SOIL ACIDITY AND PLANT NUTRIENT MANAGEMENT

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Chapter I

Comparison of Animal Manure with Lime in Correcting Aluminum Toxicity in an Acid Soil

ABSTRACT

Soil acidity is one of the most serious problems for agricultural production in acid soils. Manure is believed to be an effective alternative amendment material to lime for acid soil. The effect of feedlot manure, poultry litter on soil Al status and wheat growth was studied in this experiment compared to lime. Pot experiment was conducted by growing Custer winter wheat (Triticum aestivum L.) sensitive to Al toxicity and correlating wheat growth with soil extractable Al. An acid surface soil was mixed with 5 levels of feedlot manure, poultry litter and lime respectively and incubated at 85% of water holding capacity for 30 days in an environmentally controlled growth chamber before wheat was planted. Wheat was allowed to grow for 5 weeks after the 30-day incubation and harvested for aboveground dry matter. Application of feedlot manure and poultry litter reduced 0.01 M $CaCl_2$ extractable Al (Al_{CaCl2}), exchangeable Al (Al_{KCl}), and increased pH in soil as lime did. One g kg^{-1} of feedlot manure and poultry litter reduced Al_{CaCl2} 0.50 mg $kg^{-1}$and 0.68 mg kg^{-1}, respectively, compared to 1.46 mg kg^{-1} of that of lime. Wheat shoot dry weight negatively correlated with Al_{CaCl2}, Al_{KCl}, and positively correlated with soil pH.

However, at the same Al level, wheat dry matter weight was in the treatment order: poultry litter > feedlot manure > lime. In addition to aluminum toxicity, other growth factors might affect dry matter weight in the acid soil because animal manure might increase micronutrient availability and supply more plant growth stimulants than lime would. Manure can promote plant growth by reducing Al toxicity as lime did and by improving other plant growth conditions as well.

INTRODUCTION

Soil acidity is one of the major problems for agricultural production in many parts of the world (Kamprath, 1984). It controls the solubility and precipitation of chemical compounds of some essential plant nutrients and is therefore a deciding factor on their availability. Strongly acidic soils are phytotoxic, not only because of deficiency or excess of any one chemical element, but as the result of a complex of nutritional disorders: deficiency of essential nutrients like Ca, Mg, and Mo; decreased availability of P; and toxicity of Al, Mn, and H^+ (Haynes and Mokolobate, 2001). The relative importance of each of these factors is difficult to generalize across soils with inherently different soil solution chemistry. However, in strongly acidic soils ($pH < 5$) Al toxicity is considered the most detrimental problem (Foy, 1984; Kochian and Shaff, 1991). The initial and most obvious symptom of Al toxicity is the inhibition of root growth and injured root are characteristically stubby with reduced growth of the main axis and inhibited lateral root formation (Foy, 1988). Inhibition of root growth occurs through impedance of both cell elongation and cell division (Kochian, 1995). Since root growth is restricted, plant water uptake is considerably reduced. As a result, nutrient and/or water stresses are common in plants suffering from Al toxicity (Foy, 1984).

It is an established fact that liming acid soils improves the conditions for plant growth by increasing soil pH, decreasing the concentration of active Al level and increasing the supply of Ca and other nutrients (Adams, 1984).

However, it has been discovered that liming may also result in negative effects on plant growth and soil properties (Ahmad and Tan, 1986). Phosphorus and Mn deficiencies can be induced by lime applications (Kamprath, 1970). It was also noted that a reduction in uptake of P, Zn, B, and Mn occurred in corn plants as liming raised soil pH to neutral values (Farina et al., 1980). Liming has been found to decrease Mg content of plants (Grove and Sumner, 1985; Pavan et al., 1984). Furthermore, liming when needed is not practiced by many producers due to land ownership issues and cost constrains.

An alternative approach to liming may be the application of organic materials to reduce Al toxicity. As early as 1933, there were reports that the addition of organic matter could prevent Al toxicity (Hester, 1935; Mattson and Hester, 1933). Beneficial effects of organic matter application on aluminum detoxicification have been further confirmed by later investigations in acid soils and solution culture (Ahmad and Tan, 1986; Hoyt and Turner, 1975). Animal manure contains large amount of organic matter. It can be used as a source of organic matter to correct Al toxicity and at the same time as nutrient source.

Over 2.2 billion tons of animal manure is produced annually in the United States (Wright, 1998). Manure is often considered a waste product rather than a valuable resource (Hatfield and Stewart, 1998). Understanding the role of animal manure in acid soil can promote its proper use as a lime replacement and nutrient source. However, the importance of manure to correct aluminum toxicity compared to lime haven't been well documented. The objective of this study was to compare the effects of two types of manure and lime application on the aluminum status and wheat growth in an acid soil.

MATERIALS AND METHODS

Soil used for the greenhouse experiments was surface soil (0-15cm) collected from the Agronomy Research Station of Oklahoma State University in Perkins, Oklahoma, where winter wheat had not been able to be established due to low pH and aluminum toxicity. The soil series is Teller (fine-loamy, mixed, thermic Udic Argiustolls) (Table 1.1). Soil samples was air-dried in greenhouse and passed through 5 mm sieve. Soil properties are listed in Table 1.1. Soil test P is barely enough for plant growth. Soil test K was sufficient. Soil pH was low and Al saturation was high. Poultry litter and feedlot manure used as amendments were collected from a litter compost facility and a feedlot. Both were ground to pass 2 cm sieve. Poultry litter represents manure with low C/N while feedlot manure, with a high C/N. The nutrient contents of the manure used are shown in Table 1.2.

There were three treatments — feedlot manure (FM), poultry litter (PL) and lime (L), with 5 levels in each treatment. The rate of manure added to the soil was calculated to supply 0, 25, 50, 100 and 200 mg kg^{-1} available N, assuming N availability from manure is 50% of total N. The amount of application rates for all treatments are listed in Table 1.3. Supplementary fertilizer, 100 mg N kg^{-1} as urea to supply adequate N and 10 mg

P_2O_5 kg^{-1} as KH_2PO_4 to supply needed P were added to lime treatment based on soil test recommendation. All the treatments were replicated 5 times.

Two kg of soil and specific amount of manure or lime in different treatments were thoroughly mixed and placed into each of the 15(d)x15(h) cm plastic pots. All pots were incubated at 85% field water holding capacity at 25°C for 30 days before wheat was planted with sixteen wheat seeds per pot. The seedlings were thinned to 7 plants per pot shortly after germination and grown for 5 weeks. Water was adjusted to 85 % of the field water-holding capacity during the growing period. All the pots were randomly arranged in the environmentally controlled growth chambers and re-located once a week. Wheat shoots were harvested by cutting at the soil surface. All plants were washed with tap water and rinsed with deionized water, dried at 80° C for 24 hours and dry matter weight was recorded. Soil samples were collected before planting, immediately after harvest, and again 55 days after harvest.

Soil pH was measured in a 1:1 soil to H_2O suspension with an Accumet pH meter; Extractable Al and Exchangeable Al was extracted in 0.01M $CaCl_2$ and 1M KCl, respectively (Sumner and Miller, 1996) and measure by an ICP (Soltanpour et al., 1996) .

RESULTS AND DISCUSSION

Effect of manure application on pH and extractable Al in soil

Table 1.3 shows the changes of Al extracted by 0.01 M $CaCl_2$ (Al_{CaCl_2}) and by 1 M KCl (Al_{KCl}), and pH changes at 5 different manure and lime application rates after amended soils were incubated for 30 days.

Addition of feedlot manure and poultry litter to soil increased soil pH as lime did. Soil pH was well correlated with the amendments added (Table 1.4). However, the rate of pH increase by feedlot manure (FM) and poultry litter (PL) addition was much smaller than that by lime. FM raised soil pH by 0.042 units per g kg^{-1} and PL by 0.040 units per g kg^{-1} while lime increase soil pH by 0.75 units per g kg^{-1}. It seemed that the pH changes at low manure application rate was small. However, large amount of manure application introduced significant soil pH increase. The pH increase due to manure application was in agreement with the observations of other researchers (Hue and Licudine, 1999; Shen and Shen, 2001; Whalen et al., 2000; Wong et al., 1998). The reason for pH increase by addition of manure could be explained by addition of basic cation from manure (Wong et al., 1998). However, in this experiment, the difference between pH increase rate of FM and that of PL was not significant although the concentration of basic cation of PL was higher than that of FM. This result was not in agreement with the observation of (Wong et al., 1998) who found that the increased soil pH was directly proportional to the base cation (Ca, Mg and K) concentrations of the added organic material. The explanation of this might be that PL contained higher NH_4-N than FM. When the NH_4-N was nitrified to NO_3-N, there was a release of protons and decrease of soil pH (Haynes, 1993), which might offset the pH increase introduced by base cation addition.

$CaCl_2$ (0.01M) is a commonly used extractant (Sparks, 1996), and removes fraction of Al that may be closely related to plant response (Baligar et al., 1992; Hoyt and Nyborg, 1970; Machado and Gerzabek, 1993; Wright et al., 1989). Al extracted by 0.01 M $CaCl_2$ decreased as application rate increased in all treatments. However, the reduction of Al_{CaCl_2} by poultry litter and feedlot manure was much smaller than that by the lime

(Table 1.3). One g kg^{-1} of feedlot manure and poultry litter decreased the Al_{CaCl_2} by 0.50 mg kg^{-1} and 0.68 mg kg^{-1}, respectively, while 1 g kg^{-1} of lime reduced Al_{CaCl_2} by 1.46 mg kg^{-1} (Table1.4).

The reduction of Al_{CaCl_2} by FM and PL was linearly correlated with manure application rates, while the relationship of Al_{CaCl_2} with lime application rate was non-linear (Table 4). This trend probably reflects changes in the speciation of Al in the soils. It is well known that Al present in the soil solution in different forms and concentrations depends on pH (Lindsay, 1979). There is an equilibrium among forms of Al controlled by soil pH as the following: $Al^{3+} \leftrightarrow Al(OH)^{2+} \leftrightarrow Al(OH)^{+}_{2} \leftrightarrow Al_y(OH)^{+z}_{3y-z} \leftrightarrow Al(OH)_3$. Monomeric Al^{3+} ion will be dominant when the soil pH is less than 5.0 and Al^{3+} ion can be extracted easily by 0.01 M $CaCl_2$, while the amount of monomer Al^{3+} ion will decrease rapidly at pH values higher than 5.0 due to the formation of monomer and /or polymer hydroxyl species of Al and /or the precipitation of $Al(OH)_3$ (Hsu and Rich, 1960; Marion et al., 1976). These forms of Al existing mainly above the pH value of 5.0 are so strongly adsorbed by soils that they are not extractable by diluted neutral salts (McLean, 1965) like 0.01 M $CaCl_2$. It was reported that there was an approximate tenfold decrease in polynuclear Al concentration in dilute $CaCl_2$ suspensions for a pH rise of 1.0 in acid soils (Bache and Sharp, 1976). As manure was added to acid soil, soil pH increase, which partly explained the decrease of Al_{CaCl_2}. However, the rates of Al reduction due to pH increase in feedlot manure and poultry litter treatments were larger than that in lime treatment (Table 1.3). This suggests that other mechanisms might have impact on Al_{CaCl_2} reduction. Adsorption of Al onto decomposing organic residues would tend to reduce exchangeable Al levels at the same time (Hoyt and Turner, 1975). Phosphate in manure might also play a role in precipitate Al especially for poultry litter, which contained a large amount of P. In this experiment, high application rates 2 and 4 g kg^{-1} of lime raised soil pH to above 5.0, over which no linear relationship existed between lime application rate and Al_{CaCl_2}.

Exchangeable Al extracted by 1 M KCl (Al_{KCl}) of different treatments displayed a trend similar to Al_{CaCl_2}. Al_{KCl} decreased with increased application rate in poultry litter and feedlot manure treatments (Table 1.3) The Al_{KCl} deceased by 8.6 mg kg^{-1} and 12 mg kg^{-1} per one g kg^{-1} of feedlot manure and poultry litter, respectively, while 1 g kg^{-1} of lime reduced Al_{KCl} by 105 mg kg^{-1} on the average of first three lime application levels. Exchangeable Al constitutes an important buffered reserve of labile Al that can be solubilized readily by other exchangeable cations. Decrease of Al_{KCl} reduced the potential capacity of soil to supply soluble Al to soil solution.

LSD test showed that there were no significant differences between the Al_{CaCl2} of PL and FM treatments when soil was incubated for 30, 65 days and 120 days (Table 1.5). It seemed that amelioration effect of organic amendment on reducing Al toxicity found in this experiment could last for a long time, which was different from the results of others that the amelioration effect lasted only for a short time (Wong and Swift, 1995). The difference between this study and Wong and Swift (1995) may be due to the materials we used was not as easily decomposed as theirs.

