

USE OF COWPEA AND VETCH TO MANAGE
ACCUMULATION OF SOIL PHOSPHORUS
FROM POULTRY LITTER APPLICATIONS
IN VEGETABLE ROTATIONS

By
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1996

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 1998

OKLAHOMA STATE UNIVERSITY

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ACKNOWLEDGEMENTS

The sun is shining; it's a beautiful day; this manuscript is finished, and I can finally go outside and play!

Thank you, Josh and Shanna Borthick, for being so wonderful while your mom slaved away at the computer, with reference books and data sheets spread from one end of the house to the other.

I began this research project with vague notions of what I hoped to accomplish. I wanted to learn more about plants—to understand them inside and out. And I wanted a master's degree. Scientific research was a tedious but necessary means to an end.

The past two years have flown by. I took a lot of classes, pulled a lot of soil samples (oh, my aching back!), hoed a lot of pigweed, and filled a lot of notebooks with data that would hopefully mean something someday. I discovered the joys of teaching while serving as a Teaching Assistant for Dr. Doug Needham. Research was still a pain, though, until the unthinkable happened. I began to wonder what would happen if a plant was subjected to such and such a treatment. Had anyone investigated how plants respond to this stimulus, or that one? I actually enjoyed doing research! I wanted to do more! It was a frightening discovery, because I secretly feared I didn't have the skills a researcher needs.

But while writing this thesis, it became clear I had learned more than I realized. I know how to set up and carry out an experiment. Thank you, Brian Kahn, for the patient explanations; and Janet Cole, for the undergraduate research

project; and John Dole, for letting me manage the cut flower variety trial; and all you professors, for the journal articles you force fed us in class. I know how important it is to plan ahead, and to keep careful records, and to double check to make sure planting or harvesting procedures are done correctly. Thanks again, Dr. Kahn. I know how to present my research at a professional meeting. Thank you, Niels Maness. (I won't forget to use the hand gestures!) I know how to write a SAS program, and am no longer deathly afraid of statistics. Thank you, Mike Smith.

I still want to teach, as well as do research. Thanks, Dr. Smith, for telling me once-upon-a-time that I should become a teacher. How did you know? Thank you, Dr. Needham, for sharing your enthusiasm and dedication to students. And I still want to learn about plants, inside and out. Thank you, Jeff Anderson, for understanding my fascination with their appearance on a microscopic level. You didn't ridicule my ideas about fairies and plants and science fiction. Thanks, Dr. Cole, Bjorn Martin and Michael Wisniewski, for the electron micrographs. And before I forget, thank you, Dr. Dole and Gordon Johnson, for serving on my graduate committee and editing this thesis. Thank you, Mark Payton, for the statistical assistance. Thank you, Lou Anella and Crystal Cork, for steadfast friendship.

I can't end this note without mentioning Dale Maronek, who said it's okay to put family first; and Bruce Bostian, Carla Novak, Leah Willis and Jim Motes, who shoveled and spread more poultry litter than I ever did; and some of the most important people in the world—Donna Dollins, Margaret Struble, Rhiannon Battles, Linda Dotter and Stephanie Larimer, who have made my life so much easier.

TABLE OF CONTENTS

Chapter	Page
I. LITERATURE REVIEW	1
History of manures	1
Inorganic fertilizers	2
Poultry manure and phosphorus	3
Poultry litter application rates and P accumulation	4
Litter as a vegetable crop fertilizer	6
Residual effects	9
Use of legumes to control soil P levels	10
Literature Cited	12
II. USE OF COWPEA TO MANAGE SOIL PHOSPHORUS ACCUMULATION FROM POULTRY LITTER APPLICATIONS IN A COOL-SEASON VEGETABLE ROTATION	16
Introduction	17
Materials and Methods	20
Results and Discussion	28
Conclusions	41
Literature Cited	44
Tables and Figures	47
III. USE OF HAIRY VETCH TO MANAGE SOIL PHOSPHORUS ACCUMULATION FROM POULTRY LITTER APPLICATIONS IN A WARM-SEASON VEGETABLE ROTATION	73
Introduction	74
Materials and Methods	78
Results and Discussion	86
Conclusions	93
Literature Cited	96
Tables and Figures	99

LIST OF TABLES

Table	Page
2.1. Total elemental composition of poultry litter applied to each vegetable crop	46
2.2. Amount of poultry litter applied during production of three cool-season vegetable crops. 1X refers to poultry litter at the rate recommended by soil tests to supply preplant N to a vegetable crop. 2X is litter at twice the recommended rate	47
2.3. Amount of N, P, and K applied with pre-plant fertilizer treatments and topdressings during production of three cool-season vegetable crops	48
2.4. Foliar elemental concentrations in two cowpea cover crops.....	49
2.5. Yields of two cowpea cover crops.....	50
2.6. Response of 'Everest' broccoli to fertilizer treatments	51
2.7. Response of 'Ozarka II' spinach to fertilizer treatments	52
2.8. Effects of a legume by fertilizer treatment interaction on shoot Ca levels in spinach.....	53
2.9. Effects of fertilizer treatments on turnip greens.....	54
2.10. Mean values of soil nutrients. Means are an average of five soil sampling events	55
2.11. Summary of main effects and interactions affecting soil nutrient values	56
2.12. Change over time in soil P values, at 0-15 cm, in plots where cowpea cover crops were grown	57
2.13. Change over time in soil P values, at 0-15 cm depth, in fallowed plots	58
2.14. Estimated amount of P removed by three cool-season vegetable crops and two cowpea cover crops.....	59
2.15. Effect on N values, at 0-15 cm depth, of a legume X litter interaction at Time 3 (September 1996) soil sampling ..	60
2.16. Simple effects of cover crop treatments on the amount of N at 15-30 cm depth, at September 1996 and September 1997 soil samplings	61
2.17. Effects of a cover crop X time interaction on levels of soil Zn at the 0-15 cm depth at July 1995, September 1996 and September 1997 soil samplings.....	62

2.18. Effects of fertilizer treatments on levels of soil Zn at the 0-15 cm depth at September 1996 and September 1997 soil samplings	63
2.19. Effects of cover crop treatments on soil pH at two soil testing depths, at September 1996 and September 1997 soil samplings	64
3.1. Total elemental composition of poultry litter applied	98
3.2. Amount of poultry litter applied during production of two warm-season vegetable crops	99
3.3. Amount of N, P, and K applied with fertilizer treatments during production of two warm-season vegetable crops	100
3.4. Foliar element concentrations and shoot yields of 1996-1997 vetch cover crop	101
3.5. Effect of fertilizer treatments on 'Bodacious' sweet corn	102
3.6. Effect of cover crop and fertilizer treatments on Magnum 45' muskmelons	103
3.7. Mean soil test values for N, P, K and pH at five soil sampling occasions	104
3.8. Mean soil test values of Ca, Mg, Fe, B and Zn at three soil sampling occasions	105
3.9. Summary of main effects and interactions affecting soil nutrient values	106
3.10. Effects of treatment by time interactions on soil test P (0-15cm)	107
3.11. Effects of treatment by time interactions on soil test N(0-15cm)	108
3.12. Effects of treatment by time interactions on soil test N(15-30cm)	109
3.13. Estimated amount of P removed by two warm-season vegetable crops and one hairy vetch cover crop	110

LIST OF FIGURES

Figure	Page
2.1. Soil P levels at 0-15 cm, in plots where cowpea cover crops were grown	65
2.2. Soil P levels at 0-15 cm, in fallowed plots.....	66
2.3. Soil P levels at 15-30 cm, in plots where cowpea cover crops were grown.....	67
2.4. Soil P levels at 15-30 cm, in fallowed plots.....	68
2.5. Change in P values over time, averaged over all treatments....	69
2.6. Change in N values over time, averaged over all treatments ...	70
2.7. Change in K values over time, averaged over all treatments....	71
3.1. Soil P values at 0-15 cm, in plots where vetch cover crop was grown	111
3.2. Soil P values, 0-15 cm, in fallowed plots	112
3.3. Soil P values at 15-30 cm, in plots where vetch cover crop was grown	113
3.4. Soil P values, 15-30 cm, in fallowed plots.....	114

NOMENCLATURE

N	nitrogen
P	phosphorus
K	potassium
Ca	calcium
Mg	magnesium
Fe	iron
Mn	manganese
Zn	zinc
cm	centimeters
g	gram
Mg	megagram
ml	milliliter
mm	millimeter
kg·ha ⁻¹	kilograms per hectare
m	meter
m ²	square meters
1X	recommended rate of application
2X	twice the recommended rate of application
≤	less than or equal to
≥	greater than or equal to
avg	average
tmt	treatment
LSD	least significant difference
Time 1	July 1995 (cool season study) or March 1996 (warm season study) soil sampling
Time 2	May 1996 (cool season study) or October 1996 (warm season study) soil sampling
Time 3	September 1996 (cool season study) or May 1997 (warm season study) soil sampling
Time 4	May 1997 (cool season study) or October 1997 (warm season study) soil sampling
Time 5	September 1997 (cool season study) or April 1998 (warm season study) soil sampling

CHAPTER 1

LITERATURE REVIEW

"And what is soil? It is the result of the destruction of the rocks mingled with vegetable waste; it is the turning of all life, organic and inorganic, into its original elements; it is the great graveyard of creation..."—J.J. Gregory, 1886

History of manures

It is not possible to pinpoint exactly when humans first recognized the benefits of animal manures and legumes in crop production. The word "manure" originates from "manoeuvre," meaning to work with the hands. Over time, it took on the extended meaning of any process or material by which the land can be improved (Hall, 1921). Even in the earliest phases of agriculture, farmers seemed aware of soil fertility. The first recorded writings, around 2500 B.C. in Mesopotamia, told how barley (*Hordeum* spp.) yields varied in different locations (Johnson et al., 1997). The Bible mentioned the use of mineral fertilizers and soil amendments such as wood ashes, lime and saltpeter (potassium nitrate) (Tisdale et al., 1993).

The beneficial effects of manures and legumes were recognized early on. Legumes were important food crops in most of the ancient agricultural regions—the Middle East, China and India, medieval and premodern Europe, sub-Saharan Africa and the New World (Smil, 1997). Eventually, farmers learned to hoe or plow in legume “green manure” crops as well as wild plants and leaves, food-processing wastes, and animal and human manures. Ancient poets and historians, such as Homer around 800 B.C. and Theophrastus around 300 B.C., wrote about improving vineyard soils with manure and bedding from animal stalls. In medieval England, it was a common practice for tenants to bring their flocks to the lord’s land each night, thus enriching his soil (Hall, 1921).

Inorganic fertilizers

By the 19th century, scientists were discovering the crucial role of various plant nutrients, and production of commercial or inorganic fertilizers began. The German chemist, Justus von Liebig, in 1840 announced that minerals, or inorganic elements, increased crop yields and were essential for plant growth. J.B. Lawes and J.H. Gilbert, founders of Rothamsted Agricultural Experimental Station in England, began experimenting with chemical fertilizers on a small scale in 1837 and in field plots in 1843. Superphosphate was first made and used

on the Rothamsted farm in 1840; three years later the first factory was erected near London (Gregory, 1886). Potassium fertilizers were readily available by mining underground salt beds. Nitrogen was the last of the plant macronutrients to become commercially available on a large-scale basis. Several methods were developed to produce inorganic nitrogen, but were too expensive to be practical. The breakthrough occurred in the early 1900s with the invention of ammonia synthesis by German scientists Fritz Haber and Carl Bosch. The first ammonia factory opened in Germany in 1913 to make explosives for World War I. By the 1950s, the Haber-Bosch process was being used to produce 10 million tons a year of ammonia-N for crop production (Smil, 1997).

Poultry manure and phosphorus

Despite the tremendous increase in yields made possible by inorganic fertilizers, animal manures have remained the primary crop fertilizer in many countries and in regions of concentrated livestock production. Animals and humans excrete more than 70% of most nutrients in their food, including almost all of the phosphate (Hedley et al., 1995). Chickens (*Gallus domesticus*) may excrete more than 85% of the dicalcium phosphate fed to them to improve bone development (Robinson and Sharpley, 1995). The high phosphorus

level contributes to poultry manure's dual reputation as a valuable source of plant nutrients and a potential source of environmental pollution.

An estimated 7.76 billion broiler chickens and 300 million turkeys (*Meleagris gallopavo*) were produced in the United States in 1997 (National Agricultural Statistics Service, 1998). Production tends to be concentrated in small geographical areas. It is common to find 20,000 to 80,000 or more birds per farm, with farms side-by-side. Manure and litter—a mixture of excrement and bedding materials—are major by-products of the poultry industry. Although the quantity of litter produced on poultry farms varies considerably, depending on the species of birds and on management practices, an estimated 5 kg (11 lbs) of dry matter manure is produced per animal per year (Payne and Donald, 1992). Thus, about 40 billion kg (40 million metric tons) of dry manure is produced in the United States each year. The volume of waste produce increases when the manure is mixed with litter materials.

Poultry litter application rates and P accumulation

The most common recycling method for poultry wastes is land application, often in pastures near the poultry production houses

(Govindasamy et al., 1994). Around 73% of confined-production manures are directly land-applied (Edwards and Daniel, 1992). Phosphorus buildup may occur at or near the soil surface after repeated, long-term applications, especially at high application rates (Sharpley et al., 1993; Edwards and Daniel, 1992; Earhart, 1995). The accumulation may result in loss of P in rainfall runoff (Nichols et al., 1994; Edwards and Daniel, 1993 and 1994; Edwards et al., 1996; Giddens and Barnett, 1980). Runoff of P has been associated with eutrophication of surface waters. To control runoff P losses, farmers have been encouraged to incorporate litter after application, to rotate fields, and to use a buffer strip at the edge of the field (Johnson et al., 1997); to apply litter during active periods of crop growth (Robinson and Sharpley, 1995); to market litter as a fertilizer or soil amendment, feed additive, or energy source (Johnson et al., 1997); and to add chemicals that will immobilize N and P in the litter (Chapman, 1996). Litter amended with alum [$(\text{Al}_2\text{SO}_4)_3 \cdot 16\text{H}_2\text{O}$] or ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) had less soluble P when applied to soils than unamended litter (Shreve et al., 1996). High application rates may also lead to leaching of P, depending on soil properties such as texture and adsorption capacity (Lucero et al., 1995).

Litter as a vegetable crop fertilizer

In addition to land application, poultry litter is also used as a crop fertilizer. Litter contains nutrients needed for plant growth and adds organic matter to the soil (Edwards and Daniel, 1992; Robinson and Sharpley, 1996; Zhang and Hamilton, 1996). Since plants tend to require smaller amounts of P than are supplied by litter, farmers in many states are encouraged to apply litter or manure based on crop P requirements instead of N requirements, especially on high P soils (Johnson et al., 1997; Robinson and Sharpley, 1996).

Research in greenhouses and in the field has shown mixed results on the effectiveness of poultry manure or litter as a fertilizer for fruits and vegetables. Tomatoes (*Lycopersicon esculentum* Mill.) grown on manure-treated plots had higher yields than tomatoes grown with commercial fertilizers during growing seasons with normal rainfall, but had lower yields during seasons of high or excessive rainfall due to rotting of fruit or to the pickers overlooking fruits under the dense foliage (Rahn, 1949; Ware and Johnson, 1968). Row application of manure reduced yields, stands and vigor of tomato plants compared to broadcast applications (Ware and Johnson, 1968). Tomato and pepper (*Capsicum annuum* var. *annuum* L.) yields were

equal or higher when fertilized with composted chicken manure than with 10-10-10 fertilizer (Maynard, 1994).

Yields of lettuce (*Lactuca sativa* L.) grown in the greenhouse in a mix of broiler litter and composted shredded pine (*Pinus* sp.) bark or peanut (*Arachis hypogaea* L.) hulls were usually higher than yields of lettuce grown in potting mix alone (Flynn et al., 1995). Strawberries (*Fragaria x ananassa* Duchesne.) grown on raised beds in the greenhouse flowered earlier and had a higher fruit yield when fertilized with 200 kg·ha⁻¹ of litter compared with treatments of ammonium nitrate (34.5N-0P-0K) or fluid N with 10 g·kg⁻¹ microelements (30N-0P-0K) (Rubeiz et al., 1997). In another greenhouse study, seedlings of collards (*Brassica oleracea* L. var. *acephala* DC.), cabbage (*Brassica oleracea* L. var. *capitata* L.) and broccoli (*Brassica oleracea* L. var. *italica* Plenck.) were successfully grown in a composted, sieved mix of 1 litter : 1 standard greenhouse potting media (Guertal et al., 1997). Field-grown broccoli fertilized by composted manure (Maynard, 1994) or non-composted litter (Brown et al., 1994) outyielded broccoli fertilized by commercial fertilizers.

Several researchers have tried to determine the effects of high rates of litter. High application rates have been shown to reduce yields in some crops, possibly due to nutrient imbalances caused by a

buildup of toxic levels of ammonia, nitrite, nitrate and soluble salts (Edwards and Daniel, 1992). Sweet corn (*Zea mays* L.) matured one week earlier when fertilized with 40 $\text{mt}\cdot\text{ha}^{-1}$ of litter compared with the recommended rate of a commercial fertilizer (Brown et al., 1994). On the other hand, adequate yields were reported in no-till corn production when moderate rates (11.2 and 22.4 $\text{mt}\cdot\text{ha}^{-1}$) of poultry litter were used, but high rates (44.8 $\text{mt}\cdot\text{ha}^{-1}$) usually resulted in seedling death or low corn stands (Carreker et al., 1973). Litter applied at rates higher than twice the recommended amount decreased yields of spring sweet corn and fall broccoli (Earhart, 1995). In production of tomatoes, litter rates of 20.1 $\text{mt}\cdot\text{ha}^{-1}$ and 40.2 $\text{mt}\cdot\text{ha}^{-1}$ increased yield and decreased days to maturity compared with tomatoes fertilized by 13N-13P₂O₅-13K₂O at recommended rates (Brown et al., 1995). Snap bean (*Phaseolus vulgaris* L.) yields generally showed a linear response with increasing application rates of litter (Brown et al., 1993). Litter rates equal to or higher than 53 $\text{g}\cdot\text{kg}^{-1}$ were toxic to collard seedlings in a greenhouse pot study (Lu and Edwards, 1994). The high rates caused stunting and death of the seedlings within seven days of transplanting into the litter-amended sandy loam soil.

Residual effects

Both positive and negative residual effects of manure have been reported. Cantaloupes (*Cucumis melo* L. Reticulatus group) and watermelons [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] were successfully grown on plots where manure was broadcast in winter in a rye (*Secale cereale* L.) or wheat (*Triticum* sp.) cover crop that was later plowed under (Rahn, 1949). Snap bean yields in the fall were higher on plots that received spring litter applications than on plots that received a commercial fertilizer in the fall (Brown et al., 1993). However, the residual benefits of a spring manure application were not adequate for maximum production of fall collards, turnips (*Brassica rapa* L. Rapifera group) and lettuce (Ware and Johnson, 1968). In a greenhouse study, a litter rate of $106 \text{ g} \cdot \text{kg}^{-1}$ caused stunting in the first, and possibly second, of three successive crops of cabbage planted in pots following collards (Lu and Edwards, 1994). Three consecutive years of composted chicken manure applications resulted in a decrease in yield of eggplant (*Solanum melongena* L.) and peppers but slightly improved performance of cauliflower (*Brassica oleracea* L. var. botrytis L.) (Maynard, 1994).

