. Relationship between P uptake by pasture in 1991 and Mehlich 3 extractable P.

Fig. 16. Relationship between P uptake by pasture in 1991 and Bray 1 extractable P.
Fig. 17. Relationship between P uptake by pasture in 1992 and Mehlich 3 extractable P. (Regression made using All treatments)

\[ y = 12.2 + 0.69x - 0.002x^2 \]
\[ r^2 = 0.806 \]

Fig. 18. Relationship between P uptake by pasture in 1992 and Bray 1 extractable P. (Regression made using All treatments)

\[ y = 6.6 + 0.996x - 0.0039x^2 \]
\[ r^2 = 0.773 \]
Fig. 19. Relationship between P uptake by pasture in 1992 and Mehlich 3 extractable P.

\[ y = 7.8 + 0.79x - 0.0025x^2 \]
\[ r^2 = 0.925 \]

Fig. 20. Relationship between P uptake by pasture in 1992 and Bray 1 extractable P.

\[ y = -0.338 + 1.235x - 0.0053x^2 \]
\[ r^2 = 0.933 \]
A curvilinear relationship described forage yield compared with the M3 and B1 levels of extracted P for both years (Figs. 21, 22, 25 and 26). The relationship between M3 and B1 soil P tests and forage yield were similar in 1991, ($r^2 = 0.548$ for M3 and $r^2 = 0.545$) and 1992 ($r^2 = 0.765$ for M3 and $r^2 = 0.730$) (Figs. 21, 22, 25 and 26). Relationships between soil test P and forage yield were improved by omitting the data from the inorganic fertilizer treatments in both 1991 and 1992 (Figs. 23, 24, 27 and 28). In both 1991 and 1992, when the inorganic fertilizer treatments were removed from the regression, the relationship of forage yield to P levels extracted by the M3 and B1 procedures were highly correlated, i.e., $r^2 > 0.97$ for M3 and B1 in 1991 (Figs. 23 and 24), and $r^2 > 0.99$ for M3 and B1 in 1992 (Figs. 27 and 28). As with P uptake, the high P fixing capacity of the soil caused soil test P levels from the inorganically applied P to be a poor determiner of forage yield. Increases in forage yield was not caused by increased P availability but reflects correction of N deficiency.
Fig. 21. Relationship between Mehlich 3 extractable P and forage yield in 1991. (Regression made using All treatments)

\[ y = 5353.9 + 109.9x - 0.345x^2 \]
\[ r^2 = 0.548 \]

Fig. 22. Relationship between Bray 1 extractable P and forage yield in 1991. (Regression made using All treatments)

\[ y = 5782.6 + 41.9x + 1.39x^2 \]
\[ r^2 = 0.545 \]
Fig. 23. Relationship between Mehlich 3 extractable P and forage yield in 1991.

\[ y = 3348 + 195.1x - 1.11x^2 \]
\[ r^2 = 0.973 \]

Fig. 24. Relationship between Bray 1 extractable P and forage yield in 1991.

\[ y = 2633 + 234.7x - 1.19x^2 \]
\[ r^2 = 0.979 \]
Fig. 25. Relationship between Mehlich 3 extractable P and forage yield in 1992. (Regression made using All treatments)

\[ y = 3922.8 + 1128.1x - 0.324x^2 \]
\[ r^2 = 0.765 \]

Fig. 26. Relationship between Bray 1 extractable P and forage yield in 1992. (Regression made using All treatments)

\[ y = 3191.8 + 169.0x - 0.530x^2 \]
\[ r^2 = 0.730 \]
Fig. 27. Relationship between Mehlich 3 extractable P and forage yield in 1992.

Fig. 28. Relationship between Bray 1 extractable P and forage yield in 1992.
Summary

The results from this study show that the M3 and B1 soil test extracts for P are highly correlated. Nevertheless, substantial differences in levels of P were extracted by the two soil tests from different soil depths. Higher levels of P were extracted by the M3 soil test in the 0 to 5 cm soil depth. The higher levels of P extracted by the M3 in this soil depth compared with the B1 procedure reflects the higher total acidity in the M3 than in the B1 extraction solution. The B1 extractant also could have been partially neutralized in the surface 0 to 5 cm soil depth by added limestone and soil hydroxides and oxides at the initiation of the investigation. The M3 reactant is more buffered, and hence extracted higher levels of soil P. The B1 soil test extracted higher levels of P from the subsoil than the M3 procedure. The higher P displacement from the subsoil by the B1 extractant is caused by the higher F- in the B1 extraction solution. The higher F- in the B1 extractant caused more extraction of Al- and Fe-bound P. The higher levels of P extracted by the B1 procedure in the subsoil may be an overestimate of plant available P. Both forage yield and P uptake were highly correlated with both the M3 and B1 soil tests when the inorganic fertilizer treatments were omitted from the regression. This correlation is a reflection of the high P fixation capacity of this soil. Slow conversion of organic P from PL to soil P results in higher uptake of the P from the organic source than from the inorganic P compounds. Increased forage yield with increased soil test P levels was a reflection of the correction of N deficiency in the soil rather than correction of P deficiency.
Literature Cited