Effect of poultry litter, feedlot manure and lime application on wheat growth

Figure 1.1 shows the effect of poultry litter, feedlot manure and lime application on the dry matter weight of wheat grown for 35 days in growth chambers. Poultry litter and feedlot manure greatly increased wheat dry matter weight as application rate increased. Poultry litter was more effective than feedlot manure because poultry litter reduced more Al_{CaCl_2} concentration per unit of amendment and poultry litter also contained more plant nutrients than feedlot manure (Table 1.2 and 1.3).

At low rates, feedlot manure and poultry litter was a little less effective than lime in increasing wheat yield (Fig. 1.1). Due to high capacity of lime to reduce Al_{CaCl_2} as discussed early, aluminum toxicity could be relieved quickly by lime while large amount of poultry litter and feedlot manure would be needed to significantly reduce aluminum toxicity. At 100 mg kg^{-1} N level the dry matter weight of wheat in poultry litter treatment was higher than that of feedlot treatment although Al_{CaCl_2} and Al_{KCl} in poultry litter treatment was higher than that of feedlot manure treatment. In such case, the reason may be that other factors such as nutrient content in addition to N and plant stimulants in poultry litter was higher than that of feedlot manure.

Aluminum toxicity was a plant growth-limiting factor in the soil, which was shown on the regression equations describing the relationship between wheat dry weight and soil pH, $CaCl_2$ extractable Al, and exchangeable Al. As soil pH increased and Al_{CaCl_2} and Al_{KCl} decreased, wheat dry matter weight increased. All the above-mentioned parameters were well correlated with wheat dry matter weight (Table 1.6). However, the impact of them on dry matter weight for different amendment treatments was different. For example, at the same Al_{KCl} level, the dry matter weight followed the pattern: PL > FM > lime (Fig. 1.2). This implies that both animal manure and lime are effective in reducing Al toxicity in acid soils, but after Al toxicity was ameliorated, other factors such as micronutrients, and plant growth stimulants from the manure decomposition could also contribute to yield increase.

CONCLUSION

Poultry litter and feedlot manure increased soil pH, reduced $CaCl_2$ extractable Al and exchangeable Al in soil although their effects per unit mass were not as great as lime. However, at the same extractable aluminum level, poultry litter was more effective on the increase of wheat growth than feedlot manure and lime. This suggests that other factors such as micronutrient availability and plant growth stimulants might affect wheat growth after aluminum toxicity was alleviated.

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Tab. 1.1 Selected soil chemical and physical properties and plant available nutrient status

OC	NO_3-N	STP†	STK‡	pH	Al Saturation§	Texture
mg kg^{-1}					%	
11	20	31	175	4.3	28	sandy loam

† Soil test P using Mehlich 3 extraction
‡ Soil test K using Mehlich 3 extraction
§ Percentage of exchangeable Al of total exchangeable cations

Tab. 1.2 pH and major nutrient concentrations of feedlot manure and poultry litter used in the incubation study

	pH	OC	Total N	P_2O_5	K_2O	Ca	Mg	NH_4-N	NO_3-N
		———	———	$g\ kg^{-1}$	———	———	———	—$mg\ kg^{-1}$	—
Feedlot manure	6.5	229	16.6	9.5	13.2	14.6	5.2	626	72
Poultry litter	8.2	131	32.8	43	29.3	27.0	5.7	5800	204

Tab. 1.3 Effect of poultry litter, feedlot manure and lime on soil pH, extractable Al (Al_{CaCl2}), exchangeable Al (Al_{KCl}) 30 days after amendments application

Treatment	Rate	Available N†	Al_{CaCl2}	Al_{KCl}	pH
	g kg^{-1}	——— mg kg^{-1} ———			
Poultry litter	0	0	7.1a ‡	128a	4.25a
	1	25	5.8b	112b	4.34b
	2	50	4.4c	100c	4.33b
	4	100	2.5d	68d	4.40c
	8	200	1.4e	27e	4.61d
Feedlot manure	0	0	7.1a	128a	4.25a
	1.5	25	5.4b	109b	4.36b
	3	50	4.1c	98c	4.37b
	6	100	2.1d	62d	4.54c
	12	200	0.7e	24e	4.78d
Lime	0	100	6.7a	86a	4.60a
	0.5	100	4.0b	67b	4.56a
	1	100	1.1c	22c	4.99b
	2	100	0.1d	16d	6.03c
	4	100	0.0d	6.1e	7.09d

† Available N from manure was assumed to be 50% of total N.
‡ LSD (0.01)

Tab. 1.4 The relationship between Al_{CaCl_2}, Al_{KCl} , pH and amendment application rate after amended soil were incubated for 30 days

Amendments	Al extracted	Regression	r^2
Feedlot manure	Al_{CaCl_2}	$y = -0.50x + 6.9^{\dagger}$	0.906*
	Al_{KCl}	$y = -8.6x + 123$	0.971**
	pH	$y = 0.042x + 4.3$	0.942**
Poultry litter	Al_{CaCl_2}	$y = -0.68x + 6.2$	0.881*
	Al_{KCl}	$y = -12x + 124$	0.968**
	pH	$y = 0.040x + 4.3$	0.917**
Lime	Al_{CaCl_2}	$y = 4.86e^{-1.44x}$	0.858*
	Al_{KCl}	$y = 83.9e^{-0.713x}$	0.887*
	pH	$y = 0.75x + 4.3$	0.978**

† Where y: Al_{CaCl_2}, Al_{KCl} (mg kg^{-1}) and pH accordingly, x: amendment rate (g kg^{-1}).
*, * * Significant at the 0.05 and 0.01 probability levels, respectively.

Tab. 1.5 T tests for Al_{CaCl_2} changes over time for all treatment at 5 levels as a whole

	Feedlot manure			Poultry litter			Lime		
Day	Mean	n		Mean	n		Mean	n	
	mg kg^{-1}			mg kg^{-1}			mg kg^{-1}		
30	3.8	25	a†	4.2	25	a	2.3	25	a
65	3.7	25	a	4.1	25	a	2.5	25	a
120	3.6	25	a	4.1	25	a	2.5	25	a

†LSD $\alpha = 0.01$

Tab. 1.6 Relationship between wheat dry weight and soil pH, $CaCl_2$ and KCl extractable Al

Treatment		Regression equation	r^2
	pH	y=4.832x -20.3	0.916**
Poultry liltter	Al-$CaCl_2$	y= -0.2751x + 2.03	0.896*
	Al-KCl	y=-0.0168x +2.23	0.986**
	pH	y=2.414x -10.134	0.932**
Feedlot manure	Al-$CaCl_2$	y=-0.1727x +1.30	0.738*
	Al-KCl	y =- 0.0118x + 1.63	0.891*
	pH	y = 0.3256x - 1.07	0.721
Urea	Al-$CaCl_2$	y = -0.138x + 12.32	0.686
	Al-KCl	y = -0.0023x + 0.5957	0.819*
	pH	y = 0.2397x -0.6868	0.995**
Lime	Al-$CaCl_2$	$y = 0.5313x^{-0.1573}$	0.946**
	Al-KCl	$y = -1.835x^{-0.3498}$	0.918**

* significant at 0.05 level
** significant at 0.01 level

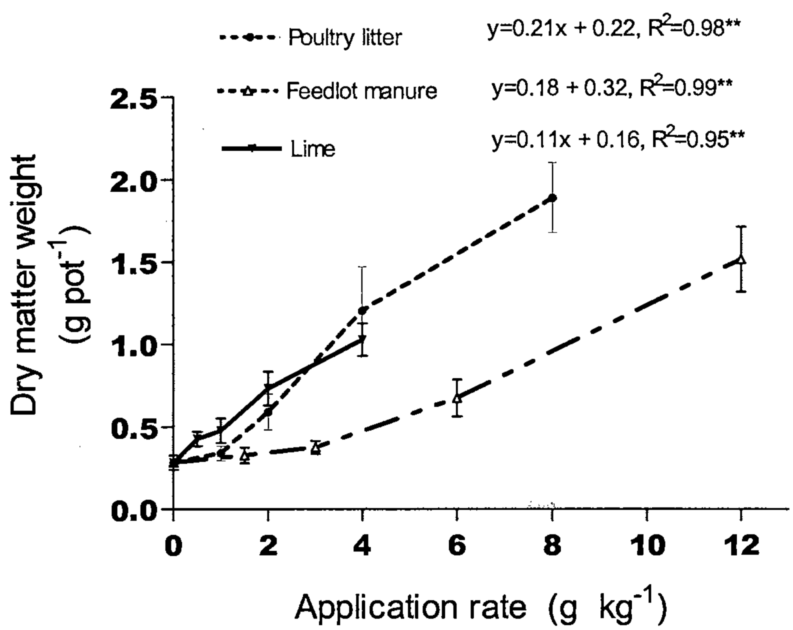

Fig. 1.1 Effect of poultry litter, feedlot manure and lime amendment on wheat dry matter weight growing for 35 days in pot experiment

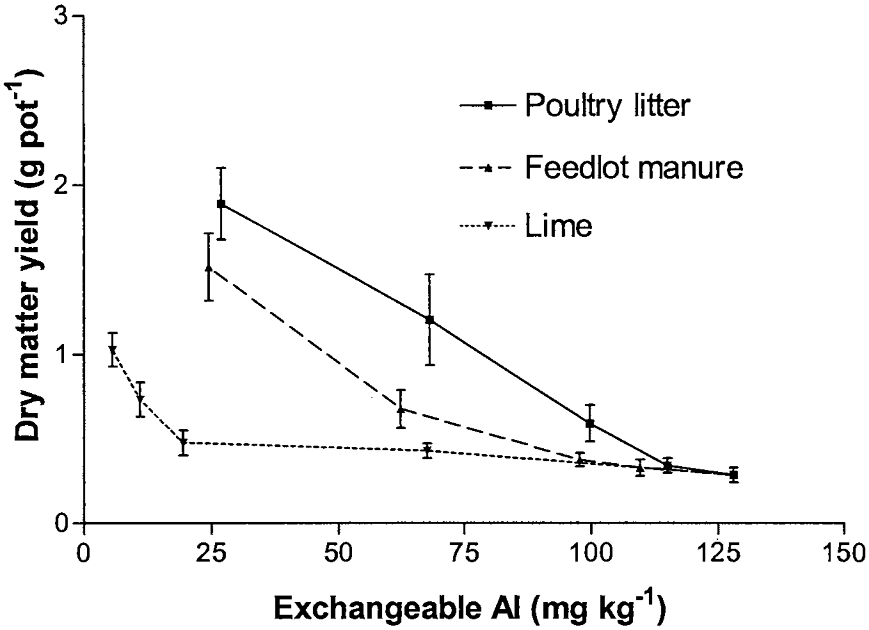

Fig. 1.2 Effect of exchangeable Al (extracted by 1M KCl) on dry matter weight of winter wheat growing in poultry litter, feedlot manure and lime amended soils for 35 days

Chapter II

Contribution of pH Change, Phosphorus and Organic Matter Associated with Manure Application to Reduction of Al Toxicity

ABSTRACT

Alleviation of aluminum (Al) toxicity in acid soils by application of manure can be attributed to the pH increase, organic bonding and phosphate reaction with Al in the soil. This experiment using soil incubation was conducted to investigate the relative importance of those mechanisms. The overall effect of manure application on extractable Al was investigated by amending an acid soil with feedlot manure at 0, 1.5, 3, 6, and 12 g kg^{-1}. The impact of pH increase due to manure application was studied by adjusting soil pH with HCl or NaOH to seven pH levels between pH 4.08 to 6.55 for each of 0, 3, and 6 g kg^{-1} manure application rate. The contribution of phosphorus addition to Al reduction was examined by adding solution of KH_2PO_4 to soil also amended with manure at rate of 0, 3, and 6 g kg^{-1}. Al in soil was extracted by 0.01 M $CaCl_2$, 1 M KCl, 0.33 M $LaCl_3$, and 0.5 $CuCl_2$ at the 1st, 7th and 30th day of incubation. The effect of organic matter on Al decrease was calculated by subtracting pH effect, and phosphate effect from the overall effect of feedlot manure. In our experiment, the contribution of pH accounted for 10-20% of Al_{CaCl2} reduction, and 15-16 % of Al_{KCl} reduction; phosphate, 4-9 % of Al_{CaCl2} and 6% of Al_{KCl} and organic matter, 71-86% of Al_{CaCl2} and 78% of Al_{KCl} reduction. It seemed that organic binding with Al played a more important role than pH increase and phosphorus addition to an acid soil through manure application.

INTRODUCTION

Aluminum toxicity is the most serious factor affecting plant growth in acid soils (Raij, 1991). Manure has been considered as an alternative amendment material to reduce aluminum toxicity in acid soil where lime application is not practicable (Hue and Licudine, 1999.; Shen and Shen, 2001).