Use of legumes to control soil P levels

Repeated litter applications may lead to excessive soil P levels in vegetable production systems, especially at the high rates needed to supply adequate N to crops. Since legumes have a reputation for high P uptake, Earhart (1995) proposed that vegetable crops be rotated with legume cover crops to control soil P accumulation from poultry litter applications. Legumes tend to require larger amounts of P than many of the common grain crops grown in Oklahoma (Johnson et al., 1997). Cover crops absorb nutrients while actively growing, and if significant biomass accumulation occurs, could affect such properties as the distribution and forms of nutrients in soils (Lal et al., 1991). Johnson et al. (1998) pointed out that management of available P is not directly related to crop yield, because plants can only extract immobile nutrients from a thin layer of soil surrounding the root. They also stated that it would require crop removal of about 15 lb P_2O_5 /acre to lower the Mehlich-III soil test P by a value of 1.0 (on a Grant silt loam soil). The removal or addition of about 9 kg/ha of P_2O_5 is required to change the Bray-P soil test by 1 kg/ha (Miller and Reetz, Jr., 1995). Bray-P levels have been found to be lower under legume cover crops than grass covers, although soil pH, organic

C, total N and exchangeable cations were generally higher under the legumes than the grasses (Wilson et al., 1982).

Smyth and Cravo (1990) said that cowpeas [*Vigna unguiculata* (L.) Walp.] and other legumes may require relatively high levels of soil and foliar P to carry out symbiotic N₂ fixation. They assessed nodulation in cowpeas following a broadcast P treatment and found nodule number increased up to the rate of 44 kg·ha⁻¹ of P, while nodule mass, N uptake and final grain yield increased to the highest rate of P (176 kg·ha⁻¹).

No applicable literature was found on the use of legume cover crops to control the P that accumulates in soils with repeated poultry litter applications. Results from Ohno and Crannell (1996) suggest that legumes could cause an increase in available P on acidic soils, when anions released from the legume organic matter compete with phosphate anions for binding sites in the soil. If a legume crop does cause an increase in available P, it could decrease fertilizer application rates to subsequent crops. It could also cause legumes to be less effective at controlling P buildup from poultry litter applications.

Literature Cited

- Brown, J.E., C.H. Gilliam, R.L. Shumack, and D.W. Porch. 1993. Commercial snap bean response to fertilization with broiler litter. *HortScience* 28(1):29-31.
- Brown, J.E., J.M. Dangler, C.H. Gilliam, D.W. Porch, and R.L. Schumack. 1994. Comparison of broiler litter and inorganic nitrogen, phosphorus, and potassium for double-cropped sweet corn and broccoli. *J. Plant Nutr.* 17(5):859-867.
- Brown, J.E., C.H. Gilliam, R.L. Shumack, D.W. Porch, and J.O. Donald. 1995. Comparison of broiler litter and commercial fertilizer on production of tomato, *Lycopersicon esculentum*. *J. Veg. Crop. Prod.* 1(1):53-62.
- Carreker, J.R., S.R. Wilkinson, J.E. Box, Jr., R.N. Dawson, E.R. Beaty, H.D. Morris, and J.B. Jones, Jr. 1973. Using poultry litter, irrigation, and tall fescue for no-till corn production. *J. Environ. Qual.* 2(4):497-500.
- Chapman, S.L. 1996. Soil and solid poultry waste nutrient management and water quality. *Poultry Sci.* 75(7):862-866. (Abstr.)
- Earhart, D.R. 1995. Developing environmentally sound poultry litter management practices for sustainable cropping systems. *Sustainable Agr. Res. and Educ. & Agr. in Concert with the Environ.: Southern Region.* LS92-48.
- Edwards, D.R., and T.C. Daniel. 1992. Environmental impacts of on-farm poultry waste disposal: A review. *Bioresource Technol.* 41:9-33.
- Edwards, D.R., and T.C. Daniel. 1993. Waste management: Effects of poultry litter application rate and rainfall intensity on quality of runoff from fescuegrass plots. *J. Environ. Qual.* 22:361-365.
- Edwards, D.R., and T.C. Daniel. 1994. Quality of runoff from fescuegrass plots treated with poultry litter and inorganic fertilizer. *J. Environ. Qual.* 23:579-584.

- Edwards, D.R., P.A. Moore, Jr., T.C. Daniel, and P. Srivastava. 1996. Poultry litter-treated length effects on quality of runoff from fescue plots. *Trans. Amer. Soc. Agr. Eng.* 39(1):105-110.
- Flynn, R.P., C.W. Wood, and E.A. Guertal. 1995. Lettuce response to composted broiler litter as a potting substrate component. *J. Amer. Soc. Hort. Sci.* 120(6):964-970
- Giddens, J., and A.P. Barnett. 1980. Soil loss and microbiological quality of runoff from land treated with poultry litter. *J. Environ. Qual.* 9(3):518-520.
- Govindasamy, R., M.J. Cochran, and E. Buchberger. 1994. Economic implications of phosphorus loading policies for pasture land applications of poultry litter. *Water Resources Bul.* 30(5):901-909.
- Gregory, J.J. 1886. *Fertilizers: where the materials come from: where to get them in the cheapest form: how to compound formulas, etc., etc.* Rand, Avery, Boston.
- Guertal, E.A., B.K. Behe, and J.M. Kemble. 1997. Composted poultry litter as potting media does not affect transplant nitrogen content or final crop yield. *HortTechnology* 7(2):142-145.
- Hall, A.D. 1921. *Fertilizers and manures.* 2nd ed. Murry, London.
- Hedley, M.J., J.J. Mortvedt, N.S. Bolan, and J.K. Syers. 1995. Phosphorus fertility management in agroecosystems. In: H. Tiessen (ed.). *Phosphorus in the global environment.* Wiley, New York.
- Johnson, G.V., W.R. Raun, H. Zhang, and J.A. Hattey. 1997. *Oklahoma soil fertility handbook.* 4th ed. Okla. State Univ. Dept. of Agron.
- Johnson, G.V., N.T. Basta, H.A. Zhang, J.A. Hattey, W.R. Raun, and J.H. Stiegler. 1998. Science-based animal waste phosphorus management for Oklahoma. *Okla. Coop. Ext. Serv. Production Technol.* 98(1).

- Lal, R., E. Regnier, D.J. Eckert, W.M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture. In: Cover crops for clean water. Soil and Water Conservation Soc., Ankeny, Iowa.
- Lu, N.P., and J.H. Edwards. 1994. Poultry litter quantity influences collard growth in pots and affects cabbage growth and nutrient uptake. *HortScience* 29(10):1143-1148.
- Lucero, D.W., D.C. Martens, J.R. McKenna, and D.E. Starner. 1995. Poultry litter effects on unmanaged pasture yield, nitrogen and phosphorus uptakes, and botanical composition. *Commun. Soil Sci. Plant Anal.* 26(5&6):861-881.
- Maynard, A.A. 1994. Sustained vegetable production for three years using composted animal manures. *Compost Sci. & Utilization.* 2(1):88-96.
- Miller, D.A., and H.F. Reetz, Jr. 1995. Forage fertilization. In: R.F. Barnes, D.A. Miller, and C.J. Nelson (eds). *Forages: Volume 1: An introduction to grassland agriculture.* Iowa State Univ. Press, Ames, Iowa.
- National Agricultural Statistics Service. 1998. Poultry production and value. *Bul. Pou* 3-1(98), US Dept. of Agr., Washington, DC.
- Nichols, D.J., T.C. Daniel, and D.R. Edwards. 1994. Nutrient runoff from pasture after incorporation of poultry litter or inorganic fertilizer. *Soil Sci. Soc. Am. J.* 58:1224-1228.
- Ohno, T., and B.S. Crannell. 1996. Green and animal manure-derived dissolved organic matter effects on phosphorus sorption. *J. Environ. Qual.* 25:1137-1143.
- Payne, V., and J.O. Donald. 1992. Poultry waste management and environmental protection manual. Auburn Univ. Ext. ANR-580.
- Rahn, E.M. 1949. Poultry manure as a fertilizer for vegetable crops. Univ. of Delaware Agr. Expt. Sta. Res. Bul. 281.
- Robinson, J.S., and A.N. Sharpley. 1995. Water quality: Release of nitrogen and phosphorus from poultry litter. *J. Environ. Qual.* 24(1):62-67.

- Robinson, J.S., and A.N. Sharpley. 1996. Reaction in soil of phosphorus released from poultry litter. *Soil Sci. Soc. Am. J.* 60:1583-1588.
- Rubeiz, I.G., A.M. Chehab, M.M. Freiwat, and M.T. Farran. 1997. Broiler litter and inorganic nitrogen fertilizer influence on yield and earliness of June-bearing strawberry. *HortScience* 32(3):487. (Abstr.)
- Sharpley, A.N., S.J. Smith, and W.R. Bain. 1993. Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoma soils. *Soil Sci. Soc. Am. J.* 57:1131-1137.
- Shreve, B.R., P.A. Moore, Jr., D.M. Miller, T.C. Daniel, and D.R. Edwards. 1996. Long-term phosphorus solubility in soils receiving poultry litter treated with aluminum, calcium, and iron amendments. *Commun. Soil Sci. Plant Anal.* 27(11&12):2493-2510.
- Smil, V. 1997. *Cycles of life: Civilization and the biosphere*. Scientific Amer. Library, New York.
- Smyth, T.J., and M.S. Cravo. 1990. Critical phosphorus levels for corn and cowpea in a Brazilian Amazon oxisol. *Agron. J* 82:309-312.
- Tisdale, S.L., W.L. Nelson, J.D. Beaton, J.L. Havlin. 1993. Soil fertility: Past and present, p. 1-13. In: P.F. Corey (ed). *Soil fertility and fertilizers*. 5th ed. Macmillan, New York.
- Ware, L.M., and W.A. Johnson. 1968. Poultry manure for vegetable crops: Effects and value. *Auburn Agr. Expt. Sta. Res. Bul.* 386.
- Wilson, G.F., R. Lal, and B.N. Okigbo. 1982. Effects of cover crops on soil structure and on yield of subsequent arable crops grown under strip tillage on an eroded alfisol. *Soil Tillage Research*. 2:233-250.
- Zhang, H., and D.W. Hamilton. 1996. Use [sic] animal manure as a plant nutrient source. *Okla. Coop. Ext. Serv. Production Technol.* PT 96-25

CHAPTER 2

Use of Cowpea to Manage Soil Phosphorus Accumulation from Poultry Litter Applications in a Cool-Season Vegetable Rotation

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Additional index words. *Vigna unguiculata*

Abstract. Cowpea [*Vigna unguiculata* L. (Walp.)] cover crops were grown in a rotation with broccoli (*Brassica oleracea* L. var. *italica* Plenck.), spinach (*Spinacia oleracea* L.), and turnip greens [*Brassica rapa* L. var. (DC.) Metzg. *utilis*] to evaluate the legume's ability to remove excess P from soils when poultry litter was used as a fertilizer. Fertilizer treatments were litter to meet each crop's recommended preplant N requirements (1X); litter at twice the recommended rate; and urea (46N-0P-0K) at the 1X rate. Following the vegetable crops, cowpeas were planted on half of each replication, while the other half was fallowed. The cowpeas were harvested at the green-shell seed stage and then underwent a simulated haying operation. Soil samples were taken from 0-15 cm and

15-30 cm depths at the onset of the study and after each crop to monitor plant nutrient levels. The cowpeas effectively lowered soil N levels but not soil P levels. However, there was no consistent evidence of an increase in soil P or K levels with litter applications. Poultry litter was effective as a fertilizer for all three vegetable crops, although the 1X rate appeared inadequate for maximum production of broccoli and turnip greens.

INTRODUCTION

The poultry industry has grown in parts of Oklahoma, Arkansas and other Southern states, with U.S. production in 1997 reaching an estimated 7.76 billion broiler chickens (*Gallus domesticus*) and 300 million turkeys (*Meleagris gallopavo*) (National Agricultural Statistics Service, 1998). The increase in production has been accompanied by a greater output of poultry litter, with about 40 million Mg of dry manure produced each year. The volume increases when the manure is mixed with litter materials. Many states and regions have begun regulating animal waste disposal methods. Because of governmental restrictions, as well as an increasing focus on sustainable agricultural

practices, poultry litter is being used more frequently as a fertilizer for vegetables and other agricultural crops.

Poultry litter contains most mineral elements essential for plant growth and adds organic matter to the soil, making it an alternative source of fertilizer for horticultural crops (Brady, 1990; Edwards and Daniel, 1992; Robinson and Sharpley, 1996; Zhang and Hamilton, 1996). Research in greenhouses and in the field has shown mixed results on the effectiveness of poultry manure or litter as a fertilizer for fruits and vegetables. Cruciferae crops such as broccoli, cabbage (*Brassica oleracea* L. var. capitata L.), cauliflower (*Brassica oleracea* L. var. botrytis L.), collards (*Brassica oleracea* L. var. acephala DC.), and turnips have been successfully grown with litter or manure (Brown et al., 1994; Earhart, 1995; Guertal et al., 1997; Lu and Edwards, 1994; Maynard, 1994; Ware and Johnson, 1968).

Litter is usually applied to a field based on the amount of N needed by crops. Poultry litter is low in N, so large quantities may be needed to supply enough N to meet crop demands. Application of a large quantity of litter can cause a buildup of soil P (Sharpley et al., 1993; Edwards and Daniel, 1992; Earhart, 1995), because plants tend to take up less P than is provided in litter. The ratio of N:P uptake for crops grown in the Southern Plains is 8:1, while the average N:P ratio

in litter is 3:1 (Edwards and Daniel, 1992). Excessive P near the soil surface is subject to rainfall runoff (Edwards and Daniel, 1993 and 1994; Edwards et al., 1996; Giddens and Barnett, 1980; Nichols et al., 1994), and may be carried to surface bodies of water where it may accelerate eutrophication. Levels of P must be managed if litter is to be used as a long-term fertilizer in agricultural production.

Legumes have a reputation for high P uptake which may deplete soil P levels (Griffith, 1974). Legumes tend to require larger amounts of P than many of the common grain crops grown in Oklahoma (Johnson et al., 1997). Daniel (1934) analyzed the nutrient content of 25 grasses and 12 legumes and found that legumes contain an average of 1.75 times as much P as grasses. Cowpeas were in the middle range of foliar P concentration among grasses and legumes. Bray-P levels in the zero to 0.15-meter depth were lower under legume cover crops than grass covers, although soil pH, organic C, total N, and exchangeable cations were generally higher under the legumes (Wilson et al., 1982). Winter legumes lowered soil pH and extractable P in the zero to 0.075-meter depth and redistributed potassium to the surface (Hargrove, 1986).

Smyth and Cravo (1990) said that cowpeas and other legumes may require high levels of soil and foliar P to carry out symbiotic N₂

fixation. They assessed nodulation in cowpea following a broadcast P treatment and found nodule number and mass increased, as did N uptake and final grain yield, to the highest rate of P ($176 \text{ kg} \cdot \text{ha}^{-1}$) applied. Cover crops absorb nutrients while actively growing, and if significant biomass accumulates, the cover crops could affect the distribution and forms of nutrients in soils (Lal et al., 1991).

Earhart (1995) proposed that vegetable crops be rotated with legume cover crops to control soil P accumulation from poultry litter applications. In a runoff study (Robinson and Sharpley, 1996), poultry litter P was less available for surface runoff than P from commercial fertilizers, for the first 68 days following application. Thereafter, the trend was reversed, with greater P losses in runoff from the litter. This initial slow availability could allow sufficient time for a legume crop to become established and start absorbing excess P.

We found no applicable literature on the use of legumes to control soil P accumulation in vegetable production. This study examined the effectiveness of litter as a vegetable crop fertilizer, and the ability of cowpeas to reduce soil P levels in a cool-season vegetable rotation where poultry litter was used to fertilize the vegetable crops.

MATERIALS AND METHODS

Cool-season vegetable crops were fertilized by poultry litter at a rate sufficient to meet each crop's recommended preplant N requirements (1X); litter at twice the recommended rate (2X); and urea (46N-0P-0K) at the 1X rate as a control. Fertilizer treatments were hand-broadcast and incorporated to a depth of 5 to 7.5 cm. After the vegetables were harvested, cowpeas were planted on half of the plots, with the other half left fallow, to compare soil P levels in a cover cropping system vs. fallow ground.

Location: A three-year field experiment was conducted at the Oklahoma State University Vegetable Research Station in Bixby, Okla., on a Severn very fine sandy loam [coarse-silty, mixed (calcerous), thermic Typic Udifluvent] soil. The field was divided into four replications. Each replication contained six plots measuring 5.4 by 8.0 m, plus a 3-m alley in the center. Each replication was separated by a 2-m alley. The experimental area was the site of a similar study that ended the previous year, which examined the ability of grass (*Gramineae*) cover crops to absorb excess soil N from poultry litter applications to vegetable crops. Randomization of fertilizer treatments in our study was a continuation of randomization

from the prior study. Residual effects of soil P and K from previous poultry litter applications may have affected results of our study.

Experimental Design: The experiment was arranged in a split-plot design with randomized blocks, and four replications. The main plot treatments were a cowpea cover crop, and fallow ground. The sub plots consisted of the three fertilizer treatments previously indicated.

Poultry Litter: Litter was obtained from three poultry farms in northeastern Oklahoma. The litter was obtained from direct clean-outs of empty poultry houses; thus, it was slightly aged but not composted. Prior to application, the litter was analyzed for total N, P, K and Ca, plus pH, electrical conductivity, and percent water (Table 2.1). The analyses were performed by the University of Arkansas' Agricultural Services Laboratory, Fayetteville, Ark. Total amount of litter applied and the levels of N, P, and K applied with fertilizer treatments were recorded (Tables 2.2 and 2.3).

Soil Analyses: Before any crops were planted, soil samples were collected from each plot at two depths: 0-15 cm and 15-30 cm, and analyzed for nitrate-N, P, K, Ca, Mg, Fe, B, Zn and pH. Five soil cores were removed from each plot and mixed to form a composite sample. The initial samples were taken on 25 July 1995. Soil samples were also collected following each legume cover crop and vegetable crop.

For the sake of brevity, sampling periods are referred to as Time 1, Time 2, etc. Timing of sample collections was as consistent as possible, but varied some depending on the weather, field conditions, and the ideal planting date for each crop. Samples were analyzed by the OSU Soil, Water and Forage Analytical Laboratory in Stillwater, Okla., using the Mehlich III extraction for P, K, Ca and Mg; calcium sulfate extraction of nitrate-N; DTPA extraction of Fe and Zn; and hot water extraction of B. Phosphate (phospho-molybdate blue) and nitrate (cadmium reduction) were analyzed colorimetrically using flow injection instrumentation. Solutions containing the other elements were analyzed using inductively coupled plasma (ICP) emission spectroscopy (Zhang et al., 1983).

Vegetable Crops: Three cool-season vegetable crops, all produced commercially in Oklahoma, were grown to assess the effects of the cover crop and fertilizer treatments: 'Everest' broccoli, 'Ozarka II' spinach, and 'Alltop' turnip greens. Commercial insect, weed and disease control methods were followed according to Oklahoma Cooperative Extension Service recommendations. Sprinkler irrigation was used as needed to prevent drought stress. Fallow areas were tilled at a shallow depth (5 to 7.5 cm) as needed to control weeds.

After harvests, plots were disked and worked with a field cultivator to a depth of 12 to 15 cm.

Broccoli—The broccoli was direct seeded on 17 Aug. 1995.

Before planting, the fertilizer materials, trifluralin at $0.18 \text{ liters}\cdot\text{ha}^{-1}$ for weed control, and diazinon at $1.45 \text{ liters}\cdot\text{ha}^{-1}$ for soil insect control were incorporated. The control plots contained an average of $33 \text{ kg}\cdot\text{ha}^{-1}$ residual N. Preplant urea and 1X litter were applied at rates to supply $67 \text{ kg}\cdot\text{ha}^{-1}$ N, while 2X litter was applied at a rate to supply $134 \text{ kg}\cdot\text{ha}^{-1}$ N. Spacing was 10 cm between seeds, in four rows 0.9 m apart, per plot.