Summary and Conclusions

The poultry industry is one of the most economically important industries in the state of Virginia. Broiler cash receipts at the farm level exceeded 300 million dollars in fiscal year 1992 and were second only to cattle and calf sales (Va. Agricultural Statistics, 1993). The number one concern confronting the poultry industry today is the economically feasible and environmentally prudent disposal of the large amounts of wastes, predominately poultry litter (PL), generated during production processes. Unimproved mixed species pastures, predominately tall fescue (*Festuca arundinacea*), bluegrass (*Poa pratensis*) and orchardgrass (*Dactylis glomerata*) occupied approximately half a million ha in Virginia in 1992. The purpose of this study was to investigate the short-term effects of various rates of PL application on unimproved pasture.

A Starr clay loam (fine-loamy mixed thermic Fluventic Dystrochrepts) in the Piedmont region was selected for this investigation. The soil has a high P fixation capacity, and hence, frequently supplies inadequate P for crop production. Eight treatments applied in quadruplicate on the soil were: 5 poultry litter rates (5.7, 11.4, 17.1, 22.9, and 28.6 mt ha⁻¹ in 1991 and 4.0, 8.1, 12.1, 16.1, and 20.2 mt ha⁻¹ in 1992); a control; and two inorganic fertilizer treatments. Various plant response and soil parameters were measured during the course of this investigation. Measured plant responses during this investigation included dry matter yield, N recovery and use efficiency, P recovery and use efficiency, and changes in botanical composition. Soil parameters investigated were accumulation and downward movement of P and extractable P by the Mehlich 3 (M3) and the Bray 1 (B1) procedures. These two soil tests were as well compared with P uptake and yield of harvested forage. Results during the course of this investigation are summarized:
1) Dry matter yield increased curvilinearly with rate of PL application. In 1991, 28.6 mt PL ha\(^{-1}\) produced dry matter yields of 12 mt ha\(^{-1}\) and in 1992 rates of 20.2 mt PL ha\(^{-1}\) produced dry matter yields of 16.5 mt ha\(^{-1}\). This yield increase was attributed to correction of N deficiency in pasture by the PL application.

2) Lower levels of PL increased dry matter yields in year 2 compared with year 1. Increased dry matter yields in year 2 were caused in part, by the residual carry over of unmineralized nutrients from PL applied in year 1 and to such beneficial soil effects as increased water holding capacity attributed to the applied PL. Higher rainfall during the second year also was responsible for the higher yields.

3) Poultry litter, at even the lowest rate applied in this study (5.7 and 4.1 mt ha\(^{-1}\) in year 1 and year 2, respectively) increased the percentage of tall fescue in this mixed pasture. Hence PL, of the composition and rates applied in this study, is as suitable as presently recommended inorganic N and P fertilizer rates for pasture grass renovation. The mixed species pasture, originally an approximate 50-50 mix of tall fescue-bluegrass was changed to a predominate pasture of tall fescue. This change was due to the greater growth response exhibited by tall fescue to N applied from PL. Tall fescue was thus able to outcompete bluegrass for nutrients and light.

4) Poultry litter application of 11.4 mt ha\(^{-1}\) applied in year 1 followed by 8.1 mt ha\(^{-1}\) in year 2, was the most environmentally and economically recommendable. This PL treatment had similar dry matter yield (21.5 mt ha\(^{-1}\) versus 21.7 mt ha\(^{-1}\), over the two year investigation), N recovery and use efficiency, and P use efficiency as compared with recommended N and P synthetic fertilizer rates. Harvested forage from this rate (11.4 mt PL ha\(^{-1}\) in year 1 followed
with 8.1 mt PL ha\(^{-1}\) in year 2) recovered the highest percentage of N (72.2 and 101.0 percent in year 1 and year 2, respectively) and had the best N and P use efficiencies of all PL application rates for both years.

5) Phosphorus applied from both PL and inorganic sources accumulated in the zone of application. Accumulated P increased with amount of PL application in the surface 0 to 5 cm depth and, thus, was higher in year 2 than year 1. The highest rate of PL application (28.6 mt ha\(^{-1}\) in year 1 followed by 20.2 mt ha\(^{-1}\) in year 2) increased M3-extractable P levels by 20 fold over the control in year 2, i.e., 192 mg P kg\(^{-1}\) versus 11 mg P kg\(^{-1}\). Downward movement of P from surface applied PL occurred from only the highest level of application (529 kg P ha\(^{-1}\) from 48.8 mt PL ha\(^{-1}\) over the two year study). Surface applied P from this study moved into the 10 to 15 cm soil depth.