When manure was applied to acid soils, three mechanisms would be involved in the detoxification of Al. First, addition of manure to soils could result in an increase in soil pH (Hoyt and Turner, 1975; Hue, 1992). The magnitude of the rise in soil pH varies depending on the type of residue, its rate of application and the buffering capacity of the soil. For addition of about 20 t ha^{-1}, increases in soil pH have generally been in the range of 0.20-0.5 pH unit and, with rates of 40-50 t ha^{-1}, increases of 0.8-1.5 pH units have been recorded (Berek et al., 1995; Noble et al., 1996). As pH increases soluble Al and exchangeable Al in soil decreases. Secondly, aluminum may form soluble or insoluble complexes with organic matter or it may be non-specifically adsorbed onto exchange sites. There has been little distinction between these two mechanisms in published research. Therefore, aluminum will be described as being "bound" to organic matter for easy discussion. Adsorption of Al onto decomposing organic residues and complexation of Al by solid-phase organic matter will favor a reduction in Al concentrations in soil solution and exchangeable Al levels (Bessho and Bell, 1992; Hoyt and Turner, 1975). Finally, manure contains relatively high concentration of phosphorus due to the phosphorus addition in animal feed. The majority of phosphorus in manure is in the inorganic form of orthophosphate and the most of the rest of organic phosphorus is easily decomposable by microorganisms to the inorganic form (Zhang et al., 2000). Therefore, the phosphate in manure should be readily reactive once it is added into soil and it may precipitate Al from solution (Lindsay, 1962). However, the contribution of each mechanism to the reduction of aluminum toxicity in acid soils remains to be studied.

Several soil test methods have been used to predict the conditions limiting plant growth and estimate the pools of Al in soil which should been ameliorated. Reports found that 0.01 M $CaCl_2$, which reflects soil solution Al, was superior to other extractants for predicting the pH/Al toxicity response (Shuman et al., 1990; Webber et al., 1982; Wright et al., 1989). Furthermore, 0.01 M $CaCl_2$ extractable Al has been shown to be well correlated with the free ion activity of Al in soil solution and it has been argued that this is precisely the reason for its superior efficacy in predicting Al toxicity as a function of pH (Wright et al., 1989). The most commonly employed extractant for Al is 1M KCl. This extractant is used both for the determination of exchangeable Al, which is utilized in the calculation of effective CEC and Al saturation, and in some cases for the determination for lime requirement (Kamprath, 1970). For soils high in organic matter, 1 M KCl is still employed in the operationally defined ECEC measurement; however, if the quantity of organically bound Al is desired a more aggressive extractant is needed. Both $LaCl_3$ and $CuCl_2$ have been shown to be far more effective than KCl in displacing organically bound Al (Bloom et al., 1979; Hargrove and Thomas, 1981; Juo and Kamprath, 1979; Oates and Kamprath, 1983a; Oates and Kamprath, 1983b). Copper has a high affinity for the carboxyl sites that bind Al and can readily replace Al bound to organic matter. Lanthanum has been found to be somewhat less effective in displacing organically bound Al. However, Oats and Kamprath (1983b) found that $LaCl_3$ extractable Al was the most effective predictor of lime requirement for acid soils having varying organic matter compared to either KCl, which extracted too little, or $CuCl_2$, which extracted too much Al. In general, $CaCl_2$, KCl, $LaCl_3$ and $CuCl_2$ extractable Al can be considered to approximately represent water-soluble Al, exchangeable Al, exchangeable Al plus loosely organic bound Al and exchangeable Al plus all organic bound Al, respectively.

This experiment was designed to investigate the mechanisms of Al reduction by manure addition to an acid soil. Contribution of pH changes, organic complexation and reaction with phosphate to the forms of Al extracted by different extractants were examined.

MATERIALS AND METHODS

A lab incubation study was conducted to examine the relative importance of pH change, organic materials and phosphorus addition to soil Al levels. The whole experiment was divided into three sets:

Set 1 was used to investigate the comprehensive effect of feedlot manure on Al extracted by 4 different extractants. Soil and feedlot manure used in this experiment is the same as described in Chapter I. Feedlot manure was added to soil at the rate of 0, 1.5, 3.0, 6.0 and 12 g kg^{-1}. Soil of 200g and specific amount of manure were mixed in 250ml plastic cups. De-ionized water was added to 80% field water holding capacity. Cups were covered with lids and kept at 25°C to incubate for 30 days. All the treatments were replicated three times. The amended soil was sampled on the 1st, 7th and 30th day for analysis. Al in soil samples was extracted by 0.01M $CaCl_2$, 1 M KCl, 0.33 M $LaCl_3$, and 0.5 M $CuCl_2$, and measured by an ICP (Bertsch and Bloom, 1996; Soltanpour et al., 1996). Soil pH was determined with 1:1 soil:water ratio (Thomas, 1996).

Set 2 was designed to determinate the effect of pH changes at different manure application rates on Al extracted by different extractants. Soil pH was adjusted to the targeted levels: pH 4.0 4.2, 4.4, 4.6, 4.8, 5.0 and 5.2 with HCl or NaOH at each of the 3 feedlot manure application rates (0, 3 and 6 g kg^{-1}). However, the actual pH shifted due to soil buffering capacity change from the manure addition. Soil, manure and incubation conditions, sampling and analysis were similar to those described in set 1.

Set 3 was designed to estimate the effect of phosphorus at different manure application rates on Al extracted by 4 different extractants. Extra phosphate as KH_2PO_4 was added as solutions with different concentration at the rate of 20, 40, 80 and 160 mg kg^{-1} P to soil amended with feedlot manure at 0, 3 and 6 g kg^{-1} respectively. Soil and incubation conditions, sampling and analysis were similar to those stated in set 1.

The effect of organic matter in feedlot manure on Al extracted by different extractants was calculated by subtraction of the effects of pH observed in set 2 and the effect of phosphate in set 3 from the overall effect observed in set 1.

Statistical analysis was performed with SAS procedures ANOVA and GLM (SAS Institute, 1999).

RESULTS AND DISCUSSION

Effect of feedlot manure on Al extracted by $CaCl_2$, KCl, $LaCl_3$, and $CuCl_2$

Fig. 2.1 shows the Al extracted from manure-amended soils by 4 different extractants after 1, 7, and 30 day incubation. Addition of feedlot manure reduced Al extracted by 0.01 M $CaCl_2$ (Al_{CaCl_2}), 1 M KCl (Al_{KCl}), 0.3 M $LaCl_3$ (Al_{LaCl_3}), and 0.5 M $CuCl_2$ (Al_{CuCl_2}). As feedlot manure application rate increased, less Al was extracted by all four extractants in the 1st, 7th and 30th day, respectively. In addition, as incubation time increased the Al_{CaCl_2}, Al_{KCl}, Al_{LaCl_3} and Al_{CuCl_2} decreased at each manure application rate accordingly. However, all three sampling dates had similar trends in Al reduction with manure rates. The effect of time on Al decrease might be introduced by pH increase during the incubation period (Fig. 2.2). The partial anaerobic condition in the water filled pores in soil might cause pH increase over time. After one day incubation, 12 g kg^{-1} feedlot manure reduced Al_{CaCl_2} 6.4 mg kg^{-1} (70%) compared to 0 application rate treatment; Al_{KCl} by 65 mg kg^{-1} (54%); Al_{LaCl_3} by 48 (22%) and Al_{CuCl_2} by 33 mg kg^{-1}(11%). Al_{CaCl_2} represents the water soluble Al in soil which contains the toxic forms of Al in soil. Although the absolute amount of Al_{CaCl_2} reduced was small compared with the Al extracted by the other methods, relative Al_{CaCl_2} reduction was the greatest. Therefore, feedlot manure was efficient in ameliorating Al toxicity in an application rate practical to most farmers. Al_{KCl} extracted mostly exchangeable Al and was the potential source of solution Al in soil. When solution Al decreased, exchangeable Al would be released from exchange sites to maintain equilibrium with solution Al. The reduction of absolute and relative amount Al extracted by KCl was larger than Al_{LaCl_3} and Al_{CuCl_2}, respectively. It was possible that some of Al bonded with organic matter in the soil amended with feedlot manure could not be extracted by KCl.

Multiple mechanisms could involve in the reduction of Al in soil amended by animal manure. The above results were the overall effect. The contribution from pH increase, phosphate and organic matter addition to Al deduction will be discussed in the following sections.

Effect of soil pH change on Al extracted by $CaCl_2$, KCl, $LaCl_3$, and $CuCl_2$

Fig. 2.3, 2.4, 2.5, and 2.6 show Al extracted from manure amended soils with different pH levels. As soil pH increased, Al extracted by $CaCl_2$, KCl, $LaCl_3$, and $CuCl_2$ decreased in three manure application rates and the trend in different incubation time was similar. The only difference was that soil pH increased slightly due to the incubation time, which also resulted in slight decrease of Al extracted by different extractants. The extractable Al was negatively correlated with soil pH. At the first day, Al extracted by different extractants was linearly correlated with soil pH. By calculating the slopes of the relationship between Al extracted by different extractants and soil pH, the effect of unit pH change on Al extracted by different extractants could be compared. As for Al extracted by $CaCl_2$, the slopes were 7.32 mg per pH unit when no feedlot manure was applied, 5.85 mg per pH unit with the low feedlot manure application rate (3 g kg^{-1}) and 2.28 mg per pH unit with the high feedlot manure application (6 g kg^{-1}). After manure was added to soil, soluble Al was significantly reduced by organic binding, pH increase and the reaction with phosphorus. Therefore, the effect of change of soil pH after manure application on soluble Al was smaller than that without manure application. The might suggest that lime has less effect on Al toxicity after manure was applied even the pH of manure amended soil is still low than that introduced by application of lime alone.

The calculated slopes of Al_{KCl} vs pH were 58.4, 56.2 and 46.3 mg per pH unit at 0, 3, and 6 gkg^{-1} manure rate, respectively. The relative change of slopes was small in different manure application rate. The slopes of Al_{LaCl_3} vs pH were 60.1, 59.9 and 55.9 mg per pH unit and was similar to those of Al_{KCl}. The slopes of Al_{CuCl_2} were 35.2, 32.2 and

26.1 mg per pH unit at 3 manure application rates accordingly. It seems that effect of pH on Al_{KCl} and Al_{LaCl_3} was greater than on Al_{CuCl_2}.

Effect of Phosphate addition on Al extracted by $CaCl_2$, KCl, $LaCl_3$, and $CuCl_2$

Fig. 2.7, 2.8, and 2.9 shows the Al extracted by different extractants after 1, 7, and 30 day incubation. Phosphate addition to soils with and without manure reduced Al extracted by $CaCl_2$, and KCl. However, it increased Al extracted by $LaCl_3$ and had not significant effect on Al extracted by $CuCl_2$. The trends for Al extracted by 4 extractants in the 1st, 7th and 30th day were similar. Al_{CaCl_2} and Al_{KCl} were negatively correlated with phosphate added. Al_{CaCl_2} was decreased by P addition from 8.85 to 5.54 mg kg^{-1} when there was no manure application while it decreased from 2.80 to 1.60 mg kg^{-1} at highest manure application rate. Higher rate of manure application already reduce Al_{CaCl_2} significantly, therefore the additional effect of P on Al reduction was much smaller than that at lower manure rates. The trend of Al_{KCl} as impacted by P and manure addition was similar to that of Al_{CaCl_2}.

However, $LaCl_3$ extracted more Al from P treatment than that from control. The mechanism for the Al increase may be that phosphorus can react with Al in soil. The more phosphorus added, the more Al reacted with the phosphorus. When $LaCl_3$ is used to extract Al, more Al will release at higher phosphorus rate due to high capacity of La to precipitate phosphate. From our result, it may suggest that 0.3 M $LaCl_3$ and 0.5 M $CuCl_2$ may not be suitable methods for estimation of organic bound Al when high amount of phosphate appears.

Estimate of the effect of organic matter on the Al extracted by $CaCl_2$, KCl, $LaCl_3$, and $CuCl_2$

The composition of manure is very complicated. It is difficult to separate all its organic components from the others. Methods in doing so will generally cause denaturation of organic matter (Georing and Soest, 1970). Low-molecular-weight organic acids have been used to demonstrate the capacity of -OH and -COOH groups to complex aluminum (Hue et al., 1986). H-peat and fresh alfalfa meal have been involved in the observation of the effect of pure organic matter on soil Al changes (Hargrove and Thomas, 1981; Hoyt and Turner, 1975). However, the composition of these materials was quite different from that of manure. In this experiment, a calculation method was employed to estimate the bonding capacity of organic matter in manure to reflect the actual situation in soil.