The broccoli received topdressings of $50 \text{ kg}\cdot\text{ha}^{-1}$ N from urea on 22 Sept. and 6 Oct. Seedlings were thinned on 7 Sept. to one plant every 20 cm. Representative samples of petioles were taken from four plants per plot on 13 Oct. to determine N concentration in the plants. Marketable heads of broccoli were hand-harvested on four dates: 23, 27, and 30 Oct. and 2 Nov. The few non-marketable heads were not harvested. About 30 plants were harvested from the middle two rows of each plot, for a total sampling area of 5.4 m^2 per plot. Stalks were trimmed to 20.5 cm from the top of the dome before the heads were weighed.

Spinach—The spinach was seeded 24 Sept. 1996, and re-seeded 8 Oct. due to a stand failure. The control plots contained an average of $50 \text{ kg} \cdot \text{ha}^{-1}$ residual N. Preplant applications of urea and 1X litter supplied $35 \text{ kg} \cdot \text{ha}^{-1}$ N, while 2X litter supplied $70 \text{ kg} \cdot \text{ha}^{-1}$ N. During the first planting, metolachlor was applied at a rate of $0.2 \text{ liter} \cdot \text{ha}^{-1}$ for weed control and incorporated at the same time as the fertilizer treatments. On 7 Oct., one day before the second spinach planting, cycloate herbicide at $3.36 \text{ kg} \cdot \text{ha}^{-1}$ was tilled in. Each plot contained three 4-row beds. Seeds were sown 2.5 cm apart in rows 0.6 m apart. The spinach was too small for a fall harvest, and was overwintered. A topdressing of ammonium nitrate to supply $36.7 \text{ kg} \cdot \text{ha}^{-1}$ N, and ammonium sulfate to supply $18.3 \text{ kg} \cdot \text{ha}^{-1}$ N was applied 10 Feb. 1997.

The spinach was harvested on 15 Apr. Plants were harvested from a 3-m section of the center bed in each plot, for a total harvested area per plot of 5.4 m^2 . The plants were cut by hand at soil level, counted, and weighed. Representative subsamples were gathered for drying and foliar analysis.

Turnip Greens—The turnip greens were planted 30 Sept. 1997 at an in-row spacing of about 50 seeds per meter, in rows 0.6 m apart. Plots contained three 4-row beds. The control plots contained an average of $37 \text{ kg} \cdot \text{ha}^{-1}$ residual N. Urea and the 1X litter were

applied preplant at rates to supply $48 \text{ kg} \cdot \text{ha}^{-1} \text{ N}$, while 2X litter was applied at a rate to supply $96 \text{ kg} \cdot \text{ha}^{-1} \text{ N}$. Trifluralin herbicide was applied at about $0.28 \text{ kg} \cdot \text{ha}^{-1}$ on 29 Sept. A topdressing of urea to provide $55 \text{ kg} \cdot \text{ha}^{-1} \text{ N}$ was applied 23 Oct. The crop was harvested 7 Nov. following the same procedures as with the spinach crop, except that plants were cut by hand at about 1.5 cm above soil level. Plants were counted and fresh mass were taken in the field. Subsamples were collected for subsequent dry mass determinations and elemental analyses.

Cowpea Rotations: 'Mississippi Pinkeye' cowpeas were grown on half of the plots, with the other plots fallowed, in summer 1996 and summer 1997. The seeds were treated with a slurry of 19 g of cowpea-type *Rhizobium* inoculant in 36 ml water per 4.6 kg of seed. No fertilizers were applied to the cowpea crops. Each plot contained six rows, 0.9 m apart, of cowpeas. Seeds were planted at 5 cm apart within rows and seedlings later were thinned to 10 cm apart. The 1996 crop was planted on 31 May, following incorporation of metolachlor herbicide at a rate of $0.18 \text{ liters} \cdot \text{ha}^{-1}$. The cowpeas were thinned on 3 July. The crop was harvested on 2 Aug. The 1997 crop was planted 29 May but due to a poor stand was replanted on 20

June. Two herbicides were applied to the soil on 1 June—metolachlor at 0.18 liters·ha⁻¹ and glyphosate at 3.5 kg·ha⁻¹. Harvest was 28 Aug.

In both years, one data row was harvested in each plot by hand-cutting plants near the ground level. The data plants were depodded. Marketable pods were shelled, and green-shell seeds were weighed. Depodded plants were placed in burlap bags, dried, and weighed. Representative samples of the foliage were collected for elemental analysis. The remaining crop was harvested with a flail-vacuum machine and removed from the field in a simulated haying operation. *Tissue Analyses:* Foliar samples, collected as described above, were dried at 48C for ≥7 days and reweighed, then ground in a Wiley mill to pass through a no. 40 U.S. standard testing sieve (0.42 mm). The samples were analyzed by the Samuel Roberts Noble Foundation, Inc., Ardmore, Okla., or Ward Laboratory Inc., Kearney, Neb. With the exception of the broccoli, for which only N concentration was determined, all crops were analyzed for concentrations of N (crude protein), P, K, Ca, Mg, Mn, Fe, and Zn.

Statistical Analyses: Data were evaluated with analysis of variance procedures. Cowpea data were analyzed by year for effects of fertilizer treatment. Vegetable crop data were analyzed by year for main effects of legume treatment (cowpeas versus fallow), fertilizer

treatment, and interactions. Soils data were analyzed across the five sampling times, so the soils data analysis included main effects of legume treatment, fertilizer treatment, and time, as well as interactions. If the main effect of fertilizer treatment was significant ($P \leq 0.05$), means were separated using the least significant difference (LSD) at $P \leq 0.05$. For the soils data, trend analysis was used to partition main effects of time into linear and quadratic components. Significant interactions were partitioned using the MIXED procedure of SAS (SAS, 1982), with means separated by least squares at $P \leq 0.05$.

RESULTS AND DISCUSSION

Cowpea Crops: The fertilizer treatments did not affect foliar concentrations of N, P, K, Ca, Mg, Mn, Fe or Zn in cowpeas in either year. Data on foliar elemental concentrations, and seed and shoot yields, are provided (Tables 2.4-2.5). Yields differed between 1996 and 1997 crops. The smaller seed yield in 1996 was probably a result of an early harvest date, before the plants had reached maximum yield. The 1997 crop had less foliage fresh mass than in 1996, probably because of the late replanting date, but was harvested when green shell seed yield appeared to be optimal.

Vegetable Crops: Vegetables were less succulent when grown on 1X litter plots than on control or 2X litter plots, with lower fresh mass and less foliar N (Tables 2.6-2.9). Broccoli and turnip greens responded similarly to urea and 2X litter fertilizers, whereas with the spinach, yields were similar in the urea and 1X litter treatments. With one exception, cover cropping had no significant effects on subsequent vegetable crops.

The 1X litter rate may not have supplied enough available N to the vegetable crops. Only 30% to 80% of N from manure or litter is available the year of application (Brady, 1990; Zhang et al., 1998). The remaining N, initially immobilized in an organic form, becomes available in subsequent years (Zhang, et al., 1998).

Broccoli—The 1X litter rate was not adequate for maximum production of marketable broccoli. Plants grown with the 1X rate had less foliar N and smaller marketable heads than plants grown with the other two fertilizer treatments (Table 2.6). Total marketable head mass was lower in the 1X litter plots than in the urea plots, while total marketable yield of the 2X litter plants was not significantly different than either of the other treatments. In contrast to our findings, Earhart (1995) did not report yield reductions in broccoli

fertilized by the 1X rate of litter. Other studies on litter as a fertilizer for broccoli (Brown et al., 1994; Maynard, 1994) used extremely high application rates compared to our 1X and 2X rates.

The broccoli was the only vegetable crop of the study not preceded by a cover crop treatment. A test of legume effects to determine if there were random effects of position in the field was statistically insignificant.

Spinach—The spinach harvest was 10 days behind schedule due to persistent rains, so the plants were overmature and starting to bolt. Spinach plants receiving the 2X litter rate were more succulent than plants in the 1X litter plots, with higher N and less dry matter (Table 2.7). Neither litter treatment differed from urea in dry matter and N concentration.

Spinach stands were reduced in plots receiving the 2X litter rate (Table 2.7). However, individual plants compensated for the decreased population by growing larger. As a result, total yields on a fresh mass per hectare basis were the same for all treatments. Stand differences could have been caused by the litter treatment. Alternatively, stand differences could have been caused by residual effects of a pre-emergence herbicide, although stands did not differ in the 1X litter and control plots that also were treated with the pre-

emergence herbicide. Our first spinach crop failed after three inches of rain fell the night the seeds were planted, compacting the soil surface so much that seedlings could not break through. Before replanting, the field was disked in an attempt to move the preplant herbicide below the soil surface. The effort may not have been entirely successful. A stand count two weeks after replanting showed substantial variability, with fewer seedlings in the 2X litter plots. Since the replanted spinach was too immature to harvest until the following spring, rows were not thinned to decrease the variability because we expected winterkill to affect stand count.

The main effect of cover crop treatment was not significant for any measured variable involving spinach plants. However, a legume by fertilizer treatment interaction was evident for shoot Ca levels. Fertilizer treatments did not affect shoot Ca levels for spinach plants which followed cowpeas. For spinach following fallow, plants from 1X and 2X litter plots were similar in shoot Ca levels, but plants grown with 2X litter were higher in Ca than plants grown with urea (Table 2.8).

We found no literature on poultry litter as a fertilizer for spinach. Researchers have reported adverse impacts of high rates of litter application on other crops, possibly due to toxic concentrations

of ammonia, nitrite, nitrate and soluble salts (Edwards and Daniel, 1992), but the researchers used litter at rates substantially higher than the application rates we used in this study.

Turnip Greens—Turnip greens grown in the 1X litter plots had lower yields on a fresh mass per hectare basis and a higher percentage of dry mass than plants grown under the other two fertilizer treatments. The fresh mass differences were not statistically significant among individual plants (Table 2.9). Leaf dry mass responses were similar between plants fertilized with urea and those receiving the 2X litter rate, although elemental concentrations sometimes differed.

A legume by fertilizer treatment interaction was evident for turnip shoot N levels. N levels were affected by the cover crop treatment, but only in plants fertilized at the 1X litter rate. In the 1X plots, turnip greens following cowpeas had more N (6% on avg) than plants following fallow (5.5% on avg).

Fertilizer treatments did not affect concentrations of P, Mn, Fe, or Zn in turnip leaves (Table 2.9). There were some significant effects of the fertilizer treatments on K, Ca and Mg. The K leaf concentration was smaller, and the Ca concentration was higher, in urea-fertilized plants than in litter-fertilized plants. The Mg level

was smaller in 1X litter plants than urea-fertilized plants, but the Mg level in 2X litter plants was not significantly different than levels in the other two treatments. The concentration of Fe was the only measured variable for which the main effect of a cover crop treatment was significant: 502 ppm following fallow compared to 401 ppm following cowpeas.

Soils:

In general, cover crop and fertilizer treatments had few main effects on soil nutrient levels (Table 2.10). Many interactions were observed among time, cover crops and fertilizer rates (Table 2.11).

Phosphorus—There was a slight but significant buildup in P at the 0-15 cm depth [P(0-15cm)] in the soils treated with the 2X litter rate, with an average value of $282 \text{ kg}\cdot\text{ha}^{-1}$, compared to 252 and 258 $\text{kg}\cdot\text{ha}^{-1}$ for urea and 1X litter plots, respectively (Tables 2.12-2.13). There were no significant differences due to fertilizer treatments in P at the 15-30 cm depth [P(15-30cm)].

Cowpea cover crops were not effective at controlling soil P levels (Fig. 1-4). P values were similar in both cowpea and fallowed plots, at both depths, regardless of fertilizer treatment. We believe soil sampling and analysis procedures were not precise enough to detect

differences that may have existed in soil P levels. Also, the cowpea crops apparently did not contain enough P to have a major impact on soil test P values (Table 2.14).

Since our study was on the site of a previous study using poultry litter as a fertilizer, P levels were already high in the soil. Baseline P levels ($\text{kg}\cdot\text{ha}^{-1}$) averaged 281 in urea plots, 264 in 1X litter plots, and 297 in 2X litter plots. Soil test P levels above 130 are considered excessive in Oklahoma (Johnson et al., 1998). When the P levels in a soil sample are excessive, soil testing labs sometimes do not determine precise amounts (G.V. Johnson, personal communication). The soil testing lab was not informed that the soil samples were for a research project. Therefore, values of soil P may not be as precise as some other data.

Cowpeas, just like any other crop, absorb nutrients while actively growing. When significant crop biomass is harvested and removed from the field, as in the case of the cowpeas, P levels in the soil should have dropped slightly. The three vegetable crops and two cowpea crops absorbed an estimated $70 \text{ kg}\cdot\text{ha}^{-1}$ and $75 \text{ kg}\cdot\text{ha}^{-1}$ P in 1X litter and 2X litter plots, respectively (Table 2.14). Yet the amount of P applied with the litter was 59 in 1X litter plots and $118 \text{ kg}\cdot\text{ha}^{-1}$ in 2X litter plots (Table 2.3). Based on application rates and crop removal

estimates, the soil P levels should have dropped by $11 \text{ kg}\cdot\text{ha}^{-1}$ in 1X plots and should have increased by $43 \text{ kg}\cdot\text{ha}^{-1}$ in 2X plots.

Long-term fertility studies on soil-P depletion and enrichment in Oklahoma show that crop removal of about $7 \text{ kg}\cdot\text{ha}^{-1}$ P would lower the soil test P by a value of 1.0 (Johnson et al., 1998). However, according to soil test results, P(0-15cm) values were substantially higher following the 1997 cowpea harvest (Time 5) than before this cowpea crop was planted (Time 4) (Fig. 1).

The P levels in our litter-fertilized soils may have increased some due to mineralization of organic P supplied from previous applications. Sources (Brady, 1990; Zhang et al., 1998) disagree on the amount of P readily available in the season of application, ranging from 20% for manure (Brady, 1990) to 90% for litter (Zhang et al., 1998). However, this does not explain why P(0-15cm) values in the fallowed plots fertilized by urea, where no P was applied for nearly three years, were higher at the end of the study than at the beginning (Fig. 2).

The soil test P values may also have been affected by natural variability in the field, even within plots. New soil sampling recommendations call for 15 to 20 core samples to overcome field variability (Taylor et al., 1997). We took five core samples per plot.

There was a main effect of time, with a quadratic response, on P values at both depths (Fig. 5). P values declined steadily for almost two years, but increased substantially at Time 5, almost returning to the baseline levels.

With P(15-30cm), simple effects of the cover crop occurred twice. Soils following cowpeas averaged $221 \text{ kg} \cdot \text{ha}^{-1}$ P compared to $202 \text{ kg} \cdot \text{ha}^{-1}$ for fallow soils at Time 3; and $195 \text{ kg} \cdot \text{ha}^{-1}$ for cowpeas compared to $178 \text{ kg} \cdot \text{ha}^{-1}$ for fallow at Time 4. The fourth sampling took place in May 1997, following spinach but before cowpeas were planted.

Nitrogen—Fig. 6 shows the levels of soil N over time. There were several interactions (Table 2.11). The interactions at the 0-15 cm depth [N(0-15cm)] resulted primarily from differences found at Time 3 (September 1996, after cowpea harvest and before spinach planting) but not at the other four sampling times. At Time 3, samples from plots following cowpeas showed no effect of fertilizer treatments on N(0-15cm). Samples from plots following fallow showed higher N(0-15cm) levels where litter had been applied than where urea was used (Table 2.15). There also were simple effects of legume treatment at Time 3, in that for each given fertilizer treatment, N(0-15cm) values from plots following cowpeas were lower than those

from plots following fallow (Table 2.15). One other simple effect of legume treatment on N(0-15cm) occurred at Time 5 (September 1997, after cowpea harvest and before turnip greens), but only with the 1X litter treatment; N(0-15cm) values were lower following cowpeas ($24 \text{ kg} \cdot \text{ha}^{-1}$) than following fallow ($49 \text{ kg} \cdot \text{ha}^{-1}$).

Simple effects of legume treatment also occurred at Time 3 and Time 5 for soil N at the 15-30 cm depth [N(15-30cm)] (Table 2.16). At both times, N(15-30cm) values from plots following cowpeas were lower than those from plots following fallow. These responses generally paralleled those observed for N(0-15cm).

Potassium—Treatment effects were inconsistent for K(0-15cm) (levels of K at the 0-15 cm depth) throughout the study. For K(15-30), (levels of K at the 15-30 cm depth) however, there was a main effect of time (Fig. 7), similar to the quadratic response seen with P. Since K levels were high when the study began, soil test K values may not have been precise, because of lab analysis procedures and because of varying K levels in the field.

There was a three-way interaction between cover crop, fertilizer and time for K(0-15cm). Simple effects of the cover crop and fertilizer treatments were found only at Time 2 and Time 3, and effects of either factor were not always consistent given the other factor. At

Time 2, on the fallow soils, K(0-15cm) values were similar in the litter-fertilized plots (412 kg·ha⁻¹ in 1X litter and 405 kg·ha⁻¹ in 2X litter) but both had more K(0-15cm) than the urea plots (343 kg·ha⁻¹).

There was a simple effect of the cover crop treatment at Time 2, but only in urea plots. The urea plots following cowpeas had more K(0-15cm) (437 kg·ha⁻¹) than plots following fallow (343 kg·ha⁻¹).

Simple effects of cover crop and fertilizer treatments occurred at Time 3, when K(0-15cm) values were higher in plots following cowpeas (445 kg·ha⁻¹) than following fallow (383 kg·ha⁻¹). Litter plots did not differ in K(0-15cm) values (409 and 446 kg·ha⁻¹ for 1X and 2X litter treatments, respectively), but 2X litter plots had more K(0-15cm) than urea plots (388 kg·ha⁻¹).

Secondary and Micronutrients—Fertilizer and cover crop treatments had no detectable effects on levels of these elements in the soil, except possibly for changes over time with Zn at both soil depths and B at the 15-30 depth [B(15-30cm)] (Table 2.11). Changes over time may have been treatment-related, or may have simply reflected lab variation.

B(15-30cm) was affected by a three-way interaction. A simple effect of fertilizer treatment was found at Time 3, and simple effects of cover crop and fertilizer were found at Time 5. Effects of either

factor (cover crop or fertilizer) were not always consistent given the other factor.

For B(15-30cm), simple effects of the fertilizer treatment occurred in cowpea plots at Time 5, and in fallow plots at Time 3. Both of these occasions followed harvest of the cowpeas. At Time 5, B(15-30cm) values averaged 0.44 ppm in 2X litter plots, which was significantly higher than the 0.32 ppm in 1X litter plots. Neither value was significantly different than the 0.37 ppm of B(15-30cm) in urea-treated plots. At Time 3, the 2X litter plots contained more B(15-30cm) (0.45 ppm) than urea plots (0.32 ppm), while neither of those differed significantly from the B value in 1X litter plots (0.38 ppm).

A simple effect of the cover crop treatment affected B(15-30cm) values at Time 5, but only in the 2X litter plots. Here, B(15-30cm) was higher following cowpeas (0.44 ppm) than following fallow (0.32 ppm).

Overall, treatments appeared to have minimal effects on soil B levels.

For Zn(0-15cm), a cover crop X time interaction was significant. However, when the interaction was partitioned, means for cowpea plots and for fallow plots were not significantly different at any one given time (Table 2.17). The overall interaction probably resulted

from order of magnitude effects when comparing differences between cowpea and fallow means at each given time, and because the cowpea mean was not consistently numerically higher than the fallow mean (fallow was higher at Time 5).

Simple effects of fertilizer treatments on Zn(0-15cm) (the level of Zn in the soil at the 0-15 cm depth) occurred at Time 3 and at Time 5 (Table 2.18). No effect was seen at Time 1 because it was the baseline sampling (fertilizer treatments had not yet been applied). The 2X litter treatment resulted in the highest Zn(0-15cm) values at both Time 3 and Time 5. Values for Zn(0-15cm) were higher from 1X litter plots than from urea plots at Time 3, but not at Time 5.