6) Levels of P extracted by the M3 and B1 soil tests were highly correlated for both years (\(r^2 = 0.96\) in year 1 and \(r^2 = 0.99\) in year 2) but substantial differences in levels of P extracted were observed by soil depth for the two soil tests. The M3 extracted substantially more P from the surface 0 to 5 cm depth (21 percent in year 1 and 23 percent in year 2), most likely due to the extracted P from this soil depth being in a more readily available form to the M# procedure than the B1 soil test. The B1 soil test on average extracted from 50 to 66 percent higher levels of P from the 5 to 30 cm soil depths in year 1 and 20 to 57 percent more in these same soil depths in year 2, most likely due to the P in these soil depths being in Al-P complexes.

In conclusion, this study demonstrates that PL can serve as a valuable resource in the production and renovation of pasture in the Piedmont region of Virginia. One of the major problems demonstrated in this study, with the use of PL as a fertilizer source, is its great variability. To avoid
possible environmental problems from the application of excess nutrients or low forage yields from the application of too little PL, there is a need to analyze PL before the determination of application rates on pasture. The use of PL therefore requires a higher level of management than when synthetic fertilizer is strictly used as a source to supply nutrients to plants. Certain benefits from the use of PL can be expected that will not occur with the sole use of synthetic fertilizer. These benefits, as witnessed in this study include the increased soil water holding capacity and the carry over of unmineralized nutrients from one year to the next. To avoid possible environmental problems, the unmineralizable portion of applied PL must be strictly monitored each year. This again increases the level of time and management required by farmers but little choice appears available as the need to properly dispose of vast amounts of PL waste on ever decreasing land resources is increasing. Additionally the type of soil P test that will determine the application rates of PL needs to be carefully considered, due to the ability of different soil tests to determine considerable different levels of available P.
## Appendix A


<table>
<thead>
<tr>
<th>Treatment</th>
<th>5-2-91</th>
<th>6-20-91</th>
<th>8-13-91</th>
<th>10-25-91</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Control)</td>
<td>1.3 de</td>
<td>0.7 ef</td>
<td>1.9 bc</td>
<td>0.7 ef</td>
</tr>
<tr>
<td>2 (Inorganic P)</td>
<td>0.6 e</td>
<td>0.6 f</td>
<td>1.8 c</td>
<td>0.7 f</td>
</tr>
<tr>
<td>3 (Inorganic N &amp; P)</td>
<td>4.0 ab</td>
<td>2.8 a</td>
<td>2.2 abc</td>
<td>1.6 cd</td>
</tr>
<tr>
<td>4 (1x level of PL)</td>
<td>2.3 cd</td>
<td>1.1 e</td>
<td>2.2 abc</td>
<td>1.2 de</td>
</tr>
<tr>
<td>5 (2x level of PL)</td>
<td>3.1 bc</td>
<td>1.6 d</td>
<td>2.6 ab</td>
<td>1.9 bc</td>
</tr>
<tr>
<td>6 (3x level of PL)</td>
<td>3.5 ab</td>
<td>2.0 cd</td>
<td>2.4 abc</td>
<td>2.1 abc</td>
</tr>
<tr>
<td>7 (4x level of PL)</td>
<td>4.0 ab</td>
<td>2.3 bc</td>
<td>2.5 abc</td>
<td>2.5 a</td>
</tr>
<tr>
<td>8 (5x level of PL)</td>
<td>4.3 a</td>
<td>2.6 ab</td>
<td>2.8 a</td>
<td>2.3 ab</td>
</tr>
<tr>
<td></td>
<td>5-6-92</td>
<td>6-19-92</td>
<td>8-14-92</td>
<td>9-23-92</td>
</tr>
<tr>
<td>1 (Control)</td>
<td>0.6 f</td>
<td>0.7 e</td>
<td>1.1 e</td>
<td>0.8 e</td>
</tr>
<tr>
<td>2 (Inorganic P)</td>
<td>0.5 f</td>
<td>0.7 e</td>
<td>1.5 de</td>
<td>0.6 e</td>
</tr>
<tr>
<td>3 (Inorganic N &amp; P)</td>
<td>3.7 d</td>
<td>3.1 bc</td>
<td>1.7 d</td>
<td>2.0 e</td>
</tr>
<tr>
<td>4 (1x level of PL)</td>
<td>2.3 e</td>
<td>1.9 d</td>
<td>1.6 d</td>
<td>1.3 d</td>
</tr>
<tr>
<td>5 (2x level of PL)</td>
<td>4.0 cd</td>
<td>3.1 c</td>
<td>2.5 c</td>
<td>2.1 bc</td>
</tr>
<tr>
<td>6 (3x level of PL)</td>
<td>4.4 bc</td>
<td>3.6 abc</td>
<td>2.9 bc</td>
<td>2.6 a</td>
</tr>
<tr>
<td>7 (4x level of PL)</td>
<td>5.0 ab</td>
<td>3.9 a</td>
<td>3.2 ab</td>
<td>2.5 ab</td>
</tr>
<tr>
<td>8 (5x level of PL)</td>
<td>5.6 a</td>
<td>3.8 ab</td>
<td>3.6 a</td>
<td>2.5 a</td>
</tr>
</tbody>
</table>