The results of set 1 experiment revealed the overall effect of manure on the reduction of Al extracted by different extractants; that of set 2, the impact of pH on extractable Al; and that of set 3, the effect of phosphate addition on extractable Al. Generally, the interaction of pH, phosphorus and organic matter towards Al extracted by $CaCl_2$ and KCl was assumed to be negligible due its complexity. In the set 2 with pH changes, at a specific manure application rate, the extractable Al change introduced by pH should be credited to the pure pH changes which exclude the effect of the interaction of pH and organic matter and effect of interaction of pH with phosphate. The same explanation can be applied to set 3 with phosphate experiment. Based on the above assumption, the magnitude of the effect of organic matter in manure on the extractable Al can be calculated using the following formula:

$$Al_{om} = Al_{all} - Al_{pH} - Al_{P}$$

Where, Al_{om} is the calculated decrease of extractable Al contributed by organic matter addition, Al_{all} is the overall decrease of Al by manure addition, Al_{pH} is the decrease of extractable Al contributed by pH changes and Al_{P} is the decrease of extractable Al contributed by phosphate addition.

Based on the calculation, the magnitude of Al decrease due to different mechanisms is listed in Table 2.1. The estimated Al reduction due to organic binding accounted for more than 65% decrease of Al extracted by 4 extractants while the role of pH and phosphate is relatively small because the pH changes and phosphate addition by manure application is relatively small. It seems that organic combination with Al plays a more important role than pH increase and phosphate addition when manure is used as an alternative amendment for acid soils.

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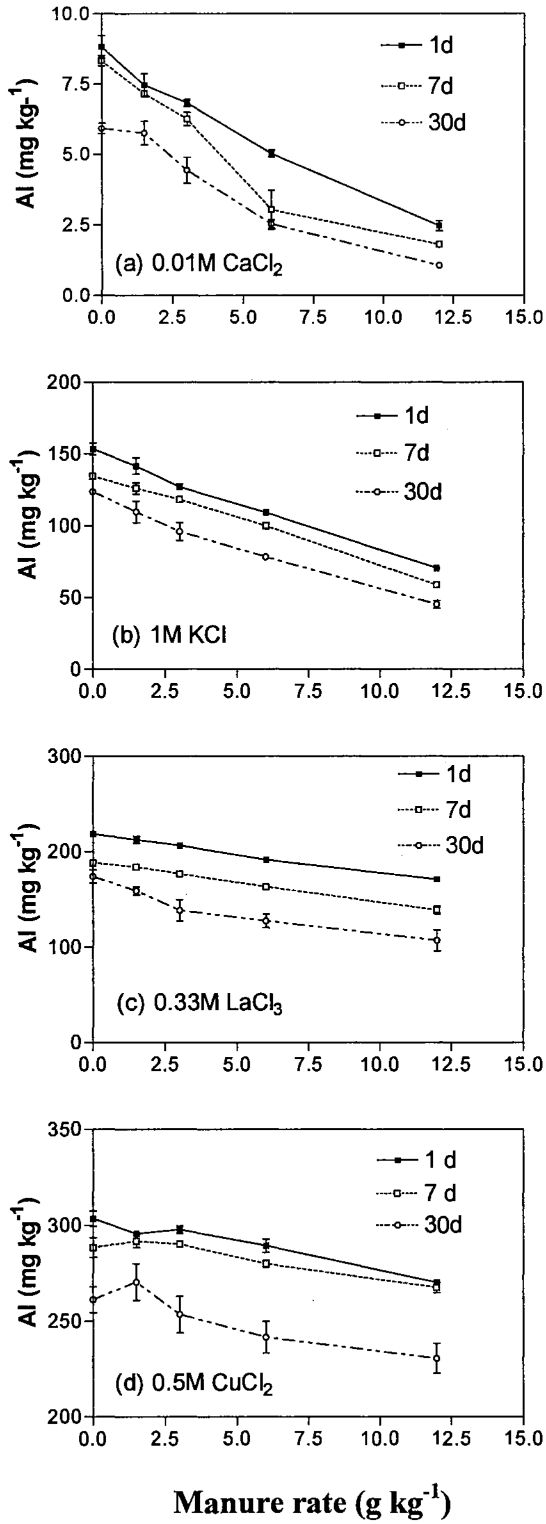

Fig. 2.1 Changes of Al extracted by $CaCl_2$ (a), KCl (b), $LaCl_3$ (c) and $CuCu_2$ (d) with different manure application rates sampled at 1th, 7th, and 30th day of incubation

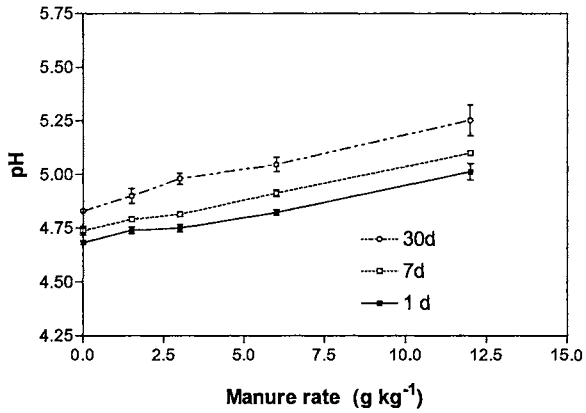

Fig. 2.2 Soil pH changes with addition of manure at 0, 1.5, 3.0, 6.0 and 12 g kg^{-1} sampled at 1st, 7th and 30th day of incubation

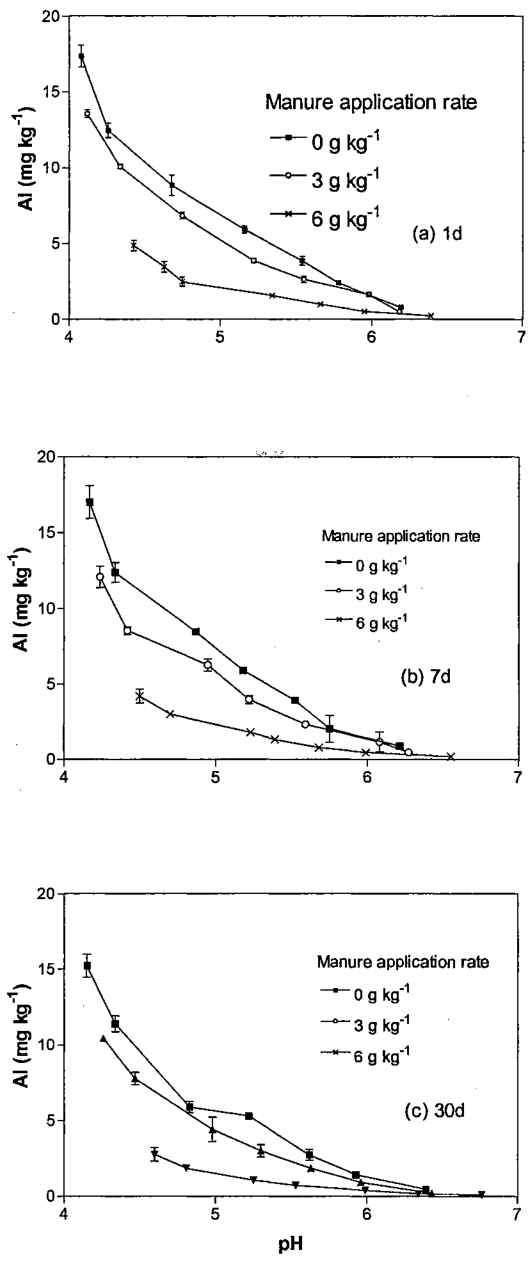

Fig. 2.3 Relationship between Al extracted by 0.01 M $CaCl_2$ and soil pH*

*Soil pH was adjusted with HCl or NaOH after 0, 3, and 6 g kg^{-1} feedlot manure was mixed with the starting acid soil

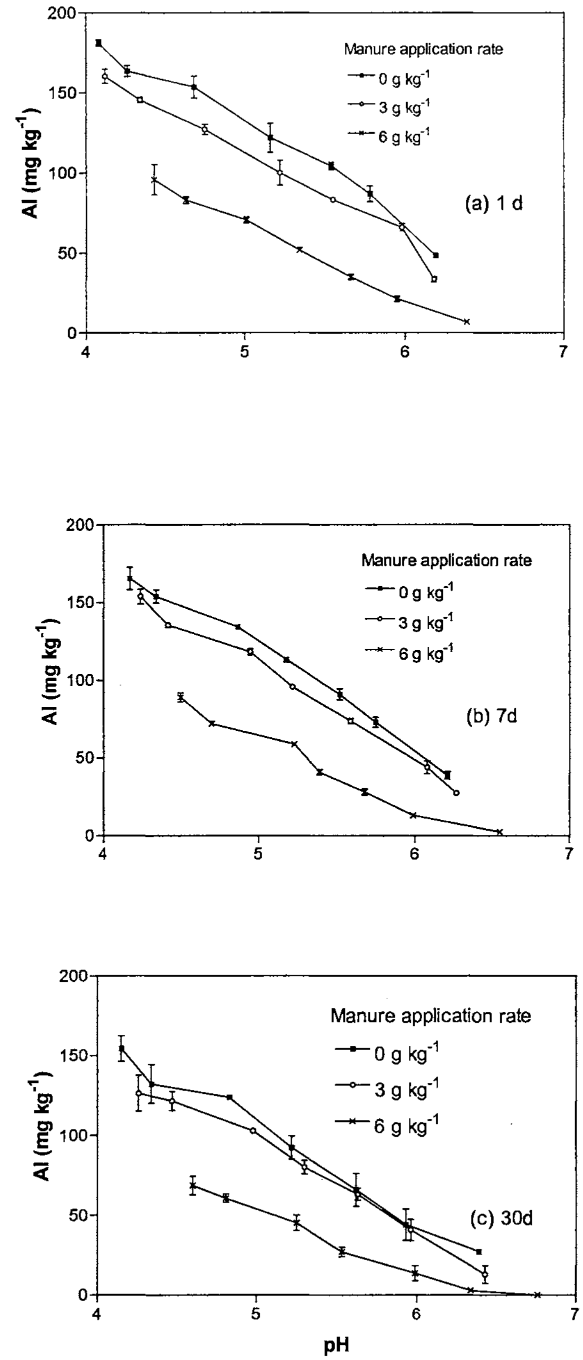

Fig. 2.4 Relationship between Al extracted by 1 M KCl and soil pH*

*Soil pH was adjusted with HCl or NaOH after 0, 3, and 6 g kg^{-1} feedlot manure was mixed with the starting acid soil

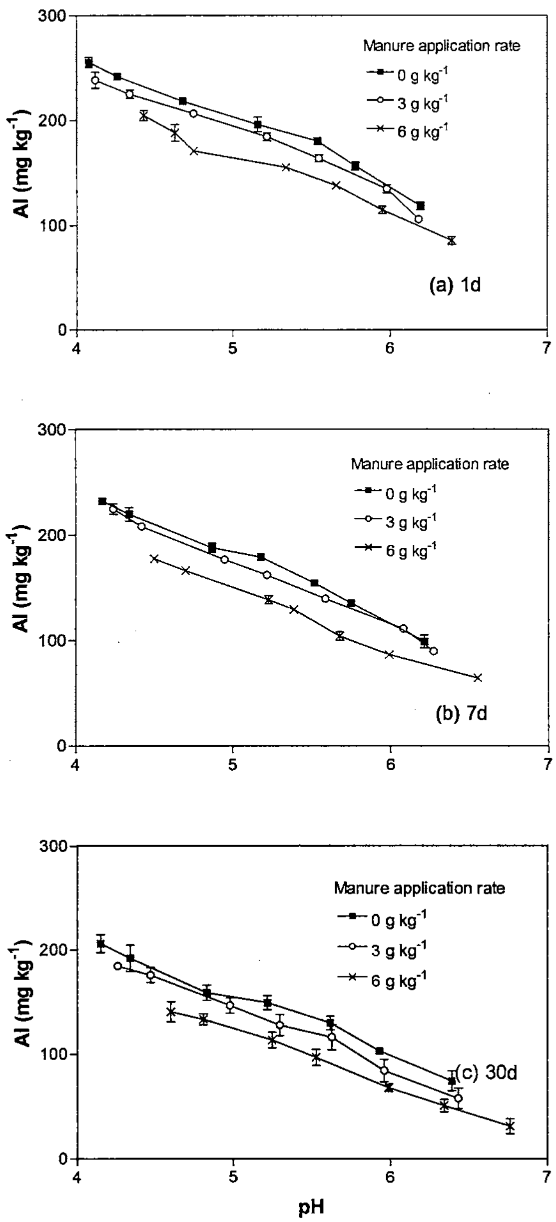

Fig. 2.5 Relationship between Al extracted by 0.33M $LaCl_3$ and soil pH*

*Soil pH was adjusted with HCl or NaOH after 0, 3, and 6 g kg^{-1} feedlot manure was mixed with the starting acid soil