For Zn(15-30cm) (the amount of Zn in the soil at the 15-30 cm depth), cover crop treatments affected values at Time 3 but not at the other sampling times. At Time 3, samples from plots following cowpeas showed higher Zn(15-30cm) values (1.85 ppm) than samples from plots following fallow (1.44 ppm).

pH—The average pH values at 0-15 cm were slightly but significantly higher with the litter treatments (6.27 in 1X litter plots and 6.30 in 2X litter plots) than with the urea (6.16), even though average pH values within treatments sometimes varied. Ammonium sulfate was applied to spinach plants in spring 1997 and could have

affected pH. Curiously, a drop in pH showed up not at Time 4, after the spinach, but at Time 5, after cowpeas.

Cover crop treatments affected pH at both soil sampling depths at Time 3 and Time 5 but not at the other sampling times (Table 2.19). At both times, and at both depths, samples from plots following cowpeas showed higher pH values than samples from plots following fallow.

CONCLUSIONS

We were able to successfully grow three cool-season vegetable crops with poultry litter as a fertilizer. However, the 1X litter rate may not be sufficient to meet crop N needs. Broccoli grown with 1X litter was smaller and had less N than plants grown with urea or 2X litter. Turnip greens in 1X plots had smaller yields and higher percent dry mass than when fertilized by urea or 2X litter. With spinach, although overall fresh mass yields were similar among all treatments, plants grown with 1X litter were less succulent and contained less shoot N than plants grown with 2X litter.

Except for a slight buildup in P(0-15cm) when litter was applied at twice the recommended rate, we found no consistent evidence of P or K accumulation in soils with the use of poultry litter to fertilize

vegetables. Overall, P and K values were about the same at the end of the study as when it began.

We were unable to show that a cowpea cover crop could remove more P from soils than leaving the ground fallow. However, improvements in soil sampling and lab analysis techniques could result in a different outcome. A longer-term study would also provide a better indication of a cowpea crop's ability to absorb P from the soil.

We used cowpeas as the cover crop in this study because they are a cash crop in Oklahoma. Other warm-season legumes, or even non-legume cover crops, may be able to absorb higher amounts of P.

When specific crops can be identified as efficient at removing excess soil P from litter applications, vegetable growers will be able to plant rotation systems that benefit themselves, poultry producers, and the environment. Poultry litter is a valuable source of nutrients for horticultural crops. The outcome of further research is important for the entire southern United States, in other poultry-producing areas of the world, and in outlying areas where it is economically feasible to transport litter for use in gardens and commercial production.

Literature Cited

- Brady, N.C. 1990. The nature and properties of soils. 10th ed. Macmillan, New York.
- Brown, J.E., J.M. Dangler, C.H. Gilliam, D.W. Porch, and R.L. Schumack. 1994. Comparison of broiler litter and inorganic nitrogen, phosphorus, and potassium for double-cropped sweet corn and broccoli. *J. Plant Nutr.* 17(5):859-867.
- Daniel, H.A. 1934. The calcium, phosphorus, and nitrogen content of grasses and legumes and the relation of these elements in the plant. *J. Amer. Soc. Agron.* 26(6):496-503.
- Earhart, D.R. 1995. Developing environmentally sound poultry litter management practices for sustainable cropping systems. *Sustainable Agr. Res. and Educ. & Agr. in Concert with the Environ.: Southern Region.* LS92-48.
- Edwards, D.R., and T.C. Daniel. 1992. Environmental impacts of on-farm poultry waste disposal: A review. *Bioresource Technol.* 41:9-33.
- Edwards, D.R., and T.C. Daniel. 1993. Waste management: Effects of poultry litter application rate and rainfall intensity on quality of runoff from fescuegrass plots. *J. Environ. Qual.* 22:361-365.
- Edwards, D.R., and T.C. Daniel. 1994. Quality of runoff from fescuegrass plots treated with poultry litter and inorganic fertilizer. *J. Environ. Qual.* 23:579-584.
- Edwards, D.R., P.A. Moore, Jr., T.C. Daniel, and P. Srivastava. 1996. Poultry litter-treated length effects on quality of runoff from fescue plots. *Trans-Amer. Soc. Of Agr. Eng.* 39(1):105-110.
- Giddens, J., and A.P. Barnett. 1980. Soil loss and microbiological quality of runoff from land treated with poultry litter. *J. Environ. Qual.* 9(3):518-520.

- Griffith, W.K. 1974. Satisfying the nutritional requirements of established legumes, p.147-167. In: D.A. Mays (ed). Forage fertilization. Amer. Soc. Agron., Crop Sci. Soc. of Amer., and Soil Sci. Soc. Of Amer., Madison, Wis.
- Guertal, E.A., B.K. Behe, and J.M. Kemble. 1997. Composted poultry litter as potting media does not affect transplant nitrogen content on final crop yield. HortTechnology 7(2):142-145.
- Hargrove, W.L. 1986. Winter legumes as a nitrogen source for no till grain sorghum. Agron. J. 78:70-74.
- Johnson, G.V., W.R. Raun, H. Zhang, and J.A. Hattey. 1997. Oklahoma soil fertility handbook. 4th ed. Okla. State Univ. Dept. of Agron.
- Johnson, G.V., N.T. Basta, H.A. Zhang, J.A. Hattey, W.R. Raun, and J.H. Stiegler. 1998. Science-based animal waste phosphorus management for Oklahoma. Okla. Coop. Ext. Serv. Production Technol. 98(1).
- Lal, R., E. Regnier, D.J. Eckert, W.M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture. In: Cover crops for clean water. Soil and Water Conservation Soc., Ankeny, Iowa.
- Lorenz, O.A., and D.N. Maynard. 1988. Knott's handbook for vegetable growers. 3rd ed. Wiley & Sons, New York.
- Lu, N.P., and J.H. Edwards. 1994. Poultry litter quantity influences collard growth in pots and affects cabbage growth and nutrient uptake. HortScience. 29(10):1143-1148.
- Maynard, A.A. 1994. Sustained vegetable production for three years using composted animal manures. Compost Sci. & Utilization. 2(1):88-96.
- National Agricultural Statistics Service. 1998. Poultry production and value. Bul. Pou 3-1(98), US Dept. of Agr., Washington, DC.
- Nichols, D.J., T.C. Daniel, and D.R. Edwards. 1994. Nutrient runoff from pasture after incorporation of poultry litter or inorganic fertilizer. Soil Sci. Soc. Am. J. 58:1224-1228.

- Robinson, J.S., and A.N. Sharpley. 1996. Reaction in soil of phosphorus released from poultry litter. *Soil Sci. Soc. Am. J.* 60:1583-1588.
- SAS Institute Inc. 1982. SAS user's guide: statistics. 1982 ed. Cary, NC: SAS Institute Inc.
- Sharpley, A.N., S.J. Smith, and W.R. Bain. 1993. Division S-8: Fertilizer management & technology: Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoma soils. *Soil Sci. Soc. Am. J.* 57:1131-1137.
- Smyth, T.J., and M.S. Cravo. 1990. Critical phosphorus levels for corn and cowpea in a Brazilian Amazon oxisol. *Agron. J* 82:309-312.
- Taylor, S.L., G.V. Johnson, and W.R. Raun. 1997. A field exercise to acquaint students with soil testing as a measure of soil fertility status and field variability. *J. Natural Resour Life Sci. Educ.* 26:132-135.
- Ware, L.M., and W.A. Johnson. 1968. Poultry manure for vegetable crops: Effects and value. *Auburn Agr. Expt. Sta. Res. Bul.* 386.
- Wilson, G.F., R. Lal, and B.N. Okigbo. 1982. Effects of cover crops on soil structure and on yield of subsequent arable crops grown under strip tillage on an eroded alfisol. *Soil Tillage Research.* 2:233-250.
- Zhang, H., M. Kress, and G. Johnson. 1983. OSU soil, water and forage analytical laboratory standard procedures. *Okla. Coop. Ext. Serv. Facts* 2901.
- Zhang, H., and D.W. Hamilton. 1996. Use [sic] animal manure as a plant nutrient source. *Okla. Coop. Ext. Serv. Production Technol.* PT 96-25.
- Zhang, H., D.W. Hamilton, and J.G. Britton. 1998. Using poultry litter as fertilizer. *Okla. Coop. Ext. Serv. Facts* F-2246.

Table 2.1. Total elemental composition of poultry litter applied to each vegetable crop.

Experiment	N (%)	P (%)	K (%)	Ca (%)	pH	Ec (μ mhos)	H ₂ O (%)
Fall 1995	3.74	1.23	2.06	2.48	7.3	11070	20.2
Fall 1996	3.62	1.31	2.71	1.89	7.1	12330	18.4
Fall 1997	2.66	1.34	1.84	2.55	6.9	12000	27.5

(Values are reported on an "as-is" basis, since litter was applied "as-is").

Table 2.2. Amount of poultry litter applied during production of three cool-season vegetable crops. 1X refers to poultry litter at the rate recommended by soil tests to supply preplant N to a vegetable crop. 2X is litter at twice the recommended rate.

Tmt	1995 Broccoli	1996 Spinach	1997 Turnip Greens	Total
	-----kg/ha-----			
1X Litter	1796	959	1811	4566
2X Litter	3593	1917	3622	9132

Amounts reported on an "as-is" basis. Control plots did not receive poultry litter applications.

Table 2.3. Amount of N, P, and K applied with pre-plant fertilizer treatments and topdressings during production of three cool-season vegetable crops.

Tmt	Broccoli 1995			Spinach 1996			Turnip Greens 1997			Total		
	N	P	K	N	P	K	N	P	K	N	P	K
	-----kg/ha-----											
Urea	167	--	--	90	--	--	103	--	--	360	--	--
1X Litter	167	22	37	90	13	26	103	24	33	360	59	96
2X Litter	234	44	74	125	25	52	151	49	67	510	118	193

Amounts reported on an "as-is" basis. N values include topdressings of urea made to vegetable crops at the appropriate time during their growing season. The broccoli received two topdressings totaling 100 kg/ha N from urea. The spinach and turnip greens each received topdressings of 55 kg/ha N from urea. Plots fertilized by urea did not receive supplemental P or K.

Table 2.4. Foliar elemental concentrations in two cowpea cover crops.

	-----1996-----			-----1997-----		
	Urea	1X Litter	2X Litter	Urea	1X Litter	2X Litter
N	3.2	2.8	3.4	2.2	2.0	2.0
P	0.45	0.45	0.49	0.45	0.41	0.44
K	2.1	2.2	2.4	1.6	1.7	1.9
Ca	2.1	2.3	2.2	2.6	2.3	2.4
Mg	0.67	0.63	0.63	0.66	0.55	0.57
Mn	74	83	86	84	70	72
Fe	158	169	201	218	169	164
Zn	29	32	33	17	21	22

Values for N, P, K, Ca, and Mg reported in %; Mn, Fe, and Zn in ppm. All values represent averages of four replications. There were no significant differences among fertilizer treatments for any of the variables tested in either year ($P \leq 0.05$).

Table 2.5. Yields of two cowpea cover crops.

	-----1996-----			-----1997-----		
	Urea	1X Litter	2X Litter	Urea	1X Litter	2X Litter
	-----kg/ha-----					
Seed Yield	1045	1267	956	2468	2258	2537
Shoot Mass	4176	3761	4188	2756	2828	2676

There were no significant differences among fertilizer treatments for seed yield or shoot mass in either year ($P \leq 0.05$).

Table 2.6. Response of 'Everest' broccoli to fertilizer treatments.

Variable	Urea	1X Litter	2X Litter	Statistical Significance ^z
Marketable heads (1000/ha)	49	46	45	NS
Marketable heads (Mg/ha)	12.5a	10.4b	11.2ab	*
Avg fresh mass/mktble head (g)	257a	223b	248a	*
Avg days to 1 st harvest	68	70	70	NS
N concn in petioles (%)	4.6a	3.4b	4.1a	**

^z Significance ($P \leq 0.05$) for the main effect of fertilizer treatment. When significance is indicated, mean separation in rows is by LSD, 5% level.

NS, *, ** Nonsignificant or significant at $P = 0.05$, or 0.01 , respectively.

Table 2.7. Response of 'Ozarka II' spinach to fertilizer treatments.

Variable	Urea	1X Litter	2X Litter	Statistical Significance ^z
Stand at harvest (1000/ha)	348a	349a	283b	*
Fresh mass (Mg/ha)	26.7	27.4	28.9	NS
Avg fresh mass (g/plant)	83b	85b	110a	**
% dry mass	13.4ab	14.0a	12.5b	*
Shoot % N	4.55ab	4.17b	4.74a	*
Shoot % P	0.81	0.80	0.86	NS
Shoot % K	4.42	4.55	4.68	NS
Shoot % Ca	2.10	2.16	2.41	Interaction*
Shoot % Mg	1.20	1.21	1.26	NS
Mn (ppm)	98	106	106	NS
Fe (ppm)	858	826	675	NS
Zn (ppm)	66	71	69	NS

^z Significance ($P \leq 0.05$) for the main effect of fertilizer treatment.

When significance is indicated, mean separation in rows is by LSD, 5% level.

NS, *, ** Nonsignificant or significant at $P = 0.05$, or 0.01 , respectively.

Table 2.8. Effects of a legume by fertilizer treatment interaction on shoot Ca levels in spinach.

Cover Crop Tmt	Urea	1X Litter	2X Litter
Cowpeas	2.11abc	1.78c	2.18abc
Fallow	2.09bc	2.55ab	2.64a

Means followed by the same letter do not differ according to the interaction LSD at $P \leq 0.05$. Value for the interaction LSD = 0.54.

Table 2.9. Effects of fertilizer treatments on turnip greens.

Variable	Urea	1X Litter	2X Litter	Statistical Significance ^z
Stand at harvest (1000/ha)	804	707	705	NS
Fresh mass (Mg/ha)	15.9a	12.5b	15.45a	**
Avg fresh mass (g/plant)	20	18	22	NS
% dry wt	8.1b	8.6a	7.9b	*
Shoot % N	6.3	5.8	5.9	Interaction *
Shoot % P	0.53	0.52	0.55	NS
Shoot % K	4.5b	5.1a	5.4a	**
Shoot % Ca	3.0a	2.6b	2.6b	*
Shoot % Mg	0.45a	0.40b	0.42ab	*
Mn (ppm)	55	58	56	NS
Fe (ppm)	421	466	468	NS
Zn (ppm)	31	30	31	NS

^z Significance ($P \leq 0.05$) for the main effect of fertilizer treatment.

When significance is indicated, mean separation in rows is by LSD, 5% level.

NS, *, ** Nonsignificant or significant at $P = 0.05$, or 0.01 , respectively.

Table 2.10. Mean values of soil nutrients. Means are an average of five soil sampling events.

	N	P	K	Ca	Mg	Fe	B	Zn
	-----kg/ha-----					-----ppm-----		
Tmt	-----0-15 cm depth-----							
Urea								
Cowpea	39	260	412	2809	427	46	0.42	1.77
Fallow	46	245	368	2747	424	46	0.35	1.73
1X Litter								
Cowpea	31	255	391	2724	417	43	0.37	1.80
Fallow	49	260	392	2798	435	46	0.39	1.79
2X Litter								
Cowpea	35	283	416	2744	423	44	0.38	2.00
Fallow	53	281	423	2772	424	43	0.38	1.96
-----15-30 cm depth-----								
Urea								
Cowpea	28	229	303	2876	428	48	0.34	1.43
Fallow	42	210	290	2787	423	46	0.31	1.25
1X Litter								
Cowpea	22	225	296	2790	410	46	0.33	1.41
Fallow	42	224	300	2947	444	47	0.34	1.29
2X Litter								
Cowpea	25	229	303	2774	418	49	0.37	1.50
Fallow	44	221	303	2785	418	46	0.36	1.40

Table 2.11. Summary of main effects and interactions affecting soil nutrient values.

Variable	Cover Crop	Fertilizer	Fertilizer by Cover Crop	Time	Time by Cover Crop	Time by Fertilizer	Time by Cover Crop by Fertilizer
N(0-15cm)			*	**	**	*	
N(15-30cm)				**	**		
P(0-15cm)		*		**			
P(15-30cm)				**			
K(0-15cm)				**	**	*	*
K(15-30cm)				**			
Ca(0-15cm)				**			
Ca(15-30cm)				**			
Mg(0-15cm)							
Mg(15-30cm)				**			
Fe(0-15cm)				**			
Fe(15-30cm)				**			
B(0-15cm)				**			
B(15-30cm)				**			*
Zn(0-15cm)		*		**	**	*	
Zn(15-30cm)	**			**	**		

*, **Significant at $P = 0.05$, or 0.01 , respectively.

Table 2.12. Change over time in soil P values, at 0-15 cm, in plots where cowpea cover crops were grown.

Fertilizer Tmt	Soil Test 1	Soil Test 2	Soil Test 3	Soil Test 4	Soil Test 5
	-----kg/ha-----				
Urea	281	284	240	230	262
1X Litter	264	275	248	227	261
2X Litter	297	297	272	258	291

Table 2.13. Change over time in soil P values, at 0-15 cm depth, in fallowed plots.

Fertilizer Tmt	Soil Test 1	Soil Test 2	Soil Test 3	Soil Test 4	Soil Test 5
	-----kg/ha-----				
Urea	253	257	233	216	265
1X Litter	269	266	248	239	279
2X Litter	286	299	257	263	298

Table 2.14. Estimated amount of P removed by three cool-season vegetable crops and two cowpea cover crops.

Fertilizer Tmt	Broccoli 1995	Cowpeas 1996	Spinach 1996	Cowpeas 1997	Turnip Greens 1997	Total
	-----kg/ha-----					
Urea	2.24*	18.79	31.35	12.40	6.90	71.68
1X Litter	2.24*	16.92	33.22	11.59	5.69	69.66
2X Litter	2.24*	20.52	33.46	11.77	6.74	74.73

*Unable to calculate from our yield data; estimated from Lorenz and Maynard, 1988. The estimate for broccoli is for heads only, since that is the portion of the crop harvested in our study.

Table 2.15. Effect on N values, at 0-15 cm depth, of a legume X litter interaction at Time 3 (September 1996) soil sampling.

Cover Crop Tmt	Urea	1X Litter	2X Litter
	-----kg/ha-----		
Cowpeas	40a	42a	54a
Fallow	63b	81a	92a

Mean separation within cover crop treatments by least squares, $P \leq 0.05$.

Table 2.16. Simple effects of cover crop treatments on the amount of N at 15-30 cm depth, at September 1996 and September 1997 soil samplings.

Soil Sampling Event	Cowpeas	Fallow
	-----kg/ha-----	
Time 3 (Sep 1996)	35	58
Time 5 (Sep 1997)	8	72

Within times, cover crop means differ at $P \leq 0.05$.

Table 2.17. Effects of a cover crop X time interaction on levels of soil Zn at the 0-15 cm depth at July 1995, September 1996 and September 1997 soil samplings.

Soil Sampling Event	Cowpeas	Fallow
	-----ppm-----	
Time 1 (July 1995)	1.54	1.50
Time 3 (Sep 1996)	2.32	2.18
Time 5 (Sep 1997)	1.70	1.79

Although the overall cover crop X time interaction was significant ($P \leq 0.01$), means for cowpea plots and for fallow plots were not significantly different ($P \leq 0.05$) at any given time.

Table 2.18. Effects of fertilizer treatments on levels of soil Zn at the 0-15 cm depth at September 1996 and September 1997 soil samplings.

Soil Sampling Event	Urea	1X Litter	2X Litter
	-----ppm-----		
Time 3 (Sep 1996)	2.08c	2.25b	2.44a
Time 5 (Sep 1997)	1.68b	1.68b	1.87a

Within times, mean separation is by least squares ($P \leq 0.05$).

Table 2.19. Effects of cover crop treatments on soil pH at two soil testing depths, at September 1996 and September 1997 soil samplings.

Soil Sampling Event	-----pH (0-15 cm)-----		-----pH (15-30 cm)-----	
	Cowpeas	Fallow	Cowpeas	Fallow
Time 3 (Sep 1996)	6.39	6.23	6.16	6.04
Time 5 (Sep 1997)	6.09	5.95	5.88	5.74

Within times and within soil testing depths, cover crop means differ at $P \leq 0.05$.