1 x = 5.7 mt ha\(^{-1}\) of PL.
2 x = 4.0 mt ha\(^{-1}\) of PL.

* LSD Column means followed by different letters are significantly different (P=0.05).
Table A2. Rainfall and departure from long-term (LT) means for 1991 and 1992, Orange, Va.¹

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>85</td>
<td>41</td>
<td>67</td>
<td>+18</td>
<td>-26</td>
</tr>
<tr>
<td>Feb.</td>
<td>21</td>
<td>83</td>
<td>62</td>
<td>-41</td>
<td>+21</td>
</tr>
<tr>
<td>Mar.</td>
<td>112</td>
<td>80</td>
<td>86</td>
<td>+26</td>
<td>-6</td>
</tr>
<tr>
<td>Apr.</td>
<td>60</td>
<td>66</td>
<td>78</td>
<td>-18</td>
<td>-12</td>
</tr>
<tr>
<td>May</td>
<td>30</td>
<td>134</td>
<td>99</td>
<td>-69</td>
<td>+35</td>
</tr>
<tr>
<td>June</td>
<td>118</td>
<td>121</td>
<td>89</td>
<td>+29</td>
<td>+32</td>
</tr>
<tr>
<td>July</td>
<td>159</td>
<td>68</td>
<td>110</td>
<td>+39</td>
<td>-42</td>
</tr>
<tr>
<td>Aug.</td>
<td>22</td>
<td>69</td>
<td>104</td>
<td>-82</td>
<td>-35</td>
</tr>
<tr>
<td>Sept.</td>
<td>70</td>
<td>101</td>
<td>89</td>
<td>-18</td>
<td>+12</td>
</tr>
<tr>
<td>Oct.</td>
<td>46</td>
<td>32</td>
<td>89</td>
<td>-43</td>
<td>-57</td>
</tr>
<tr>
<td>Nov.</td>
<td>38</td>
<td>142</td>
<td>84</td>
<td>-46</td>
<td>+58</td>
</tr>
<tr>
<td>Dec.</td>
<td>125</td>
<td>131</td>
<td>77</td>
<td>+48</td>
<td>+54</td>
</tr>
</tbody>
</table>

¹ Observations made 1 km from site.
VITA

Daniel William Lucero was born in Norfolk, Virginia on June 8, 1962. He is the son of C. Herbert Lucero and Joan Marie Lucero of Fort Valley, Virginia. He completed his elementary education in Edinburg, Virginia and his High School education in Falls Church, Virginia. Upon graduation from George Mason High School he attended James Madison University as an anthropology student. After three semesters of study, he left James Madison University to begin hitchhiking around the world. Over the next two and one half years he worked and lived in various parts of North America, Europe and Asia Minor, principally supporting himself as a fisherman.

In December of 1983, overwhelmingly aware of his lost state, he turned with faith to accept Jesus Christ as his Lord and Savior in Torremolinos, Spain. He dedicated the next four years of his life, working in Spain. During this period he lived in the towns of Torremolinos, Fuengirola and Antequera. In the spring of 1988, upon completion of the establishment of Rancho Remar, a drug rehabilitation farm in Antequera, Spain, he married the former Martina Pena from Meyzieu, France.

Upon returning to the United States he received his Bachelor of Science degree in Dairy Science from Virginia Polytechnic Institute and State University in May 1990. Upon graduation, he accepted an assignment to work with a maternal-child-care development project in North Africa. Unable to remain in Africa due to the Persian Gulf War, he returned to the United States in the fall of 1991 via Europe, and accepted a graduate teachers assistantship in the Department of Crop and Soil Environmental Sciences at Virginia Polytechnic Institute and State University under the guidance of Drs. David C. Martens and James R. McKenna.

He is a member of Phi Kappa Phi, Gamma Sigma Delta, Phi Sigma Society, and the Golden Key National honor societies as well as a member of the American Society of Agronomy. Most importantly, he is the blessed father of three beautiful children, Jeremiah, Melissa and Julia. He presently resides in Blacksburg, Virginia with his wife Martina and their three children.