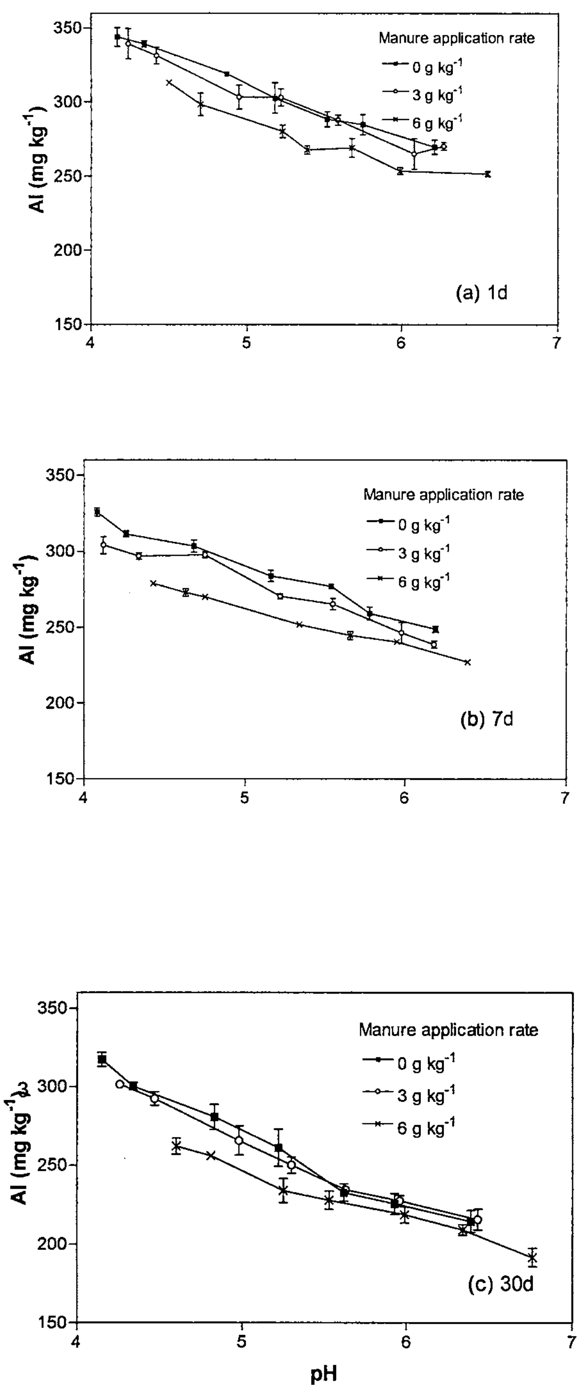

Fig. 2.6 Relationship between Al extracted by 0.5M $CuCl_2$ and soil pH*

*Soil pH was adjusted with HCl or NaOH after 0, 3, and 6 g kg^{-1} feedlot manure was mixed with the starting acid soil

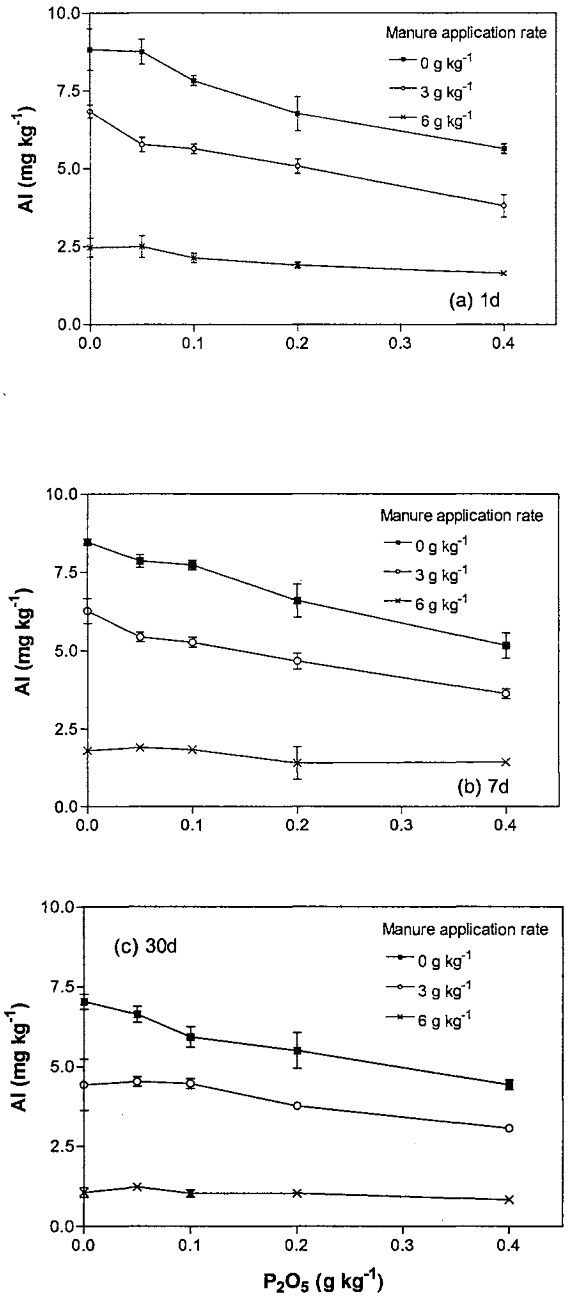

Fig. 2.7 Changes of aluminum extracted by 0.01 M $CaCl_2$ in soils with phosphate addition at manure application rate 0, 3 or 6 g kg^{-1} after incubation for 1d (a), 7d (b) and 30d (c)

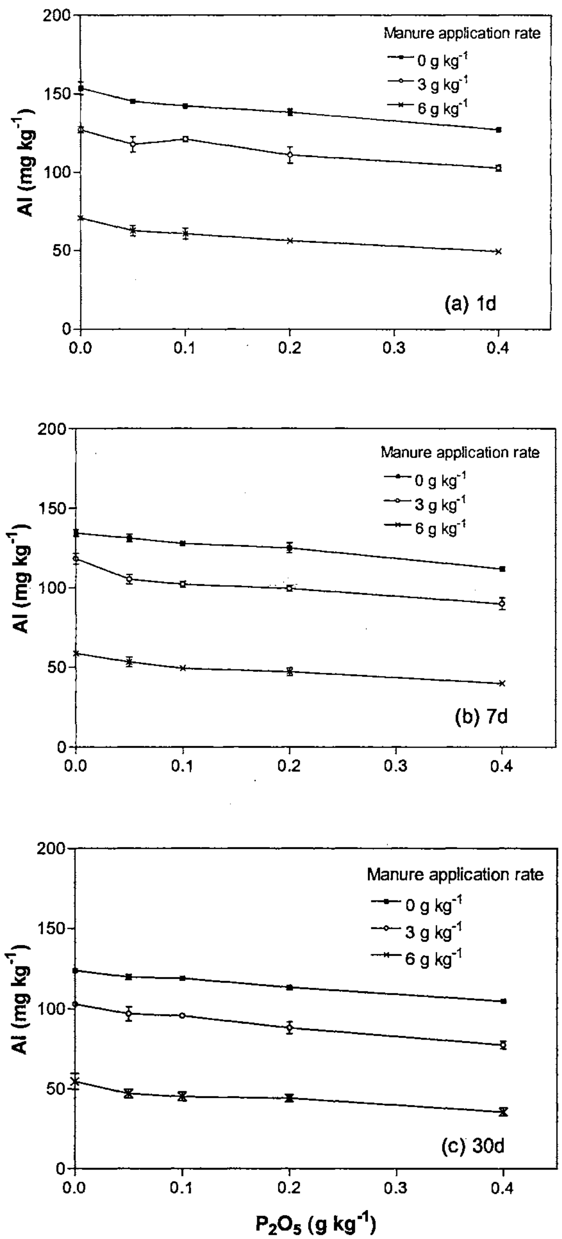

Fig. 2.8 Changes of aluminum extracted by 1 M KCl in soils with phosphate addition at manure application rate 0, 3 or 6 g kg^{-1} after incubation for 1d (a), 7d (b) and 30d (c)

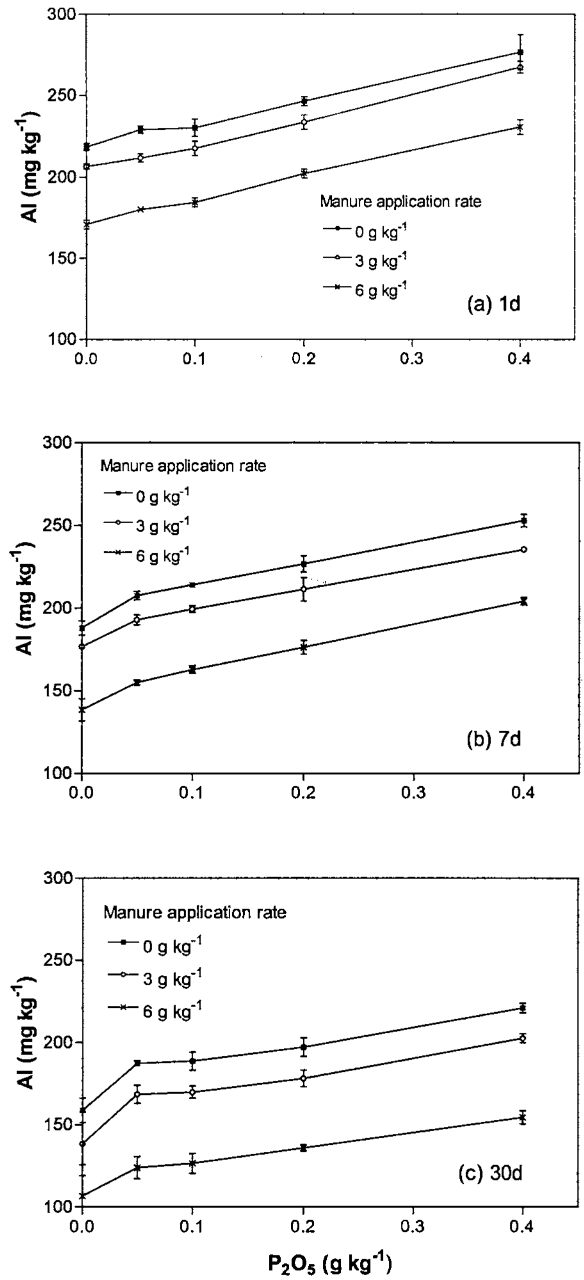

Fig. 2.9 Changes of aluminum extracted by 0.33 M $LaCl_3$ in soils with phosphate addition at manure application rate 0, 3 or 6 g kg^{-1} after incubation for 1d (a), 7d (b) and 30d (c)

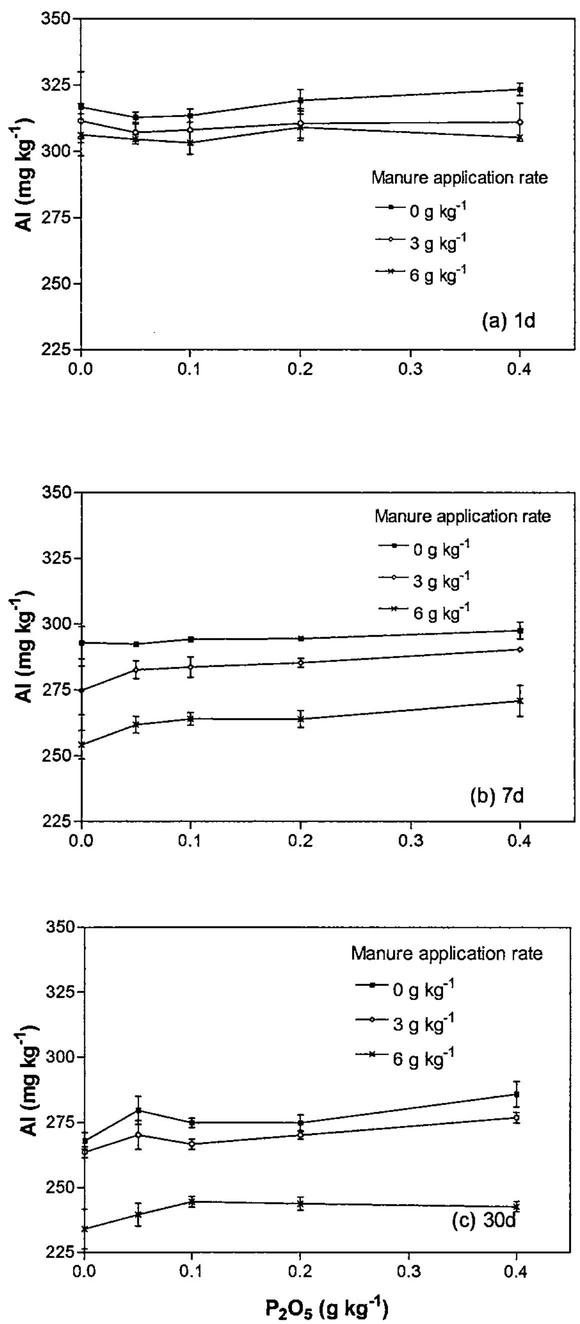

Fig. 2.10 Changes of aluminum extracted by 0.5 M $CuCl_2$ in soils with phosphate addition at manure application rate 0, 3 or 6 g kg^{-1} after incubation for 1d (a), 7d (b) and 30d (c)