Figure 2.1. Soil P levels at 0-15 cm, in plots where cowpea cover crops were grown.

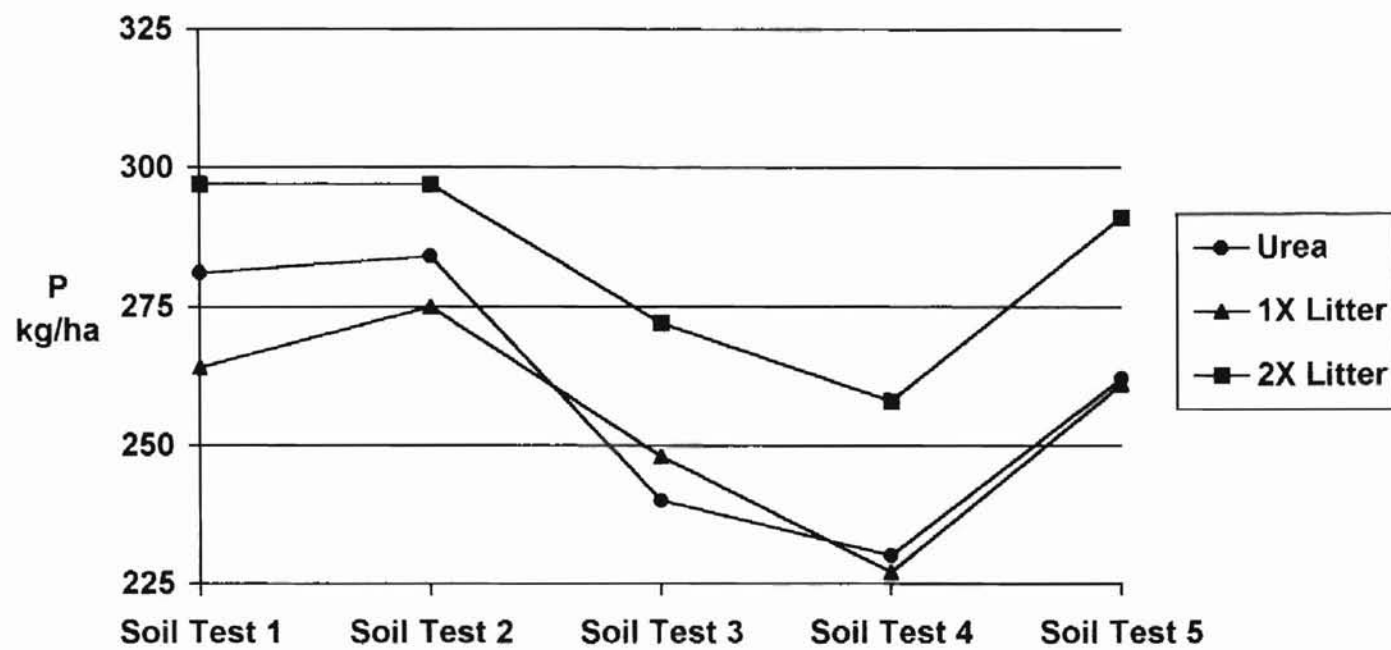


Figure 2.2. Soil P levels at 0-15 cm, in fallowed plots.

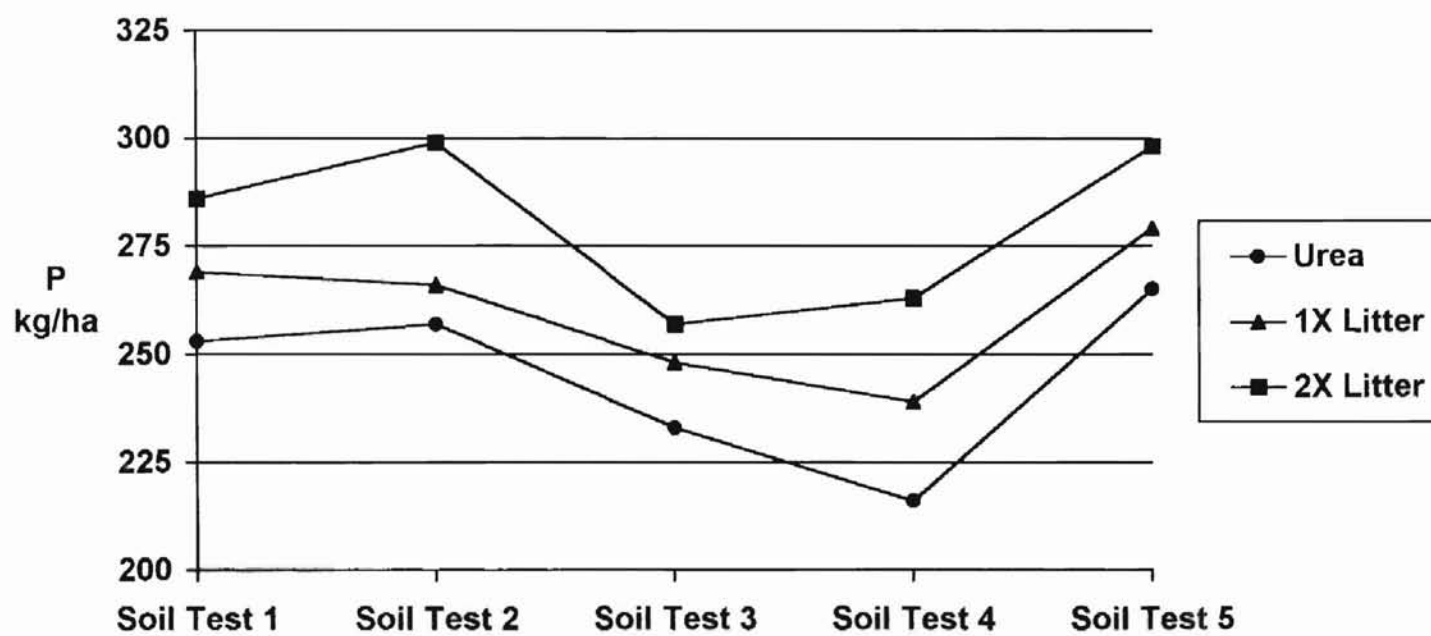


Figure 2.3. Soil P levels at 15-30 cm, in plots where cowpea cover crops were grown.

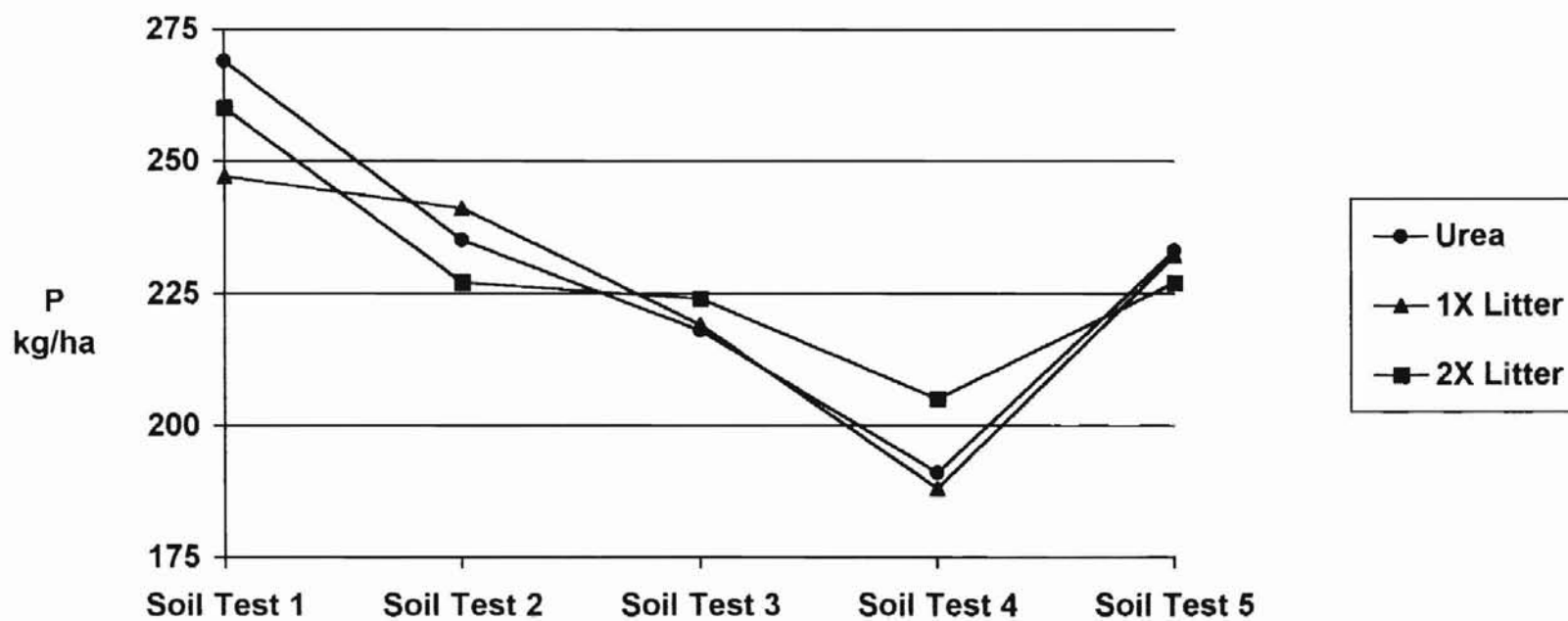


Figure 2.4. Soil P levels at 15-30 cm, in fallowed plots.

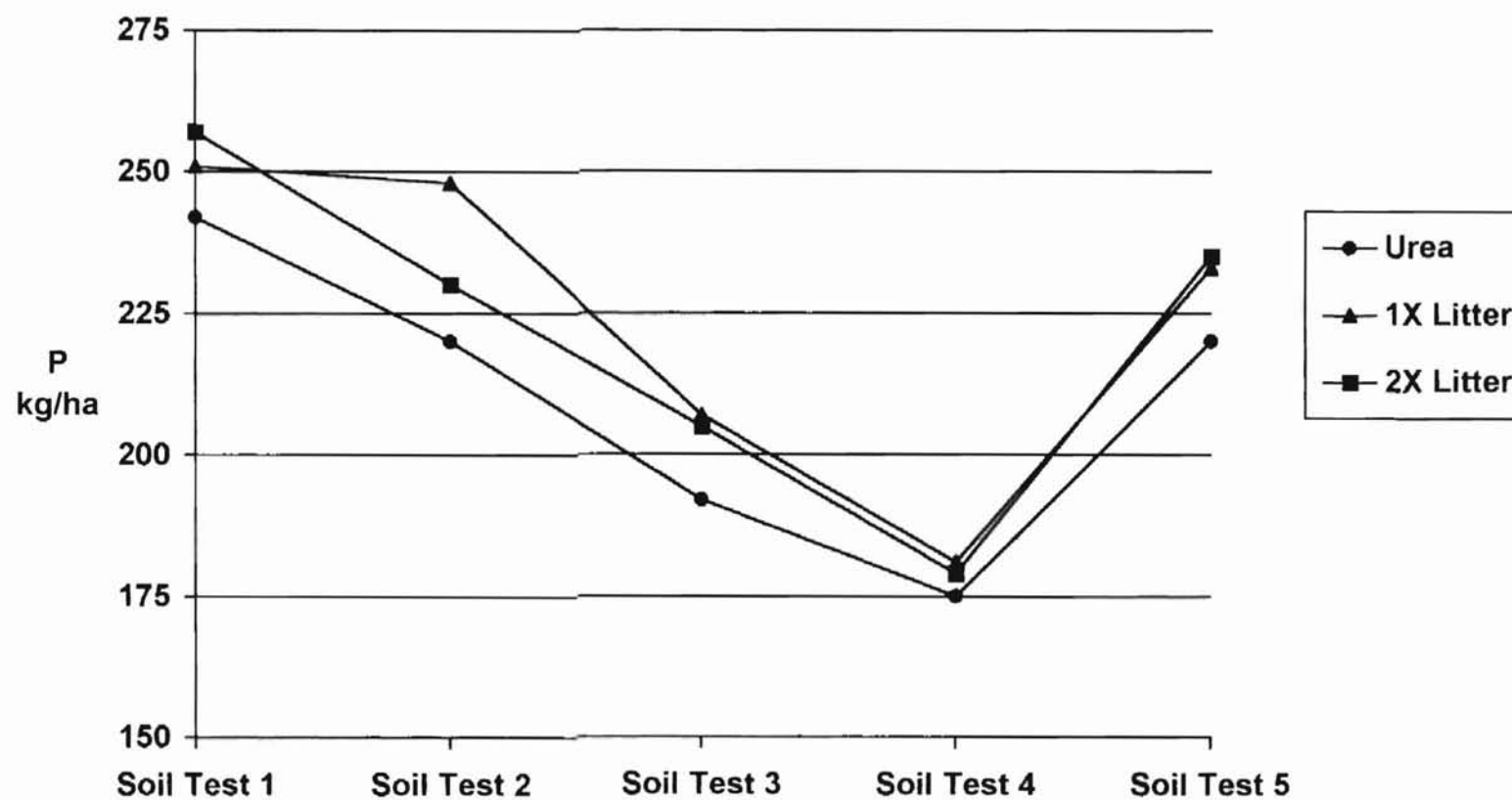


Figure 2.5. Change in P values over time, averaged over all treatments.

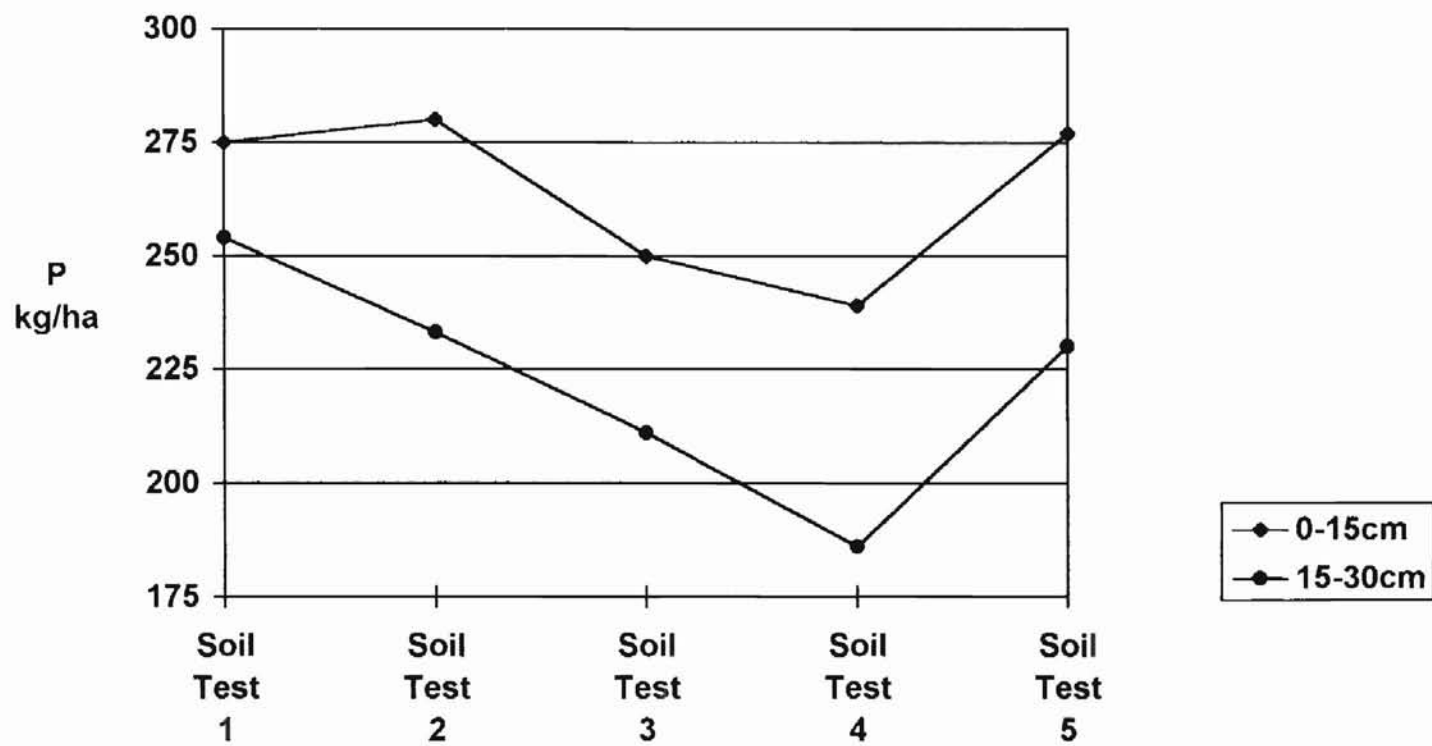


Figure 2.6. Change in N values over time, averaged over all treatments.