Tab. 2.1 Contribution of pH change, phosphate addition and organic matter on Al extracted by $CaCl_2$, KCl, $LaCl_3$ and $CuCl_2$

Extractant	Manure application rate	Total Al reduction due to manure addition		Estimated Al reduction due to pH increase		Estimated Al reduction due to P addition		Estimated Al reduction due to organic bonding	
		$mg\ kg^{-1}$	%	$mg\ kg^{-1}$	%	$mg\ kg^{-1}$	%	$mg\ kg^{-1}$	%
$CaCl_2$	3	2.1	100	0.41	20	0.19	9	1.4	71
	6	3.5	100	0.34	10	0.13	4	3.0	86
KCl	3	26	100	3.93	15	1.62	6	20	78
	6	44	100	6.95	16	2.68	6	34	78
$LaCl_3$	3	12	100	4.19	35	-4.42	-37	12	102
	6	27	100	8.78	33	-8.49	-31	26	99
$CuCl_2$	3	6	100	2.25	37	-0.13	-2	3.9	65
	6	14	100	4.02	28	-0.06	0	10	72

Chapter III

Effect of Alum-treated Poultry Litter on Soil Properties and Wheat Growth in an Acid Soil

ABSTRACT

Alum as an amendment to poultry litter reduces ammonia volatilization and water-soluble phosphorus and is a promising best management practice for poultry production and environment protection. The objective of this study was to compare the effect of Alum-treated poultry litter (PL-alum) and that of untreated poultry litter (PL) on soil properties and plant growth after they were applied to an acid soil where aluminum toxicity is a problem. Soil samples mixed with 5 levels of PL-alum and were incubated for 30 days and wheat (Triticum aestivum L.) was grown afterwards for 35 days with 85% field water holding capacity at 25 °C (day) and 15 °C (night) in an environmentally controlled growth chamber. Soil was sampled after 30-day incubation. Water-soluble P was lower in PL-alum amended soil than that in the soil amended with PL and changed slightly as application rate increased which might suggest P nutrition limitation. In the PL-alum amended soil, NH_4-N remained as the predominant inorganic N due to the restricted nitrification under acid condition. The concentration of NO_3-N was higher than that of NH_4-N in the soil amended with PL. PL-alum reduced monomeric Al in soil solution, $CaCl_2$ extractable Al and KCl exchangeable Al by 28%, 20%, and 32% while PL, by 74%, 80% and 79%, respectively. PL-alum promoted wheat growth by 379% at the highest application rate through ameliorating aluminum toxicity while PL, by 560%. Alum-treated poultry litter had the

potential to reduce nutrient pollution from soil but was not as efficient in supplying P nutrient and reducing Al toxicity as untreated poultry litter.

INTRODUCTION

Alum as an amendment added to manure has received considerable interest in manure management. The most widely used management practice is the addition of alum to poultry litter which is a mixture of manure and bedding materials such as wheat straw, rice hulls, or wood shavings added to the floor of poultry houses, and five or six flocks of broilers are grown on it over a 1-yr cycle.

It was reported that addition of alum to poultry litter greatly reduced atmospheric ammonia levels in poultry house, which decreases the potential for health-related problems of poultry and for humans working in the houses as well as other environmental pollution (Moore et al., 1995). Alum addition improved poultry performance (reduced mortality, increased weight gain and feed efficiency) and lowered fuel and electricity costs due to less need to ventilate poultry houses for NH_3 control purposes (Moore et al., 2000).

Alum-treated litter had a lower pH than that of untreated litter, which reduced ammonia volatilization. Alum-treated litter also had higher N and S concentrations thus increased the fertilizer values of poultry litter (Moore et al., 2000). Alum addition decreased the soluble P concentration in litters and in turn in runoff from fields fertilizered with alum-treated litter compared with normal litter (Shreve et al., 1995; Shreve et al., 1996.). It also reduced runoff of dissolved carbon, trace metals, and growth hormones when alum-treated litter is land applied as fertilizer (Moore et al., 1998; Nichols et al., 1997).

There is a large area of acid soils in Oklahoma. Aluminum toxicity is an important yield restriction factor for wheat production (Carver and Ownby, 1995). Many soils are getting increasingly acidic due to continuous intensive crop production with fertilizer N input without lime application.

Poultry litter has been shown to reduce Al toxicity in acid soil (Chapter I). However, when alum-treated poultry litter is applied as fertilizer, aluminum will be added to those soils. This probably changes soil properties and Al status, which may affect plant growth. However, the impact of applying alum-treated poultry litter to acid soil properties and plant growth is not well documented. The objective of this study was to compare the P, N and Al status when alum-treated and untreated poultry litter were applied to an acid soil.

MATERIALS AND METHODS

Soil and Manure Preparation

The experiment was performed in an environmental controlled growth chamber. Soil samples were collected from a surface (0-15 cm) of the Teller series, a fine-loamy, mixed, thermic Udic Argiustolls, at the Agronomy Experiment Station of Oklahoma State University in Perkins, OK, where winter wheat could not be established due to low pH and possibly high aluminum concentration in soil. The collected soil was air-dried in greenhouse and ground to pass a 5-mm sieve. Soil properties are listed in Table 3.1.

Poultry litter was collected from a compost facility and ground to pass 2-cm screen. Part of poultry litter was mixed with alum $[Al_2(SO_4)_3.15H_20]$ 10% by weight, which was considered as a proper ratio in poultry feeding operation by Moore et al., (2000), and incubated for 30 days before it was used as an amendment for this study. Properties of alum-treated and untreated poultry litter were listed in Table 3.2.

Treatments

The alum-treated poultry litter (PL-alum) and untreated poultry litter (PL) were added to each pot and mixed with soils. The application rates was based on 0, 25, 50, and 100 and 200 mg available N kg^{-1} soil assuming 50% of total N was available (Table 3.3). Each treatment was replicated 5 times. Two kg of premixed soil and poultry litter were put into a 15 cm x 15 cm plastic pot and incubated for 30 days before wheat was planted. Forty seeds of winter wheat (Custer, sensitive to Al toxicity) were planted in each pot and seedlings were thinned to 7 plants per pot shortly after germination. The wheat was grown in an environmentally-controlled growth chamber at 25 °C. Distilled water was added to the pots to keep soil moisture at about 85% field capacity. The wheat was allowed to grow for 5 weeks before above ground shoot were harvested.

Sample Collection and Analysis

Wheat was harvested by cutting the shoots at the soil surface and dried at 80° C for 24 hours to measure dry matter weight.

Soil samples were collected before planting and air dried for analysis. Soil pH was determined in 1:1 water:soil ratio (Thomas, 1996). Water soluble P was extracted with 1:10 water:soil ratio (Kuo, 1988). Soil test P (STP) was extracted by Mehlich 3

(Sim, 2000). Phosphorus in extract was measured colormetrically. NH_4-N and NO_3-N were extracted with 2M KCl (Mulvaney, 1996) and colormetrically measured by a flow injection analyzer (Lachat). Soil extractable Al was extracted with 0.01 M $CaCl_2$ and 1 M KCl separately (Bertsch and Bloom, 1996). Al in the extracts was determined by ICP-AES (Soltanpour et al., 1996). Soil solution was extracted with saturated paste using a modified, rapid centrifugation method (Elkahtib et al., 1987). Monomeric Al in solution was measured with a spectrophotometer (Bartlett et al., 1991).

RESULTS AND DISCUSSION

Effect of alum-treated and untreated poultry litter on water soluble P status and soil test P

There were great differences in water soluble P in soils between PL-alum and PL treatments (Fig. 3.1). As manure application rates increased, water soluble P increased only slightly in PL-alum treated soil while it increased rapidly in PL treated soil. This trend was in agreement with Moore et al's (1999) findings. The difference between this study and Moore et al. was that the water soluble P was very low even in the highest PL-alum treatment in our experiment. This was probably due to the low soil P concentration in the original un-amended soil. In our experiment, the initial water soluble P was only 0.3 mg kg^{-1} while it was 14 mg kg^{-1} in their results. Research has shown that water-soluble P in soils is a very good predictor of P concentrations in runoff water (Pote et al., 1999). Soils that contain high P levels can become a primary source of dissolved reactive P in runoff, and thus contribute to accelerated eutrophication of surface waters. Low water-soluble P in soil in our experiment may have less impact on the environment. However, water-soluble P may also be used as an indicator of P nutrient status. It was reported that water-soluble P correlated well with P uptake by plants (Keramidas and Polyzopoulos, 1983; Thompson et al., 1960; Tran et al., 1988). Low water-soluble P in the soil amended with PL-alum may suggest P limitation for optimum plant growth in original soils with low plant available P concentration.

Mehlich 3 extractable P (soil test P, STP) is used by soil testing lab to make fertilizer recommendation. In our experiment, it increased as both PL-alum and PL application rates increased. (Fig. 3.2). However, there were no significant differences of STP between the PL-alum and PL treatments. Moore et al. (1999) reported large differences in STP between the PL and PL-alum treatments after 3 years of annual applications. The difference between our results and theirs may be explained by tha fact that Al reacts with phosphate to form amorphous Al-hydoxyl phosphate precipitates and remains amorphous (Hue, 1982). It would take a long time for the newly-formed Al and P compounds to age and become unextractable by Mehlich 3 extractant. That means as times goes on, soil P in PL-alum amended soil will become less available to plant than that in soil amended by PL. In acid soil with less available phosphorus, alum-treated poultry litter should be applied with caution concerning P nutrition since alum reduces P availability.

Effect of alum-treated and untreated poultry litter on soil N status

Soil NH_4-N concentration increased sharply as PL-alum application rate increased in PL-alum amended soil but increased slightly as PL rate increased in the soil amended with PL (Fig. 3.3). Nitrate-N concentration was slightly decreased as PL-alum application rates increased while it increased in a trend similar to NH_4-N in PL amended soil.

At the lower application rates, NH_4-N concentration was lower than that of NO_3-N in PL-alum amended soil because the soil NO_3-N was higher than that of NH_4-N added from PL-alum. At the higher application rates, NH_4-N concentration was much higher than that of NO_3-N at each application rate. The difference of concentration of NH_4-N and NO_3-N became larger at higher poultry litter application rate. However, NO_3-N concentration in soil amended with PL was higher than that of NH_4-N in each litter application rate.

The major part of inorganic N from both PL-alum and PL was NH_4-N. In the soil amended by PL-alum, the NH_4-N added from PL-alum and that released from organic decomposition were not easily be changed to NO_3-N possibly due to low pH for PL-alum did not significantly increase soil pH. At certain low soil pH, nitrification could be restricted (Morrill and Dawson, 1967; Weber and Gainey, 1962). The effect of acidity on N changes from NH_4-N to NO_3-N may be an expression of Al toxicity (Brar and Giddens, 1968). While NH_4-N accumulated in soil of PL-alum treatment as dominant form due to poor nitrification, NO_3-N slightly decreased probably due to denitrification lose. PL-alum added available C to soil, which might stimulate the activity of microorganisms related to denitrification. In the soil amended with PL, soil pH increased by PL addition. It created a relative favorable environment for nitrification. As more NH_4-N was added to soil, more NO_3-N would form.

Moore et al. (2000) reported that there was no significant difference between concentrations of NO_3-N of alum-treated and untreated poultry litter amended soil. This is because soil pH in their experiment was more than 6 which was not a limiting factor for nitrification in their experiment.

NH_4-N can be adsorbed in soil as exchangeable ion. It is less likelyt to be leached from soil while NO_3-N is easily to be leached from soil. In acid soisl amended by PL-alum, the accumulation of NH_4-N rather than NO_3-N might reduce environmental pollution through leaching in the early stage especially in a rain season.

Effect of alum-treated and untreated poultry litter on soil Al status

Fig. 3.4 shows the relationships between the amount of monomeric Al (Al_{momo}) in soil solution, Al extracted by 0.01 M $CaCl_2$ (Al_{CaCl2}), Al extracted by 1 M KCl (Al_{KCl}) and different application rates of PL-alum and after 30-day incubation. As the application rates increased, the Al_{mono}, Al-$_{CaCl2}$ and Al_{KCl} decreased in both PL-alum and PL amended soils. At low application rates, the effect of PL-alum on the Al_{mono}, Al-$_{CaCl2}$ and Al_{KCl} was not significant. At higher application rates (> 2 g kg^{-1}), addition of PL-alum dramatically reduced the Al_{mono}, Al-$_{CaCl2}$ and Al_{KCl} in the soil although large amount of Al was added accompanying poultry litter addition. However, the efficiency of reduction was much less than that of PL treatment. At the highest rate, alum-treated poultry litter reduced the Al_{mono}, Al-$_{CaCl2}$ and Al_{KCl} by 28%, 20% and 32% compared to check while PL by 74%, 80% and 79%, respectively.

Al_{mono} is the labile aluminum species and considered as the toxic portion in soil solution (Kinraide and Parker, 1989; Ritchie, 1989), Al_{CaCl2} reflects soil solution Al (Bertsch and Bloom, 1996) and Al_{KCl} constitutes an important buffered reserve of labile aluminum that can be solubilized readily by other exchangeable cation (Lindsay and Walthall, 1989).

In mineral soils, the solubility of aluminum is controlled by pH, Al in alum-treated poultry litter did not change Al in soil solution significantly in the low application rate probably due to soil pH buffer capacity. When poultry litter application rate increased, the soil pH would rise eventually (Fig. 3.5). This may result in soil solution Al and exchangeable Al to precipitate or complex with organic compounds at high application rate. Al in PL-alum combined with organic acid and reduced its capacity to complex with Al in soil. Addition of alum to poultry litter reduced its capacity to ameliorate Al toxicity in acid soil compared to PL treatments.

Effect of alum-treated poultry litter on wheat growth

PL-alum increased wheat growth (Fig. 3.6) As the application rate increased, wheat dry matter increased, though at low rates the effect was not significant. The increase due to PL application was much higher than that of PL-alum. At highest application rate, dry matter weight of PL treatment increased by 552% while that of PL-alum treatment increased by only 379%.The impact of PL and PL-alum on wheat growth is directly related to how PL and PL-alum affected labile Al. There was a close negative relationship between the wheat dry matter weight and of monomeric Al (Al_{momo}) in soil solution, Al extracted by 0.01 M $CaCl_2$ (Al_{CaCl2}), Al extracted by 1 M KCl (Al_{KCl}) in soil (Table.3.4).

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Tab. 3.1 Selected soil properties related to Al toxicity and plant growth

pH	O C	NO_3-N	STP†	STK‡	Al Saturation	Soil texture
	mg kg $^{-1}$				%	
4.3	11	20	31	175	28	Sandy loam

† Soil test P using Mehlich 3 extraction
‡ Sol test K using Mehlich 3 extraction

Tab. 3.2 Total carbon, pH and selected nutrient concentration of alum-treated and untreated poultry litter related to Al toxicity and plant growth

	O C	Total N	pH	NH_4-N	NO_3-N	P_2O_5	K_2O	S	Ca	Mg
	— g kg^{-1} —			— mg kg^{-1} —		g kg^{-1}				
PL	130.7	32.8	8.9	5510	204	43	29.3	7.2	27.0	5.7
PL-alum	119	29.8	6.9	5010	183	39	26.7	6.6	24.5	5.2

Tab. 3.3 Treatment arrangement of alum-treated and untreat poultry litter

Treatment No.	Alum-treated poultry litter (10% alum)	Un-treated poultry litter	Estimated Available N From Manure
	———g kg^{-1}———		kg ha^{-1}
1	0	0	0
2	1.1	1.0	50
3	2.2	2.0	100
4	4.4	4.0	200
5	8.8	8.0	400

Tab. 3.4 Relationship between wheat shoot dry weight and Al, pH in soil amended with poultry litter (PL) and alum-treated poultry litter (PL-alum) growing for 35 days

Al in soil	Treatment	Regression equation	r^2
Monomeric Al	PL†	$y = -0.027x + 2.04$	0.840*
	PL-Alum‡	$y = -0.014x + 1.63$	0.991**
Al extracted by $CaCl_2$	PL	$y = -0.2761x + 2.03$	0.897*
	PL-Alum	$y = -0.357x + 3.08$	0.833*
Al extracted by KCl	PL	$y = -0.0162x + 2.27$	0.992**
	PL-Alum	$y = -0.0149x + 2.25$	0.930**
pH	PL	$y = 4.862x + 20.40$	0.912**
	PL-Alum	$y = 6.508x + 0.9795$	0.958**

* $P<0.05$,   ** $P<0.01$

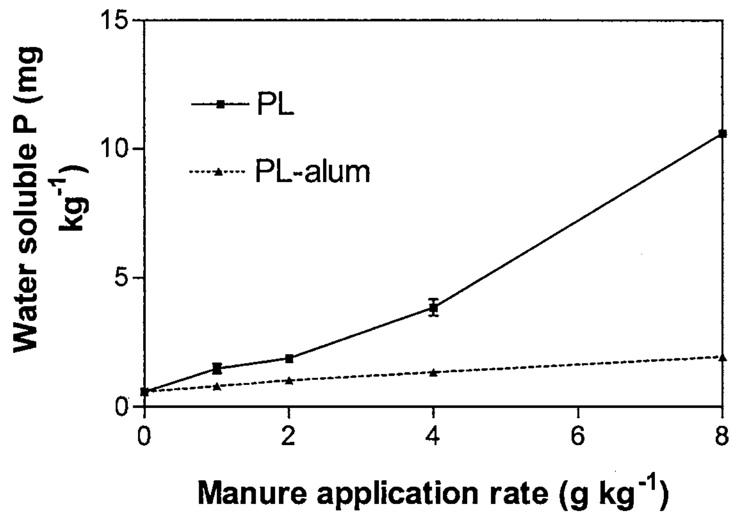


Fig. 3.1 Effect of alum-treated (Al-alum) and untreated poultry litter (PL) on water soluble P in soil after 30-day incubation

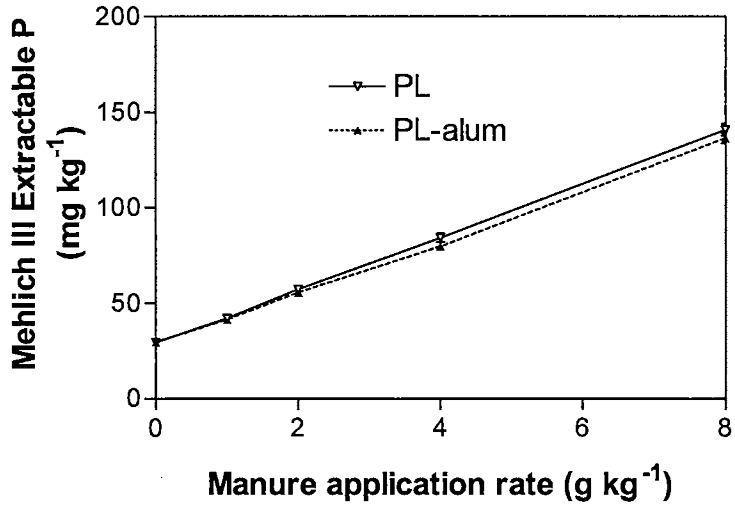


Fig. 3.2 Effect of alum-treated and untreated poultry litter on Mehlich 3 extractable P in soil after 30-day incubation

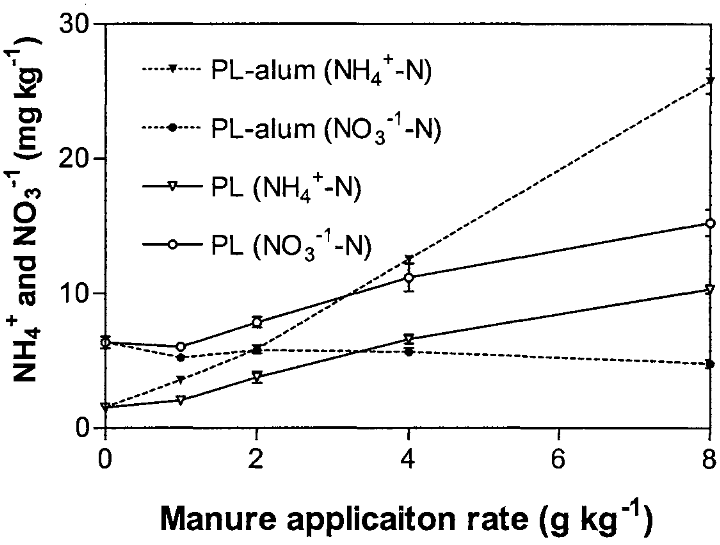
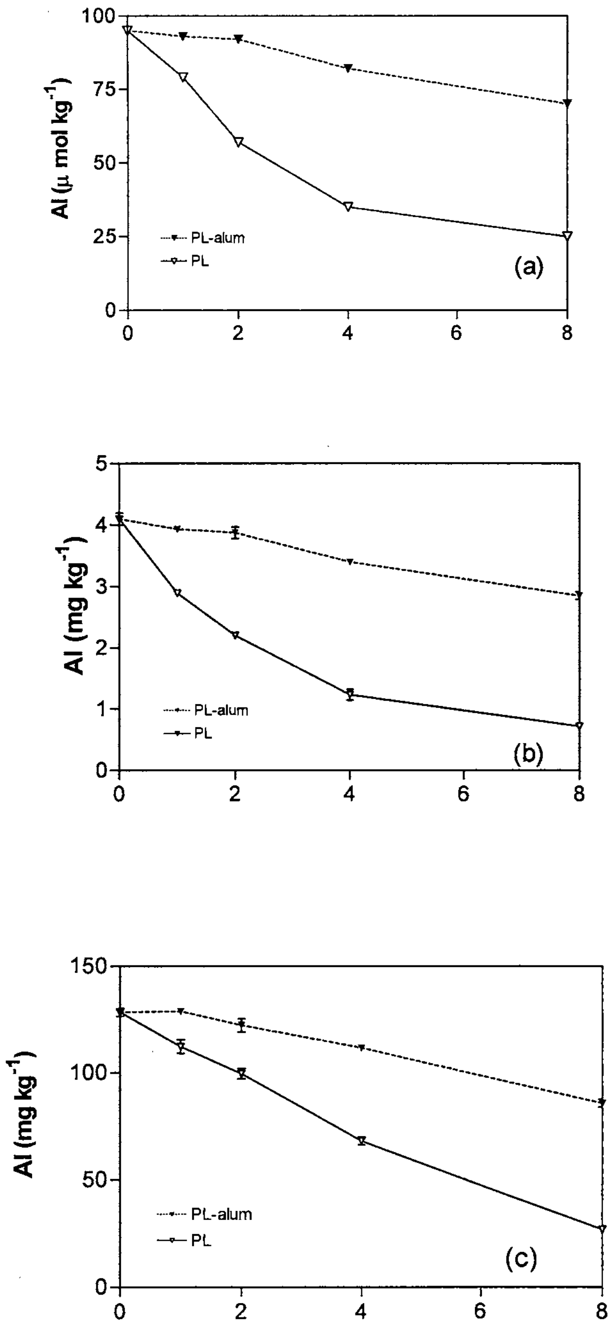


Fig. 3.3 Effect of alum-treated and untreated poultry litter on NO_3-N and NH_4-N in soil after 30-day incubation



Poultry Litter Application Rate (g kg^{-1})

Fig. 3.4 Monomeric Al (a), Al extracted by 0.01 $CaCl_2$ (b) and 1M KCl (c) after incubation for 30 days with alum-treated and untreated poultry litter and normal poultry litter

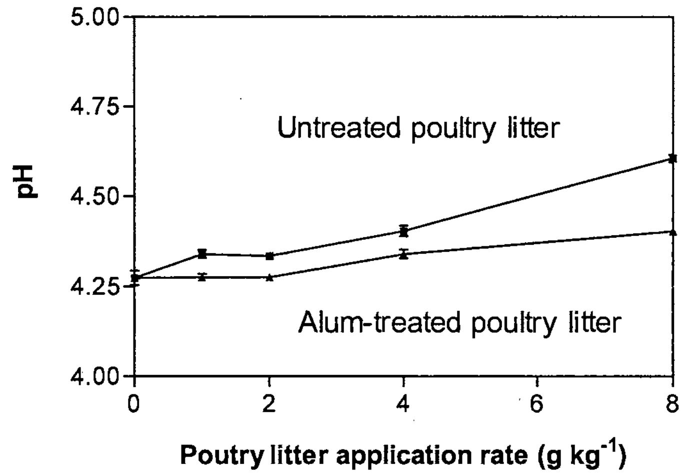


Fig. 3.5 Soil pH after incubation for 30 days with alum-treated poultry litter and normal poultry litter