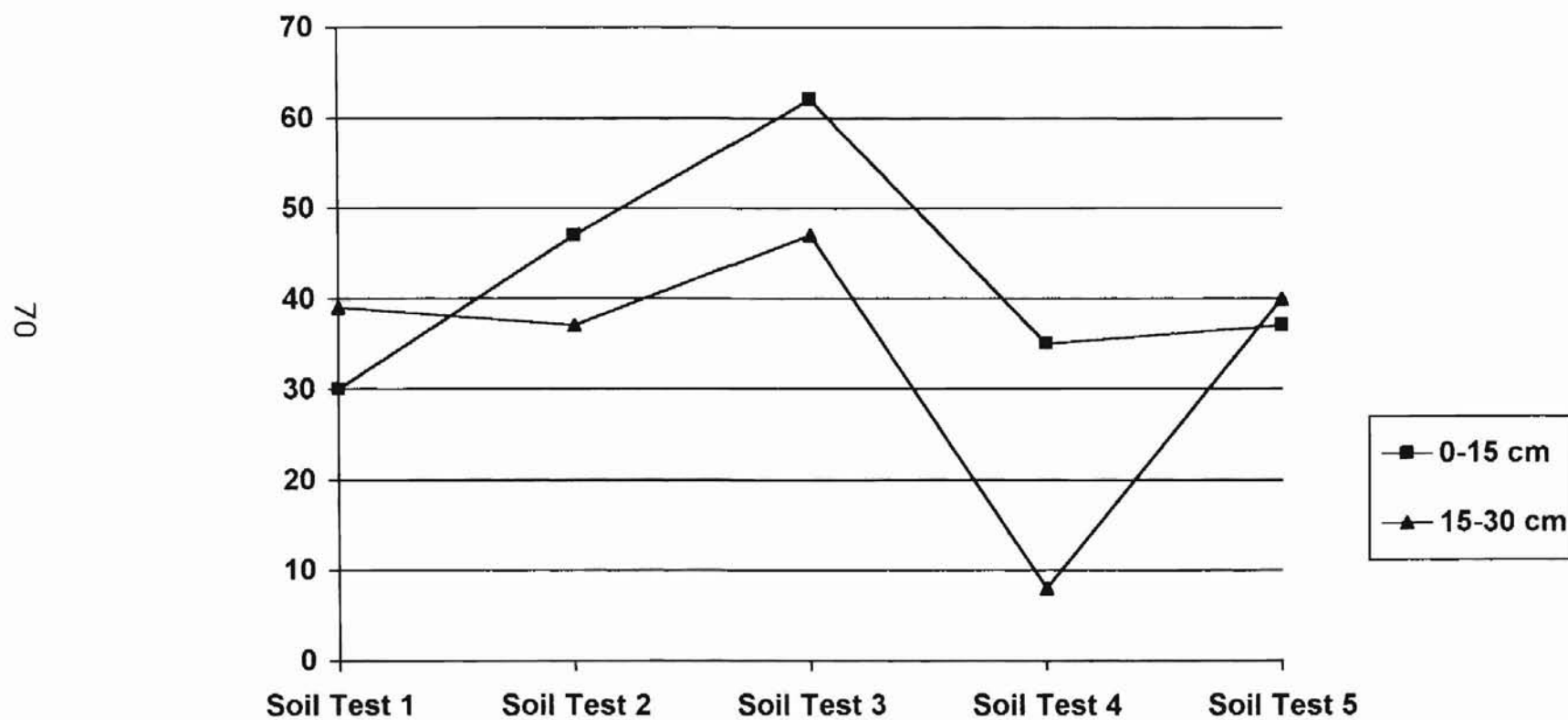
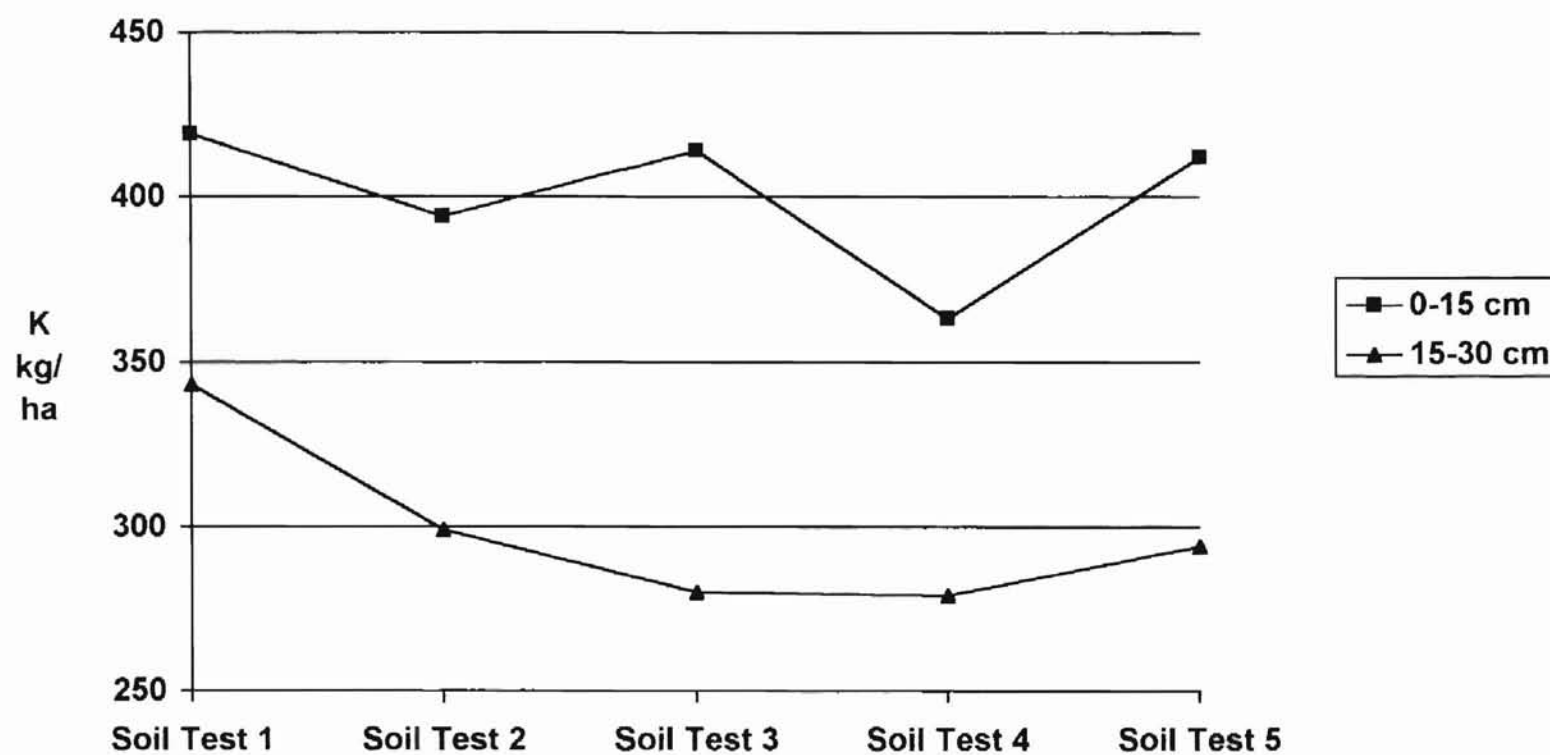


Figure 2.7. Change in K values over time, averaged over all treatments.



CHAPTER 3

Use of Hairy Vetch to Manage Soil Phosphorus Accumulation from Poultry Litter Applications in a Warm-Season Vegetable Rotation

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Additional index words. *Vicia villosa*

Abstract. Hairy vetch (*Vicia villosa* Roth) cover crops were grown in a rotation with sweet corn (*Zea mays* var. *rugosa* Bonaf.) and muskmelons (*Cucumis melo* L. Reticulatus group) to evaluate the legume's ability to remove excess P from soils when poultry litter was used as a fertilizer. Fertilizer treatments were litter to meet each crop's recommended preplant N requirements (1X); litter at twice the recommended rate; and urea at the 1X rate as the control. Following the vegetable crops, hairy vetch was planted on half of each replication, while the other half was fallowed. In the spring the vetch was removed from the field in a simulated haying operation. Soil samples were taken at 0-15 cm and 15-30 cm

depths at the onset of the study and after each crop to monitor plant nutrient levels. The vetch raised soil test N levels at the 0-15 cm depth, and was able to maintain soil test P values in 1X litter plots at levels similar to those in control plots. Soil test P did not increase after two litter applications, even at the 2X rate. Yields of both vegetable crops were comparable among all fertilizer treatments.

INTRODUCTION

Animal manures are the primary crop fertilizer in many countries and in regions of concentrated livestock production. Animals and humans excrete more than 70% of most nutrients in their food, including almost all of the phosphate (Hedley et al., 1995). Chickens (*Gallus domesticus*) may excrete more than 85% of the dicalcium phosphate fed to them to improve bone development (Robinson and Sharpley, 1995). The high phosphorus level contributes to poultry manure's dual reputation as a valuable source of plant nutrients and a potential source of environmental pollution.

An estimated 7.76 billion broiler chickens and 300 million turkeys (*Meleagris gallopavo*) were produced in the United States in

1997 (National Agricultural Statistics Service, 1998). Production tends to be concentrated in small geographical areas. It is common to find 20,000 to 80,000 or more birds per farm, with farms side-by-side. Manure and litter—a mixture of excrement and bedding materials—are major by-products of the poultry industry. Depending on the species of birds and on management practices, an estimated 5 kg (11 lbs) of dry matter manure is produced per animal per year (Payne and Donald, 1992). Thus, about 40 million Mg of dry manure is produced in the United States each year. The volume increases when the manure is mixed with litter materials.

Poultry litter can be a valuable fertilizer for vegetable production. It contains nutrients needed for plant growth and adds organic matter to the soil (Edwards and Daniel, 1992; Zhang and Hamilton, 1996). Litter is usually applied at high application rates to meet a crop's N requirements. Large or repeated applications may cause P to accumulate in the soil (Sharpley et al., 1993; Edwards and Daniel, 1992; Earhart, 1995), because plants tend to take up less P than is provided in litter. The ratio of N/P uptake for crops grown in the Southern Plains is 8:1, while the average ratio of N/P in litter is 3:1 (Edwards and Daniel, 1992). Excess P at or near the soil surface is subject to rainfall runoff (Nichols et al., 1994; Edwards and Daniel,

1993 and 1994; Edwards et al., 1996; Giddens and Barnett, 1980). Excess P is a key factor in eutrophication, or unwanted algal growth, in surface bodies of water (Smil, 1997).

In addition to potential environmental problems, high litter application rates have been shown to reduce yields in some crops, possibly due to nutrient imbalances caused by a buildup of toxic levels of ammonia, nitrite, nitrate and soluble salts (Edwards and Daniel, 1992). High rates ($44.8 \text{ mt}\cdot\text{ha}^{-1}$) of litter in no-till corn production usually resulted in seedling death or low corn stands, while adequate yields were reported when moderate rates (11.2 and $22.4 \text{ mt}\cdot\text{ha}^{-1}$) of litter were used (Carreker et al., 1973). Spring sweet corn yields were reduced when litter was applied at rates higher than twice the recommended amount (Earhart, 1995). On the other hand, high litter rates ($40 \text{ mt}\cdot\text{ha}^{-1}$) resulted in sweet corn that matured one week earlier than corn fertilized with the recommended rate of a commercial fertilizer (Brown et al., 1994).

Although poultry manure has a reputation of causing excess foliage at the expense of seeds and fruits, muskmelons (*Cucumis melo* L. Reticulatus group), watermelons [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] and tomatoes (*Lycopersicon esculentum* Mill.) were successfully grown on plots where manure was broadcast in winter in

a rye (*Secale cereale* L.) or wheat (*Triticum* sp.) cover crop that was later plowed under (Rahn, 1949). The vegetable plants receiving manure were considerably larger, had denser foliage, and produced greater yields than plants grown with an inorganic fertilizer. Rahn believed the higher yields were possible because the manure had time to be broken down by microbes, which made nutrients more readily available and resulted in less risk of toxic effects from ammonia or disturbed moisture relations.

Since legumes have a reputation for high P uptake, Earhart (1995) proposed that vegetable crops be rotated with legume cover crops to control soil P accumulation from poultry litter applications. Cover crops absorb nutrients while actively growing, and could affect the distribution and forms of nutrients in soils if significant biomass accumulates (Lal et al., 1991). Crop removal of about 7 kg·ha⁻¹ P will lower the soil test P by a value of 1.0 on a Grant silt loam soil (Johnson et al., 1998).

Legumes tend to require larger amounts of P than many of the common grain crops grown in Oklahoma (Johnson et al., 1997). Legumes contain an average of 1.75 times as much P as grasses (Griffith, 1974). Bray-P levels have been found to be lower under legume cover crops than under grass (Wilson et al., 1982).

Vetches have a relatively high requirement for P (Miller and Hoveland, 1995). In a study showing that winter legumes lowered soil pH and extractable P, hairy vetch was very effective at lowering levels of P at all depths tested, down to 30 cm (Hargrove, 1986). Hairy vetch and sweet clover (*Melilotus alba* Medik.) had higher foliar P concentrations than all of the 25 grasses and 11 other legumes evaluated (Daniel, 1934).

This study examined the effectiveness of litter as a vegetable crop fertilizer, and the ability of hairy vetch to reduce soil P levels in a cool-season vegetable rotation where poultry litter was used to fertilize the vegetable crops.

Materials and Methods

Warm-season vegetable crops were fertilized by poultry litter at two different rates, or by urea as a control. After the vegetables were harvested, vetch was planted on half of the plots, with the other half left fallow, to compare soil P levels in a cover cropping system versus fallow ground.

Location: This report highlights two years of a three-year field experiment conducted at the Oklahoma State University Vegetable

Research Station in Bixby, Okla., on a Severn very fine sandy loam [coarse-silty, mixed (calcerous), thermic Typic Udifluvent] soil. The experimental area was the site of a previous study that examined the ability of grass (*Gramineae*) cover crops to absorb excess soil N from poultry litter applications to vegetable crops. Randomization of treatments in our study was a continuation of randomization from the prior study. Residual effects of soil P and K from previous poultry litter applications may have affected results of our study. The field was divided into four replications. Each replication contained six plots measuring 10 by 8 m, plus a 3-m alley in the center. Each replication was separated by a 2-m aisle.

Experimental Design: The experiment was arranged in a split-plot design with randomized blocks, and four replications. The main plot treatment was the cover crop: vetch or fallow ground. The sub plots consisted of three fertilizer treatments: poultry litter at the rate recommended (1X) by soil tests to supply preplant N to a vegetable crop, litter at twice the recommended rate (2X), and urea (46N-0P-0K) at the recommended rate as the control. Fertilizer treatments were hand-broadcast and incorporated to a depth of 5 to 7.5 cm.

Poultry Litter: Litter was obtained from three poultry farms in Northeastern Oklahoma. The litter was partially composted before it was applied. Prior to application, the litter was analyzed for total N, P, K and Ca, pH, electrical conductivity, and percent water. The analyses were performed by the University of Arkansas' Agricultural Services Laboratory, Fayetteville, Ark. Characteristics of the litter are reported in Table 3.1. Tables 3.2 and 3.3 show the total amount of litter applied and the levels of N, P, and K applied with fertilizer treatments.

Soil Analyses: Soil samples were collected from each plot at two depths: 0-15 cm and 15-30 cm, to determine baseline levels of nitrate-N, P, K, Ca, Mg, Fe, B, Zn and pH. The initial samples were taken on 12 Mar., 1996. Soil samples were also collected following each crop. For the sake of brevity, sampling periods are referred to as Time 1, Time 2, etc. Timing of sample collections was as consistent as possible, but varied some depending on the weather, field conditions, and the ideal planting date for each crop. Samples were analyzed by the OSU Soil, Water and Forage Analytical Laboratory in Stillwater, Okla. using the Mehlich III extraction for P, K, Ca and Mg; calcium sulfate extraction of nitrate-N; DTPA extraction of Fe and Zn; and hot water extraction of B. Phosphate (phospho-molybdate blue) and

nitrate (cadmium reduction) were analyzed colorimetrically using flow injection instrumentation. Solutions containing the other elements were analyzed using inductively coupled plasma (ICP) emission spectroscopy (Zhang et al., 1983).

Vegetable Crops: Two warm-season vegetable crops were grown to assess the effects of the cover crop and fertilizer treatments: 'Bodacious' sweet corn, and 'Magnum 45' muskmelons. Standard commercial insect, weed and disease control methods were followed. Sprinkler irrigation was used as needed to prevent drought stress. Fallow areas were tilled at a shallow depth (5 to 7.5 cm) as needed to control weeds. After harvests, plots were disked and worked with the field cultivator to a depth of 13 to 15 cm.

Sweet Corn—Fertilizer treatments were applied on 9 Apr. 1996. The urea plots contained an average of $7 \text{ kg} \cdot \text{ha}^{-1}$ residual N, while P and K levels were adequate to excessive. Pre-plant urea and 1X litter were applied at rates to supply $48 \text{ kg} \cdot \text{ha}^{-1}$ N, while 2X litter was applied at a rate to supply $96 \text{ kg} \cdot \text{ha}^{-1}$ N. Amounts of litter, and of N, P, and K applied with fertilizer treatments are reported in Tables 3.2-3.3. The corn was planted on 10 Apr. The seeds were spaced every 10 cm, in rows 0.9 m apart, with eight rows per plot. Metolachlor was applied

at the rate of 0.2 liter \cdot ha $^{-1}$ for weed control on 13 Apr. The plots were thinned to one plant every 30 cm on 1 and 9 May. The corn was topdressed on 21 May with urea to supply 70 kg \cdot ha $^{-1}$ N. Leaf samples (the midrib of the first leaf above the primary ear at tasseling) were taken on 14 June from six plants per plot for elemental analyses.

The corn was hand-harvested on 26 June. Data were taken from 15 plants in the center of the middle two rows in each plot, for a total sample area of 8.1 m 2 per plot. Ears were graded in the husk into marketable (\geq 13 cm of mature kernels), immature, and cull groups. Culls primarily had irregular cob fill. We did not cull based on worm damage. Subsamples of 10 marketable ears per plot were taken for husking and for measurements of the average diameter at the base of the cob, the average length for a husked ear, and average appearance for husked ears. Appearance was determined on a 1 to 5 rating, with highest quality ears receiving a 1, and poorest ears receiving a 5.

Muskmelons—The muskmelons were seeded 11 Apr. 1997 into peat-lite mix in pressed peat pots (volume per pot 42 cm 3), which were placed in plastic flats. Young plants were grown in the greenhouse, and received water and liquid fertilizer (20N-8.8P-16.6K) as necessary.

Fertilizer treatments were applied and incorporated in the plots on 20 May. Preplant soil sample results showed an average of 29 kg·ha⁻¹ residual N in the control plots following vetch, and an average of 9 kg·ha⁻¹ residual N in control plots following fallow. P and K were adequate to excessive. Differences in preplant N levels in vetch and fallow plots were so marked that we decided to fertilize vetch plots at a different rate than fallow plots. When this was done, six cropping systems were created. Fertilizer applications in the fallow systems supplied 47 kg·ha⁻¹ N in urea and 1X litter plots, and 94 kg·ha⁻¹ N in 2X litter plots. In the vetch systems, fertilizer applications supplied 27 kg·ha⁻¹ N in urea and 1X litter plots, and 54 kg·ha⁻¹ N in 2X litter plots. Amounts of litter, and of N, P, and K applied with fertilizer treatments are reported in Tables 3.2-3.3.

Ethalfluralin at 0.6 liter·ha⁻¹ was applied for weed control on 21 May. The muskmelons were transplanted into the field on 23 May. Furrows were opened with a tractor at a between-row spacing of 2 m, with four rows per plot. One plant (in its peat pot) was set every 60 cm within a row, with 12 total pots per row. The 'Magnum 45' cultivar of muskmelon was planted in data rows. 'Starship' muskmelons were planted at the ends of each row and in guard rows. Each plant received about 200 ml of starter solution providing 1079N-949P-895K

(mg·liter⁻¹), respectively, and 0.6ml·liter⁻¹ diazinon. All plants were topdressed with urea to provide 56 kg·ha⁻¹ N on 19 June. Ten leaves per plot were sampled for elemental analyses on 17 July.

Eight selective hand harvests were made from 21 July through 8 Aug. At the fourth harvest, on 30 July, five relatively uniform, marketable fruit per plot were sampled for soluble solids with a refractometer. During harvests, fruit were separated into marketable and cull groups, with fruit number and weight measured in each group.

Vetch Cover Crops—The first vetch crop, which followed the sweet corn, was planted 9 Oct. 1996 on half of the plots after the soil was disked and packed. Seeds were planted with a grain drill at a rate of 3.4 grams·m⁻². There were eight rows, 0.9 m apart per plot. No fertilizers or herbicides were applied.

The vetch was harvested on 21 Apr. 1997 with a Lawn Genie flail vacuum. The machine cut a strip about 1.2 m wide at a height of about 3 cm. The vetch was not yet blooming but had made a dense groundcover. Data plants were taken from the approximate middle of each plot. Cut material was dumped on a tarp, and weighed. Subsamples were pulled from the cut material for further analyses.

After data plants were harvested, the flail vacuum harvester removed as much of the remaining vetch as possible to simulate a haying procedure.

The second vetch crop, following the muskmelons, was planted on 17 Oct. 1997, and harvested 3 April, 1998. Production and harvesting procedures were the same as with the 1996-97 vetch. Data analyses for the second vetch crop are not included in this thesis.

Tissue Analyses: Foliar samples, collected as described above, were dried at 48C for ≥ 7 days and reweighed, then ground in a Wiley mill to pass through a no. 40 U.S. standard testing sieve (0.42 mm). The samples were analyzed by the Samuel Roberts Noble Foundation, Inc., Ardmore, Okla., or Ward Laboratory Inc., Kearney, Neb. The sweet corn was analyzed for N content. The other crops were analyzed for concentrations of N, P, K, Ca, Mg, Zn, Fe, and Mn.

Statistical Analyses: Data were evaluated with analysis of variance procedures. Vetch data were analyzed for effects of fertilizer treatment. Sweet corn data were analyzed for main effects of legume treatment (vetch versus fallow), main effects of fertilizer treatment, and their interaction. Muskmelon data were analyzed for effects of

cropping system. Soils data were analyzed across the five sampling times, so the soils data analysis included main effects of cropping system and time, as well as their interaction. If the main effect of fertilizer treatment or cropping system was significant ($P \leq 0.05$), means were separated using the least significant difference (LSD) at $P \leq 0.05$. For the soils data, trend analysis was used to partition main effects of time into linear and quadratic components. Significant interactions were partitioned using the MIXED procedure of SAS (SAS, 1982), with means separated by least squares at $P \leq 0.05$.

Results and Discussion

Vetch Crop: Treatments did not affect vetch shoot mass on a per hectare basis (Table 3.4). The only significant difference in concentrations of foliar nutrients occurred with Zn (Table 3.4), with less Zn in plants fertilized by 2X litter than in plants fertilized by 1X litter or urea.

Vegetable Crops:

Sweet Corn— Sweet corn responded similarly to the three fertilizer treatments for all measured variables (Table 3.5). The corn was not preceded by a cover crop treatment. A test of legume effects

to determine if there were random effects of position in the field was statistically insignificant.

Muskmelons—Yield responses of the muskmelons were similar across the cropping system treatments (Table 3.6). Even though N fertilization rates were designed to balance the vetch and fallow areas, with higher amounts of fertilizer applied to the fallow areas, N concentrations often were higher in plants following vetch than in plants following fallow. Differences in N, however, did not translate into yield differences. Zn concentrations tended to be slightly higher in plants grown with urea than in plants grown with poultry litter (data not shown). Cropping system treatments did not affect concentrations of P, K, Ca, Mg, Mn, or Fe in muskmelon leaves.

Soils: In general, levels of soil elements were not affected by fertilizer or cover crop treatments. Interactions between cropping system treatment and time were significant for N at both soil sampling depths, and for P at the shallow depth. Treatments did not affect levels of P at the deeper soil depth, nor levels of K, Ca, Mg, Fe, B, or Zn at either soil sampling depth. However, concentrations of all the elements showed variation over time (Tables 3.7-3.8). Table 3.9

summarizes main effects and interactions affecting soil nutrient values in the warm-season study.

Phosphorus—Treatment effects were detected at Time 3 (after the first vetch crop was harvested and before muskmelons were planted) and Time 4 (after muskmelons), but not at other times (Fig. 3.1-3.4; Table 3.10). At Times 3 and 4, no differences in P at the shallow soil sampling depth [P(0-15cm)] due to the cover crop system were found for a given fertilizer treatment. Within the vetch system, at Time 3 and Time 4, P(0-15cm) values from 2X litter plots were higher than values from control plots, while P values from 1X litter plots were similar to those from control plots. Also, within the vetch system, 2X litter plots had more P(0-15cm) than 1X litter plots at Time 4 but not at Time 3. Within the fallow system, at Time 3 and Time 4, P(0-15cm) values were higher in 2X litter plots than in control plots, but P values were higher in 1X litter plots than in control plots only at Time 4. Also, within the fallow system, 1X litter plots and 2X litter plots did not differ in P(0-15cm) values at both Time 3 and Time 4.

Soil test P(0-15cm) was higher in 2X litter plots than in control plots at both Time 3 and Time 4 regardless of cover crop system (Table 3.10 and Fig. 3.1-3.2). The vetch system was able to maintain

P(0-15cm) in 1X litter plots at levels similar to those in control plots throughout the study. The fallow system resulted in more soil test P(0-15cm) in 1X litter plots than in control plots at Time 4 (Table 3.10 and Fig. 3.2); however, no differences could be shown at other sampling times.

The P values reported at Time 2 may not be precise. There was a substantial drop in P levels at Time 2, followed by a distinct increase in P at Time 3 (following the first vetch harvest) at both depths, in all cover crop systems (Fig. 3.1-3.4). These rapid fluctuations were not expected, especially in the control plots where no P fertilizers were applied. The harvest of the vetch biomass should have resulted in a slight decrease in soil test-P levels. Long-term fertility studies on soil-P depletion and enrichment in Oklahoma show that crop removal of about $7 \text{ kg} \cdot \text{ha}^{-1}$ P would lower the soil test P by a value of 1.0 (Johnson et al., 1998).

There are several possible explanations for the fluctuations in soil test-P values. P levels were already in the excessive range when our study began, since it was the site of a previous study where poultry litter applications were made. Baseline P levels averaged $227 \text{ kg} \cdot \text{ha}^{-1}$. Soil test P levels above 130 are considered excessive in Oklahoma (Johnson et al., 1998). When the P levels in a soil sample

are excessive, soil testing labs sometimes do not determine precise amounts (G.V. Johnson, personal communication). The soil testing lab was not requested to provide special treatment to these samples. Therefore, values of P may not be as precise as some other data. Also, the soil testing lab uses a volume measure of soil for P extraction, and assumes a standard soil bulk density. Addition of poultry litter, especially at high application rates, may lower the soil bulk density (G.V. Johnson, personal communication).

It is possible that the P levels in our litter-fertilized soils increased some due to mineralization of organic P supplied from previous applications. Sources disagree on the amount of P readily available in the season of application, ranging from 20% for manure (Brady, 1990) to 90% for litter (Zhang et al., 1998). However, this would not explain the Time 3 increase in P in the control plots.

The soil test P values may also have been affected by natural variability in the field, even within plots. New soil sampling recommendations call for 15 to 20 core samples to overcome field variability (Taylor et al., 1997). We took five core samples per plot.

Nitrogen—For N at the shallow depth [N(0-15cm)], treatment effects were detected at Time 3 and Time 4, but not at other times (Table 3.11). At Time 3, samples from plots following vetch were

much higher in N(0-15cm) than samples from plots following fallow. There were no differences due to fertilizer treatments within cover crop systems at Time 3. At Time 4, samples from vetch plots were higher in N(0-15cm) than samples from fallow plots fertilized with either urea or 1X litter. This higher N(0-15cm) value in vetch plots occurred even though higher rates of preplant N were applied in the fallow system than in the vetch system. The vetch plots may have still been getting residual N benefits from the microbial breakdown of vetch residue. Within the vetch system, there were no differences in N(0-15cm) due to fertilizer treatments at Time 4. Within the fallow system, litter plots did not differ from control plots in N(0-15cm) values, but 2X plots had more N(0-15cm) than 1X litter plots at Time 4.

It is not surprising that treatment effects were not detected at other sampling times. The Time 2 soil sampling took place 2.5 months after the sweet corn harvest. Since Time 2 was just before the first vetch crop was planted, effects of a cover crop treatment would not be expected. Any excess N remaining after the different corn fertilizer treatments may have had time to leach. Also, some of the N applied with the litter treatments may have still been in an organic form, not measured by soil tests. Only 30% to 80% of the N in litter is available

during the first year of application; the remainder is gradually converted by microbes into an inorganic form available to plants (Zhang et al., 1998). N differences may not have been apparent at Time 5 because soil samples were taken just two weeks after the vetch was harvested (this early soil sampling date was necessary so that the 1998 vegetable crop, sweet corn, could be planted on time). The vetch residue may not have had time to decompose enough to cause a difference in N values compared to values in fallowed plots, as was seen after the first vetch crop.

For N at the deep soil testing depth [N(15-30cm)], treatment effects were detected at Time 2 and Time 4, but not at other times (Table 3.12). At Time 2, no legume treatments had been applied, so no differences were expected between legume treatment plots for a given fertilizer treatment. However, samples from "future" fallow plots fertilized with urea had more N(15-30cm) than samples from "future" vetch plots fertilized with urea. Also, within future vetch plots, samples from both litter treatment plots had more N(15-30) than samples from control plots, and N(15-30cm) values were higher with 2X litter than with 1X litter. Within future fallow plots, samples from the two litter treatments did not differ in N(15-30cm) values, but N(15-30cm) values were higher in 2X litter plots than in control plots.

At Time 2, values of N(15-30cm) were usually higher in litter plots than in control plots. Residual effects of previous litter applications could have caused the higher N levels in litter plots.

At Time 4, samples from plots fertilized with urea and following vetch had more N(15-30cm) than samples from any other treatment. The remaining treatments were similar in N(15-30cm) values, except that samples from plots fertilized with 1X litter and following vetch were higher in N(15-30cm) than samples from plots fertilized with urea and following fallow. None of these findings are readily explained; results may simply reflect variation in sampling and in laboratory analysis.

Other Soil Nutrients—Treatments did not affect levels of P(15-30cm), nor levels of K, Ca, Mg, Fe, B, and Zn at both soil sampling depths. However, concentrations of these elements in the soil varied over time (Tables 3.7-3.8). For elements with five sampling times, a quadratic response was found for P(15-30cm), while K(0-15cm) and K(15-30cm) values decreased linearly. For elements with three sampling times, quadratic responses were found for Ca, Mg and Zn at both depths, and for Fe(0-15cm) and B(15-30cm), while values for Fe(15-30cm) and B(0-15cm) decreased linearly.

Treatments did not affect soil pH, but a quadratic response was found over time at both the 0-15 and 15-30 cm soil sampling depths (Table 3.8).

Conclusions

Yields of sweet corn and muskmelons fertilized by poultry litter at the recommended preplant N rate and at twice the recommended rate were comparable to yields with urea at the recommended rate. In a warm-season vegetable rotation with vetch, the 2X litter rate did not cause nutrient imbalances in any crops, and did not cause soil P levels to increase.

We did not see an accumulation of P in our soils with the use of litter. P levels at the end of the study were similar to or lower than levels when the study began (Fig. 3.1-3.4). The two vegetable crops and one vetch cover crop absorbed an estimated 35 kg·ha⁻¹ P in 1X litter and 2X litter plots (Table 3.13). The amount of P applied with the litter was 35 kg·ha⁻¹ in 1X litter plots and 70 kg·ha⁻¹ in 2X litter plots (Table 3.3). Based on application rates and crop removal estimates, the soil P levels at the fifth soil sampling should have been about the same as initial levels in 1X plots, and should have increased by about 35 kg·ha⁻¹ in 2X plots.

We were unable to demonstrate that the vetch cover crop significantly reduced soil P levels from poultry litter applications. However, improvements in soil sampling and lab analysis techniques could result in a different outcome. A long-term study would also be helpful, since crops must remove an estimated 7 kg·ha⁻¹ P to lower the soil test P by a value of 1.0 (Johnson et al., 1998).

The vetch system required less preplant fertilizer for subsequent vegetable crops, and did not affect yields of sweet corn or muskmelons. A similar cover crop system which did not affect vegetable yields could be valuable to commercial growers by reducing inputs.

Literature Cited

- Brady, N.C. 1990. The nature and properties of soils. 10th ed. Macmillan, New York.
- Brown, J.E., J.M. Dangler, C.H. Gilliam, D.W. Porch, and R.L. Schumack. 1994. Comparison of broiler litter and inorganic nitrogen, phosphorus, and potassium for double-cropped sweet corn and broccoli. *J. Plant Nutr.* 17(5):859-867.
- Carreker, J.R., S.R. Wilkinson, J.E. Box, Jr., R.N. Dawson, E.R. Beaty, H.D. Morris, and J.B. Jones, Jr. 1973. Using poultry litter, irrigation, and tall fescue for no-till corn production. *J. Environ. Qual.* 2(4):497-500.
- Daniel, H.A. 1934. The calcium, phosphorus, and nitrogen content of grasses and legumes and the relation of these elements in the plant. *J. Amer. Soc. Agron.* 26(6):496-503.
- Earhart, D.R. 1995. Developing environmentally sound poultry litter management practices for sustainable cropping systems. *Sustainable Agr. Res. and Educ. & Agr. in Concert with the Environ.: Southern Region.* LS92-48.
- Edwards, D.R., and T.C. Daniel. 1992. Environmental impacts of on-farm poultry waste disposal: A review. *Bioresource Technol.* 41:9-33.
- Edwards, D.R., and T.C. Daniel. 1993. Waste management: Effects of poultry litter application rate and rainfall intensity on quality of runoff from fescuegrass plots. *J. Environ. Qual.* 22:361-365.
- Edwards, D.R., and T.C. Daniel. 1994. Quality of runoff from fescuegrass plots treated with poultry litter and inorganic fertilizer. *J. Environ. Qual.* 23:579-584.
- Edwards, D.R., P.A. Moore, Jr., T.C. Daniel, and P. Srivastava. 1996. Poultry litter-treated length effects on quality of runoff from fescue plots. *Trans-Amer. Soc. Of Agr. Eng.* 39(1):105-110.
- Giddens, J., and A.P. Barnett. 1980. Soil loss and microbiological quality of runoff from land treated with poultry litter. *J. Environ. Qual.* 9(3):518-520.

- Griffith, W.K. 1974. Satisfying the nutritional requirements of established legumes, p.147-167. In: D.A. Mays (ed). Forage fertilization. Amer. Soc. Agron., Crop Sci. Soc. of Amer., and Soil Sci. Soc. Of Amer., Madison, Wis.
- Hargrove, W.L. 1986. Winter legumes as a nitrogen source for no till grain sorghum. *Agron. J.* 78:70-74.
- Hedley, M.J., J.J. Mortvedt, N.S. Bolan, and J.K. Syers. 1995. Phosphorus fertility management in agroecosystems. In: H. Tiessen (ed.). Phosphorus in the global environment. Wiley, New York.
- Johnson, G.V., W.R. Raun, H. Zhang, and J.A. Hattey. 1997. Oklahoma soil fertility handbook. 4th ed. Okla. State Univ. Dept. of Agron.
- Johnson, G.V., N.T. Basta, H.A. Zhang, J.A. Hattey, W.R. Raun, and J.H. Stiegler. 1998. Science-based animal waste phosphorus management for Oklahoma. Okla. Coop. Ext. Serv. Production Technol. 98(1).
- Lal, R., E. Regnier, D.J. Eckert, W.M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture. In: Cover crops for clean water. Soil and Water Conservation Soc., Ankeny, Iowa.
- Lorenz, O.A., and D.N. Maynard. 1988. Knott's handbook for vegetable growers. 3rd ed. Wiley, New York.
- Miller, D.A., and C.S. Hoveland. 1995. Other temperate legumes, p. 273-282. In: R.F. Barnes, D.A. Miller, and C.J. Nelson (eds). Forages: Volume 1: An introduction to grassland agriculture. Iowa State Univ. Press, Ames, Iowa.
- National Agricultural Statistics Service. 1998. Poultry production and value. Bul. Pou 3-1(98), US Dept. of Agr., Washington, DC.
- Nichols, D.J., T.C. Daniel, and D.R. Edwards. 1994. Nutrient runoff from pasture after incorporation of poultry litter or inorganic fertilizer. *Soil Sci. Soc. Am. J.* 58:1224-1228.

- Payne, V., and J.O. Donald. 1992. Poultry waste management and environmental protection manual. Auburn Univ. Ext. ANR-580.
- Rahn, E.M. 1949. Poultry manure as a fertilizer for vegetable crops. Univ. of Delaware Agr. Expt. Sta. Res. Bul. 281.
- Robinson, J.S., and A.N. Sharpley. 1995. Water quality: Release of nitrogen and phosphorus from poultry litter. J. Environ. Qual. 24(1)62-67.
- SAS Institute Inc. 1982. SAS user's guide: statistics. 1982 ed. Cary, NC: SAS Institute Inc.
- Sharpley, A.N., S.J. Smith, and W.R. Bain. 1993. Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoma soils. Soil Sci. Soc. Am. J. 57:1131-1137.
- Smil, V. 1997. Cycles of life: Civilization and the biosphere. Scientific Amer. Library, New York.
- Taylor, S.L., G.V. Johnson, and W.R. Raun. 1997. A field exercise to acquaint students with soil testing as a measure of soil fertility status and field variability. J. Natural Resour Life Sci. Educ. 26:132-135.
- Wilson, G.F., R. Lal, and B.N. Okigbo. 1982. Effects of cover crops on soil structure and on yield of subsequent arable crops grown under strip tillage on an eroded alfisol. Soil Tillage Research. 2:233-250.
- Zhang, H., M. Kress, and G. Johnson. 1983. OSU soil, water and forage analytical laboratory standard procedures. Okla. Coop. Ext. Serv. Facts 2901.
- Zhang, H., and D.W. Hamilton. 1996. Use [sic] animal manure as a plant nutrient source. Okla. Coop. Ext. Serv. Production Technol. PT 96-25.
- Zhang, H., D.W. Hamilton, and J.G. Britton. 1998. Using poultry litter as fertilizer. Okla. Coop. Ext. Serv. Facts F-2246.

Table 3.1. Total elemental composition of poultry litter applied.

Experiment	pH	Ec (μ mhos)	H ₂ O (%)	N (%)	P (%)	K (%)	Ca (%)
Spring 1996	7.3	13440	29.3	2.93	1.27	2.35	2.61
Spring 1997	7.4	14200	18.6	3.13	1.61	2.94	2.60

Values are reported on an "as-is" basis, since litter was applied "as-is".

Table 3.2. Amount of poultry litter applied during production of two warm-season vegetable crops.

Tmt	1996	1997	Total
	Sweet Corn	Muskmelons	
	-----kg/ha-----		
Fallow—1X Litter	1644	1503	3147
Fallow—2X Litter	3288	3006	6294
Vetch—1X Litter	1644	859	2503
Vetch—2X Litter	3288	1718	5006

Amounts reported on an “as-is” basis. Control plots did not receive poultry litter applications.

Table 3.3. Amount of N, P, and K applied with fertilizer treatments during production of two warm-season vegetable crops.

Tmt	1996 Sweet Corn			1997 Muskmelons			Total		
	N	P	K	N	P	K	N	P	K
	-----kg/ha-----								
Fallow									
Urea	118	--	--	103	--	--	221	--	--
1X Litter	118	21	39	103	24	44	221	45	83
2X Litter	166	42	78	150	48	88	316	90	166
Vetch									
Urea	118	--	--	83	--	--	201	--	--
1X Litter	118	21	39	83	14	25	201	35	64
2X Litter	166	42	78	110	28	50	276	70	128

Amounts reported on an "as-is" basis. N values include topdressings of urea made to vegetable crops at the appropriate time during their growing season. The sweet corn received a topdressing of 70 kg/ha N from urea. The muskmelons received a topdressing of 56 kg/ha N from urea. Plots fertilized by urea did not receive supplemental P or K.

Table 3.4. Foliar element concentrations and shoot yields of the 1996-1997 vetch cover crop.

Variable	Urea	1X Litter	2X Litter
N	3.60	3.43	3.54
P	0.58	0.63	0.65
K	3.79	3.99	4.19
Ca	1.86	1.72	1.71
Mg	0.43	0.41	0.40
Mn	72	76	69
Fe	808	1007	831
Zn	57a	57a	51b
Shoot mass (kg/ha)	9028	9300	9882

Values for N, P, K, Ca, and Mg reported in %; Mn, Fe, and Zn in ppm. If significant differences exist, mean separation in rows is by LSD, 5% level. (No fertilizers were applied to the vetch. The fertilizer treatments were applied to the sweet corn crop which preceded the vetch.)

Table 3.5. Effect of fertilizer treatments on 'Bodacious' sweet corn.

Variable	Urea	1X Litter	2X Litter
% N in Leaves	1.98	1.74	1.85
Marketable Ears (1000/ha)	30.7	32.7	33.3
Marketable Ears (Mg/ha)	9.3	10.0	10.4
Immature Ears (Mg/ha)	2.4	2.1	2.6
Cull Ears (Mg/ha)	1.7	1.2	1.0
Total Ears (1000/ha)	65.4	65.0	69.1
Husked Marketable Ear			
Avg Diameter at Base of Cob (cm)	3.9	4.0	4.0
Avg Length (cm)	18.2	18.1	18.4
Avg Appearance (1=best, 5=poorest)	2.0	1.7	1.7

There were no significant differences among fertilizer treatments for any of the variables ($P \leq 0.05$).

Table 3.6. Effect of cover crop and fertilizer treatments on 'Magnum 45' muskmelons.

Tmt	-----Total Fruit----- (1000/ha) (Mg/ha)		% Mktble Fruit	Avg wt/ Mktble Fruit (kg)	% Soluble Solids	% N in Leaves
Fallow						
Urea	21.7	32.2	76	1.6	10.0	4.99bc
1X Litter	22.5	33.6	75	1.6	9.5	4.44d
2X Litter	22.5	31.9	70	1.6	9.4	4.69cd
Vetch						
Urea	21.7	33.4	75	1.6	9.8	5.34ab
1X Litter	22.5	34.2	74	1.7	10.2	5.47a
2X Litter	23.6	37.4	70	1.8	10.5	5.20ab
Significance	NS	NS	NS	NS	NS	**

NS,** Nonsignificant or significant at $P \leq 0.01$, respectively. When main effect of cropping system is significant, mean separation in columns is by LSD, $P \leq 0.05$.

Table 3.7. Mean soil test values for N, P, K and pH at five soil sampling occasions.

Variable ^z	-----Soil Test 0-15cm-----					Significance
	1	2	3	4	5	
N	6.7	14.4	17.3	41.1	15.5	Tmt X Time**
P	202	168	223	226	185	Tmt X Time**
K	336	325	291	321	265	Time Linear**
pH	6.2	6.1	6.0	5.8	6.1	Time Quadratic**
Variable ^z	-----Soil Test 15-30cm-----					Significance
	1	2	3	4	5	
N	6.1	38.4	6.3	32.4	10.9	Tmt X Time**
P	181	143	191	186	159	Time Quadratic**
K	255	230	233	233	213	Time Linear**
pH	6.1	6.0	6.0	5.7	6.1	Time Quadratic**

^zN, P and K data reported in kg/ha.

*,** Significant at $P \leq 0.05$ or 0.01 , respectively.

Table 3.8. Mean soil test values of Ca, Mg, Fe, B and Zn at three soil sampling occasions.

Variable ^z	---Soil Test at 0-15cm---				---Soil Test at 15-30cm---			
	1	3	5	Significance ^y	1	3	5	Significance ^y
Ca	2588	2621	2299	Quadratic**	2611	2771	2438	Quadratic**
Mg	392	393	345	Quadratic**	379	400	351	Quadratic**
Fe	44	41	41	Quadratic**	45	42	39	Linear**
B	0.33	0.29	0.23	Linear**	0.29	0.31	0.23	Quadratic**
Zn	1.46	1.75	1.67	Quadratic**	1.26	1.31	1.16	Quadratic**

^zCa, Mg and Fe data reported in kg/ha; Fe, B and Zn data reported in ppm.

^ySignificance of the main effect of time. Linear and quadratic responses were tested. Cropping system effects were not significant at $P \leq 0.05$ for all variables in this table.

** Significant at $P \leq 0.01$.

Table 3.9. Summary of main effects and interactions affecting soil nutrient values.

Variable	Tmt	Time	Tmt*Time
N(0-15cm)	**	**	**
N(15-30cm)		**	**
P(0-15cm)	*	**	**
P(15-30cm)		**	
K(0-15cm)		**	
K(15-30cm)		**	
Ca(0-15cm)		**	
Ca(15-30cm)		**	
Mg(0-15cm)		**	
Mg(15-30cm)		**	
Fe(0-15cm)		**	
Fe(15-30cm)		**	
B(0-15cm)		**	
B(15-30cm)		**	
Zn(0-15cm)		**	
Zn(15-30cm)		**	

*, ** Significant at ($P \leq 0.05$) or 0.01, respectively.

Table 3.10. Effects of treatment by time interactions on soil test P (0-15cm).

Tmt	-----Vetch-----			-----Fallow-----		
	Urea	1X Litter	2X Litter	Urea	1X Litter	2X Litter
	-----kg/ha-----					
Soil Test 3	207c	230bc	262ab	240bc	260ab	300a
Soil Test 4	186c	232bc	289a	218c	238ab	307a

Mean separation in rows is by least squares, 5% level.

Soil Test 3=May 1997, after vetch harvest.

Soil Test 4=Oct 1997, after muskmelon harvest.

Table 3.11. Effects of treatment by time interactions on soil test N(0-15 cm).

Tmt	-----Vetch-----			-----Fallow-----		
	Urea	1X Litter	2X Litter	Urea	1X Litter	2X Litter
	-----kg/ha-----					
Soil Test 3	29a	28a	31a	9b	9b	10b
Soil Test 4	53a	50a	52a	34bc	38c	46ab

Mean separation in rows is by least squares, 5% level.

Soil Test 3=May 1997, after vetch harvest.

Soil Test 4=Oct 1997, after muskmelon harvest.

Table 3.12. Effects of treatment by time interactions on soil test N(15-30 cm).

Tmt	-----Vetch-----			-----Fallow-----		
	Urea	1X Litter	2X Litter	Urea	1X Litter	2X Litter
	-----kg/ha-----					
Soil Test 2	30d	44bc	52a	41c	43bc	49ab
Soil Test 4	49a	38b	36bc	28c	31bc	36bc

Mean separation in rows is by least squares, 5% level.

Soil Test 2=Oct 1996, after sweet corn harvest.

Soil Test 4=Oct 1997, after muskmelon harvest.

Table 3.13. Estimated amount of P removed by two warm-season vegetable crops and one hairy vetch cover crop.

Tmt	Sweet Corn 1996	Hairy Vetch 1996	Muskmelons 1997	Total
	-----kg/ha-----			
Fallow				
Urea	9*	--	19*	28
1X Litter	9*	--	19*	28
2X Litter	9*	--	19*	28
Vetch				
Urea	9*	6.1	19*	34.1
1X Litter	9*	6.7	19*	34.7
2X Litter	9*	7.4	19*	35.4

*Unable to calculate from our yield data; estimated from Lorenz and Maynard (1988).

Figure 3.1. Soil P values at 0-15 cm, in plots where vetch cover crop was grown.

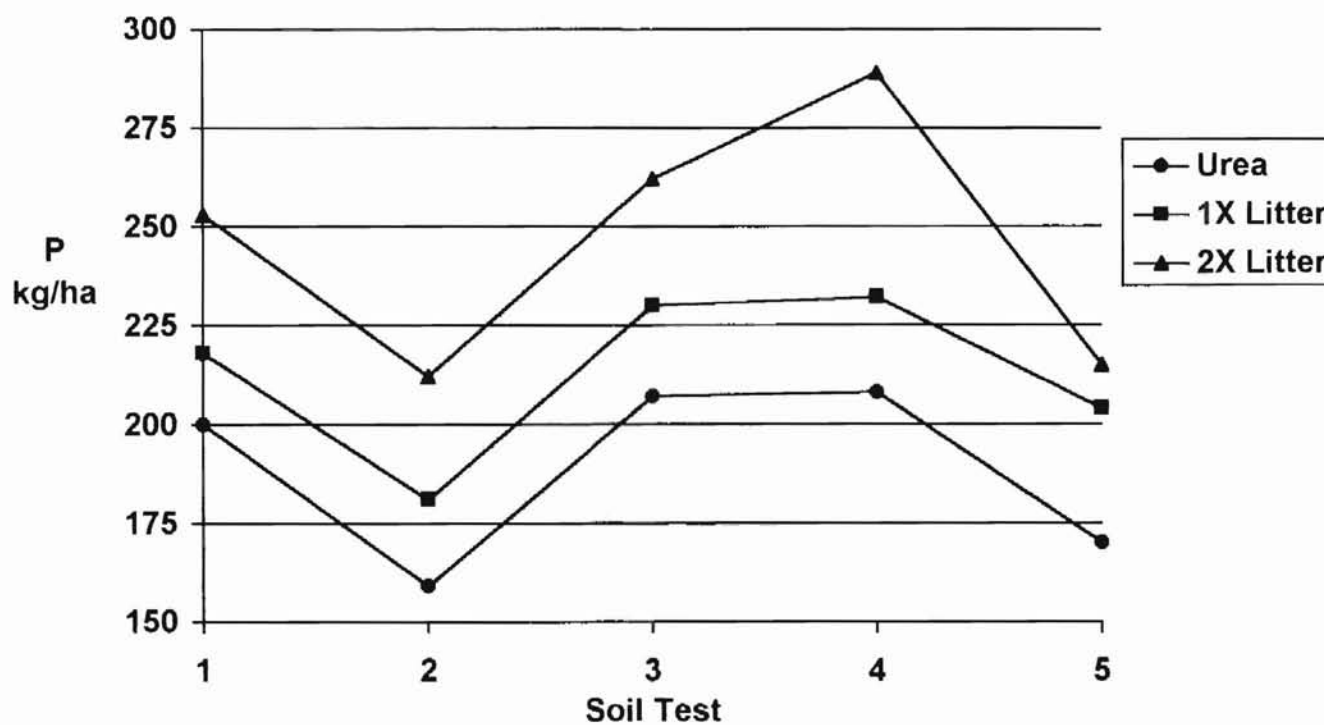


Figure 3.2. Soil P values, 0-15 cm, in fallowed plots.

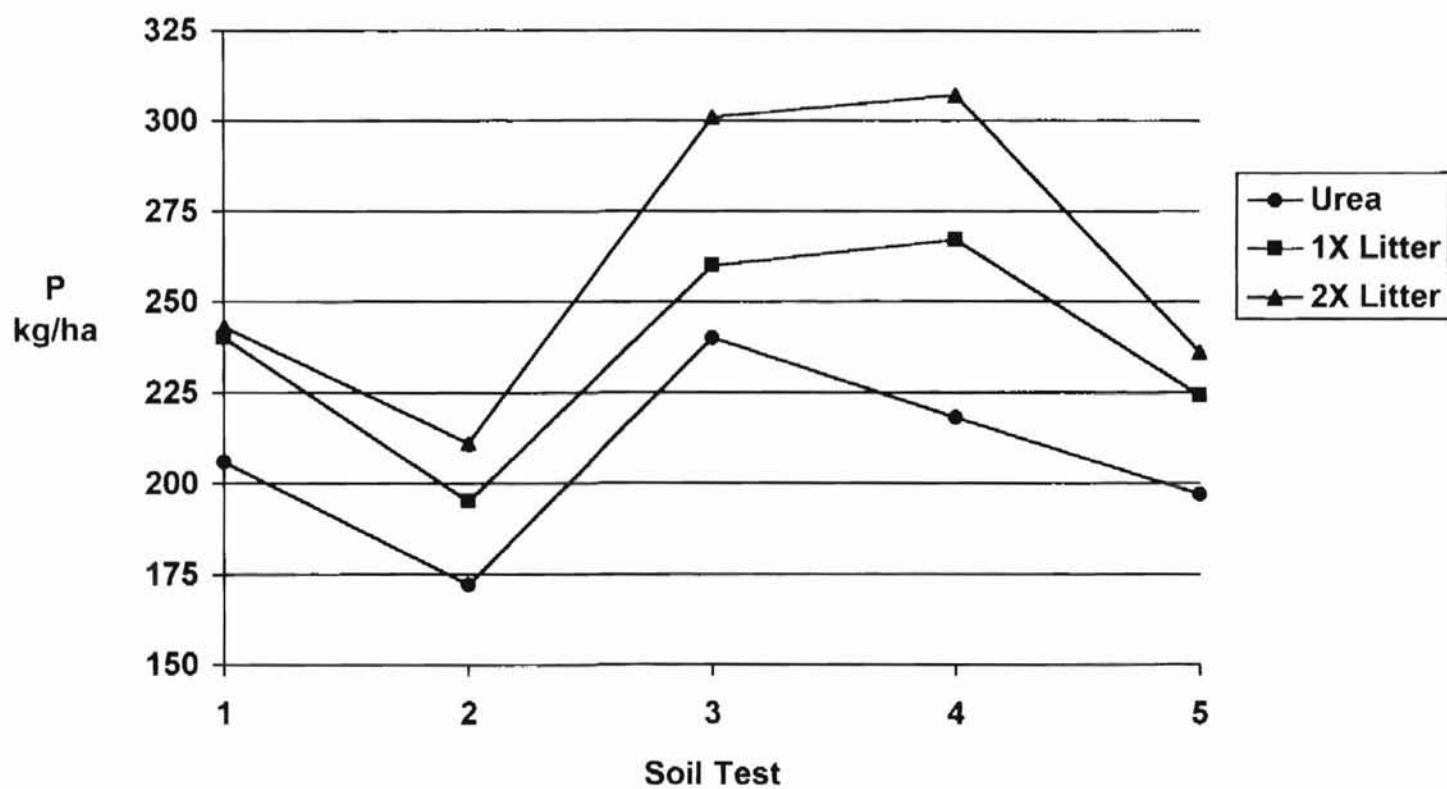


Figure 3.3. Soil P values at 15-30 cm, in plots where vetch cover crop was grown.

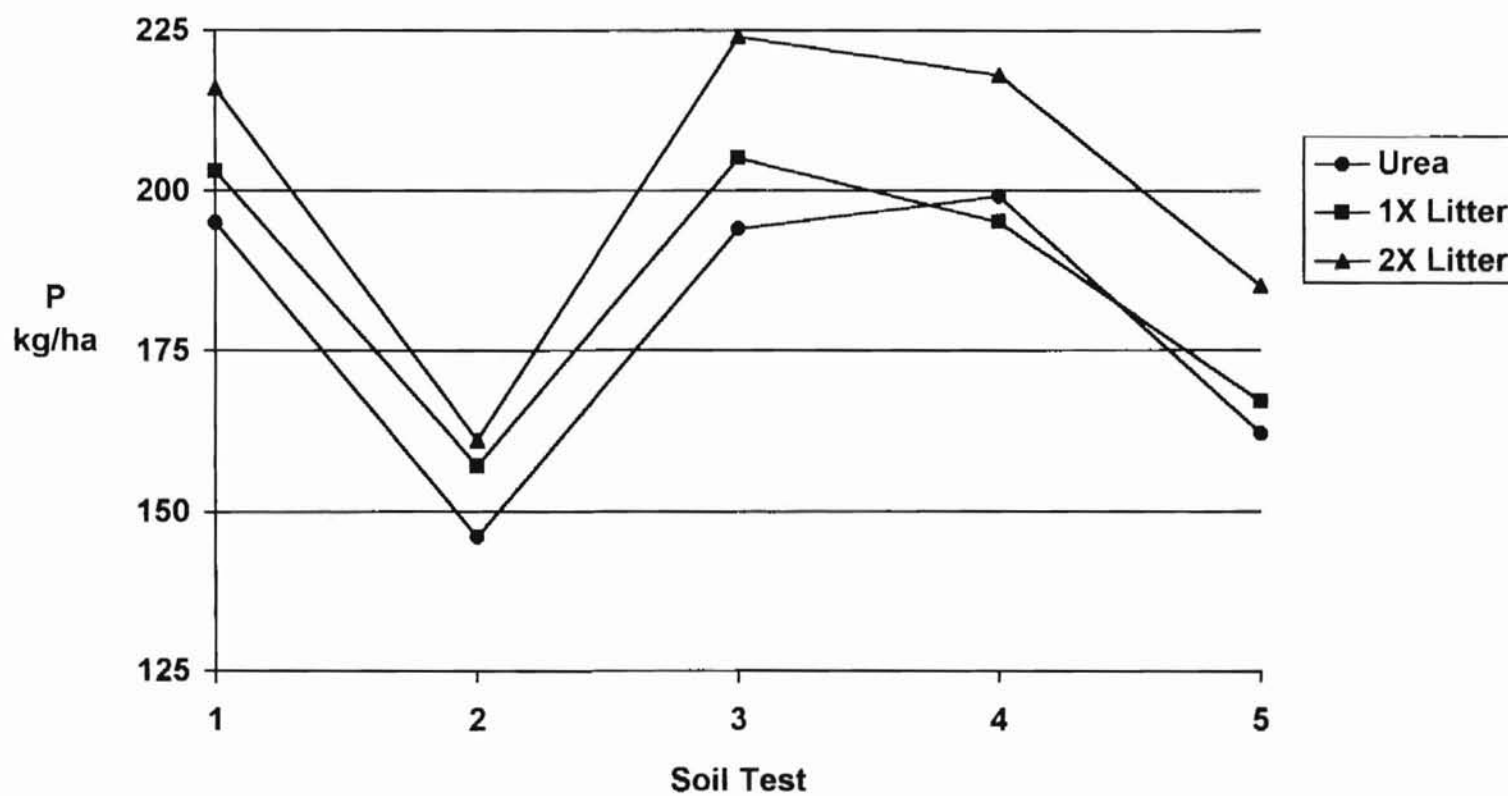
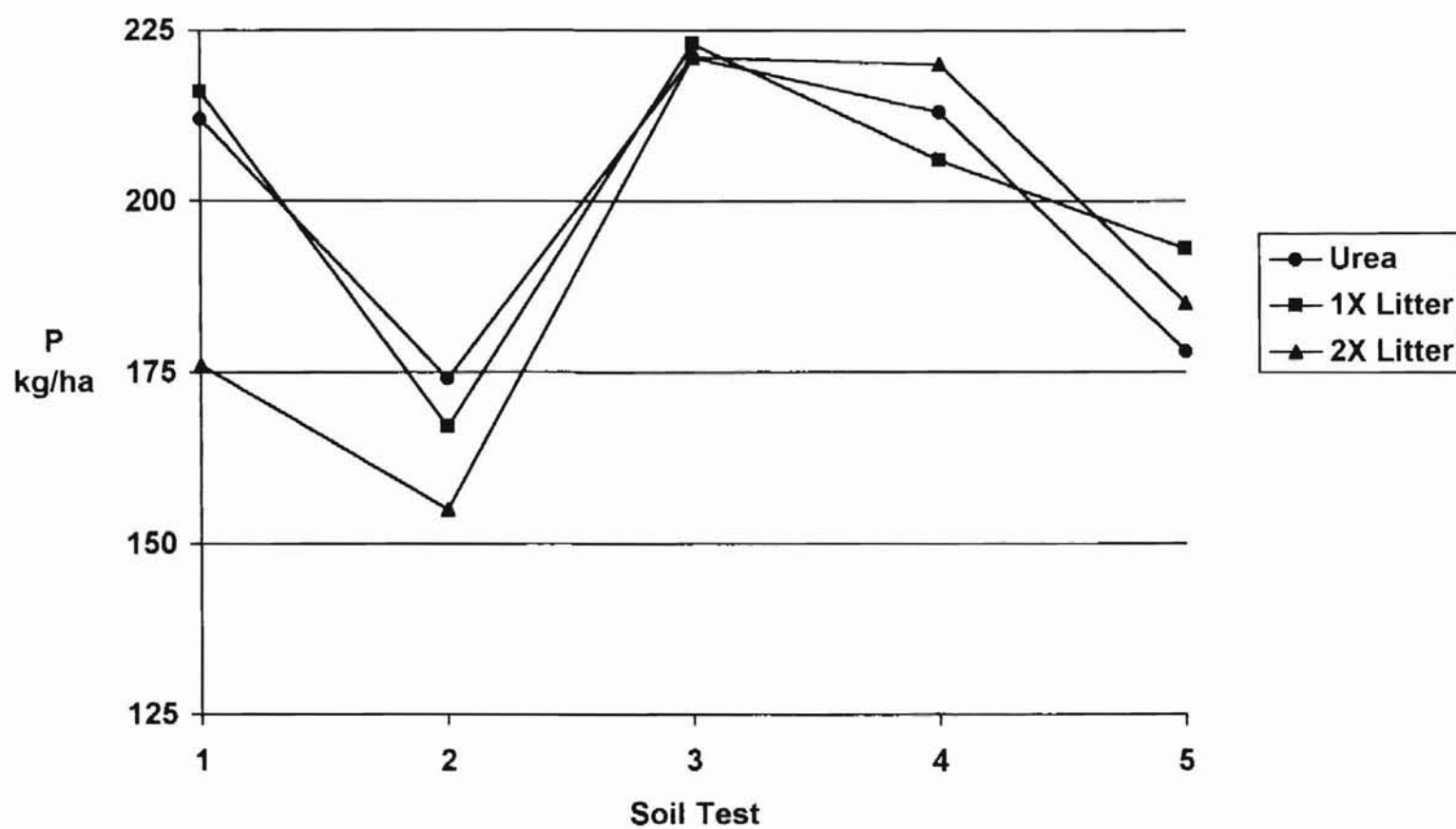


Figure 3.4. Soil P values, 15-30 cm, in fallowed plots.



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