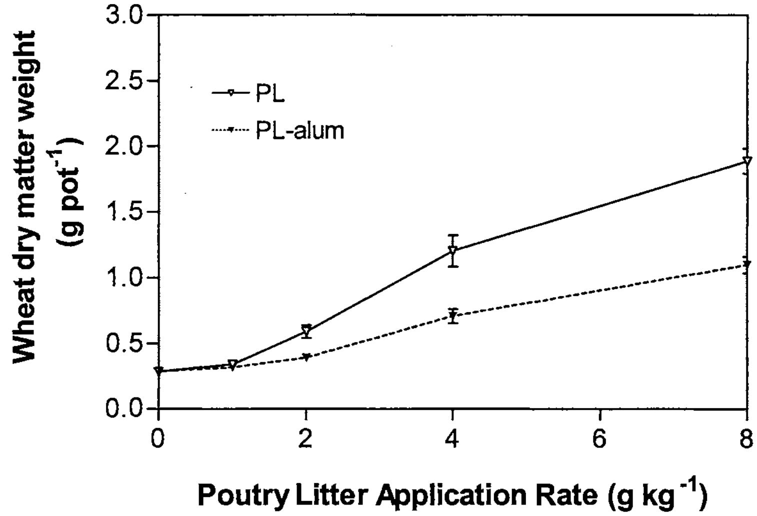


Fig. 3.6 Effect of alum-treated (PL) and untreated poultry litter (PL) on wheat growth

Chapter IV

Managing Plant Nutrients Using Geographic Information System on a Farm

ABSTRACT

Nutrient management plays an important role in improving agricultural production and reducing environmental pollution. One of the components of nutrient management is site-specific application of manure and fertilizer and at the same time monitoring soil fertility changes. Geographic Information System (GIS) integrates spatial and other information within a single system and offers a powerful tool for analyzing spatial variability. In this study, an ArcView GIS was used to establish a spatial database of soil nutrient distribution at the field level. Digital Orthophoto Quads (DOQ) were used as an aerial photograph background for drawing farm and field boundaries. Soil maps are digitized from soil survey maps. Soil nitrate, soil test phosphorus (STP), soil test potassium (STK), pH buffer index were included in soil test data and mapped by fields. Buffer zones to minimize nutrient runoff, and fertilizer recommendations were displayed in different maps as outputs. A producer can view crop rotation, soil fertility status and make fertilizer recommendation on a specific field easily with this system. The established database can be easily transferred to other farm operations for their nutrient management planning.

INTRODUCTION

Nutrient management is very important in agricultural production. Traditionally, nutrient management has been considered with optimizing the economic return from nutrients used for crop production. The main emphasis was on the expected crop response from added nutrients to the soil (Troeh and Thompson, 1993). To reach this goal, researchers have developed efficient, economic means to optimize plant nutrition use and increase crop yields. While economics still plays a vital role in farm operations, potential impact of nutrients on environmental quality has been emphasized in recent years. In the past, a farmer often applied inorganic fertilizer without giving credit for nutrients already applied in manure (Lanyon and Beegle, 1989). This has contributed to the soil fertility levels that exceed agronomic requirements. Over-applied, or the improper application of manure and fertilizer, may release nutrients into the air and water, where they no longer contribute to the production of the crop. Non-point source pollution from agricultural fields is a significant aspect to water quality degradation. Leaching of nitrate through the soil can increase ground water nitrate levels above safe drinking water limits, which can adversely affect the health of young children and livestock. Surface movement of N and P in runoff increases levels of these nutrients in surface waters, which can lead to eutrophication and fish kills (Sharpley, 1998).

Another water pollution source is Concentrated Animal Feeding Operations (CAFO). These are corporate-controlled units where tens of thousands of animals are produced in factory-like settings. Such livestock factories produce and store large quantities of animal waste. When it is not properly disposed, it also will finally enter water body to cause pollution. Because of this, CAFO Final Rule on December 15, 2002 was signed and published in the Federal Register on February 12, 2003.

In such situation, comprehensive nutrient management plans (CNMP) are developed. It integrates ecological, economic, and production considerations in meeting both the owner's/operator's objectives and the public's natural resource protection needs in accordance with conservation planning policy of Natural Resource Conservation Service (NRCS) and rely on the planning process and established conservation practice standards (Beegle et al., 2000; NRCS, 2000). One part of CNMP is to identify management and conservation actions that will be followed to meet clearly defined soil and water conservation goals. CNMP is site-specific in which a large amount of spatial data will be involved. However, currently, many farmers are struggling to follow a CNMP partly because there is not a convenient tool to make their decisions (Yule et al., 1996)

Geographic information systems (GIS) are various software applications that store, analyze, and display multiple layers of geographic information (Lang, 1998). Discrete geographic locations can be stored in computer files as sets of mathematical coordinates. This makes it possible to draw a map on a computer. Different map files, or layers, of spatial information with common geography can be displayed simultaneously and analyzed with reference to one another. Quantitative information that can be linked to geography can be used in a GIS. It not only represents quantitative information on a map but also symbolize the related points (draw them in different colors, sizes, and shapes) according to any information about them. Geographic features and phenomena can be modeled in GIS from sample data. Similarly, models of processes also can be simulated from sample data and from assumptions. Based on its powerful functions, GIS is an ideal system for analyzing the impact of development and consumption on natural resources.. EPA suggested that GIS might be used in CNMP to facilitate spatial data processing and it is expected that use will increase in the future.

The objectives of the project are to establish a spatial database to document and analyze soil nutrient distribution at the field level using GIS and to develop a nutrient management strategy based on the whole farm nutrient balance analysis. Buffer zones will be set up on the map based on existing standards. Fertilizer and manure application rates will be automatically prescribed and displayed based on crop nutrient needs and soil nutrient availability. This system will help agricultural specialists and farmers to make decisions on crop arrangement and fertilizer application according to the maps. The final decisions final decision will reduce fertilizer, and manure application compared to the one-rate application for the whole farm and at the same time to ensure a profitable crop production.

MATERIALS AND METHODS

Selected farm for study

A typical farm (Fig. 4.1) in Muskogee County, OK was selected as a case study because it is diversified with both crop production and animal feeding operations. Currently, this farm has more than 100 fields and grows a dozens different crops. The farm manager has been looking for a convenient tool for the farm production guide and nutrient management. In this study, we only selected the central part of the farm for easy display.

Sources of data

1) Digital Orthophoto Quads (DOQ) in MrSID format with projection Albers, and road and stream line digital maps were collected from the Department of GEO Information Systems, University of Oklahoma (March, 2002).

2) Soil map 1: 20,000 was from Muskogee County Soil Survey.

3) Drinking well positions were collect by a global positioning system (GPS).

4) Soil samples were collected by field for major plant available nutrients.

Procedures

1) ArcView 3.3 was used to establish spatial database. Extensions— Image Analysis, MrSID image Support, JPEG Image Support, Spatial Analyst, Geoprocessing and Database Access were added.

2) Farm boundary, field boundaries and dwelling boundaries ware digitized on screen at 1: 10,000 scale.

3) Soil map were scanned and georeferenced with the above-mentioned DOQ. Soil boundaries were digitized on screen. The digitized map was used as reference for sub-field sampling zone.

4) Roads and streams were re-digitized on DOQ. Re-projected road and stream were used only as a reference because their scales are 1:100,000, which are not as accurate as DOQ.

5) Buffer zones were created according to standards established: interstate highway 40m, state highway 15m and country road 10m, dwelling boundary 15m, and drinking well 150 m (Heathwaite et al., 1998).

6) Soil test data were archived in Microsoft Access. SQL query function in ArcView was used to link soil test database to ArcView.

7) Field area in buffer zones obtained by clipping field boundaries with buffer area. The actual fertilizer application area = (area in field boundaries) – (all field area that in each buffer zone). Field area need to be summarized because different buffer zones may produce separated buffer area in a field. All buffer areas in one field were calculated in Microsoft Access by query using the exported data.

8) Fertilizer recommendations were created by querying in Microsoft Access, based on Oklahoma State University fertilizer and lime recommendations for all major crops (Johnson et al., 2000) and linked to ArcView by query function in ArcView.

9) Shape files for each nutrient distribution and recommendation were created and displayed in layouts.

RESULTS

Buffer zones

Buffer zones are vegetation strips, which provide areas for deposition of sediment and sediment-bound pollutants and infiltration and adsorption of soluble pollutants. It has been proved to be a simple and efficient method to reduce nutrient runoff loss This study helps farmers setup the buffer zone by showing them the buffer zone map (Fig. 4.2). After establishing buffer zones, the real fertilizer application area was reduced. In this map, the actual fertilizer application area was calculated in Table 4.1. That would help farmers to calculate the actual fertilizer requirement from the arable area. From the table it could be seen that some of fields were not occupied by buffer zone. Others' area decreased from 3% to 16 %. The only extreme is Field 6. More than 35% of field was occupied by buffer zone because the field was very small and there was a wide stripe of buffer zone on the side of the field. By following at the buffer zone map, the farmer can be guided visually in planting planning (Fig 4.2). Fertilizer recommendations based on the new area generated could be setup accordingly.

Soil pH and nutrient status

There are great changes in pH from field to field on Bob Ross Farm (Fig. 4.3). Soil pH ranged from 5.2 to 7.9. This reflected the variability introduced by soil formation and farming management. In northeast area and southeast area, pH was high. Central area had the lowest pH; the pH of other area was almost neutral. The pH distribution map aids producer to place the appropriate crop to the right field or to lime them accordingly.

Nitrate in soil of the farm was generally low although some of central fields had high nitrate content (Fig. 4.4). This means most of the fields need N fertilizer application. The range of soil test phosphate (STP) was also large similar to pH (Fig. 4.5). In northeast and southwest area, STP was high. Central area STP was around the middle level while one had extreme STP value, which may be introduced by manure dumping. Soil test potassium (STK) was generally high though there are great differences among different fields (Fig. 4.6). The high K distribution area was similar to that of the P but low K area distribution was different. Northwest area has the lowest STK and the STK in the central area was among the middle level, which may be determined by parent materials of the soil. It is obvious that there were great differences in pH and nutrient in the study area, specific lime and nutrient application is very important. With the help of distribution maps, soil pH and plant nutrient status can be visually displayed for easily management. Understanding the variability of pH and nutrient distribution among the field can prevent over-application by just one-rate for the whole farm which might result in nutrient runoff and further cause environmental problems.

Fertilizer recommendation

Lime and nutrient application rates can be determined by soil nutrient status but it is also related to crop types. Fig 4.7 (A) shows the cropping plan followed at the farm before the soil test. However, with the pH and nutrient maps, a more appropriate plan was made. Because alfalfa need relatively high pH, small amount of N but a large mount of P and K we could shift alfalfa to other areas with relatively high pH and STP and STK. The new cropping plan is shown in Fig 4.7(B).

Lime and fertilizer recommendations for crop arrangement and the adjusted crop arrangement are shown in Fig. 4.8 to Fig. 4.11. Comparing the Fig. 4.8(A) and 4.8(B), we found that the area need to be lime reduced. High nitrogen application rate shifted with the shift of crops (Fig. 4.9(A) and Fig. 4.9(B)). New crop arrangement also reduced heavy P and K application in central area by moving alfalfa to the high P and K fields.(Fig. 4.10, 4.11). It seemed that the distribution of nutrient recommendation among fields was determined by crop arrangement in addition by soil nutrient distribution. Total lime and fertilizer application in the manager's crop arrangement plan and the adjusted plan was calculated and listed in Table 4.2. P and K application were significantly reduced by the change of crop planting plan, although nitrogen application was a little increased. Lime application also reduced by the re-arrangement of crop planting.

DISCUSSION

In this study, we established a spatial database for nutrient management on a specific farm. The maps created by GIS offered virtual concept about farm management system which is much receptible by farmers. It gave the farmer a useful tool in understanding the nutrient distribution in his/her farm and in discovering management problems and further help them manage their fertilizer and manure application economically and prevent over-application of fertilizer and manure at a specific field and whole farm. The digital maps and database is easily managed and updated after it is setup. The methodology used in this study can be used on other farms.

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Tab. 4.1 Actual fertilizer application area calculated by subtraction of acreage in buffer zones from acreage of fields

Field ID	Acreage	Acreage in buffer zone	Actual fertilizer application acreage	Percent of field acreage
20	9.4	0.0	9.4	100
18	80.8	0.0	80.8	100
17	62.9	0.0	62.9	100
8	58.7	1.7	57.0	97.1
7	76.5	2.7	73.8	96.5
11	41.3	2.0	39.3	95.2
26	17.2	0.9	16.3	94.8
16	13.9	0.8	13.1	94.2
5	27.3	1.6	25.7	94.1
25	25.5	1.5	24.0	94.1
14	58.9	3.5	55.4	94.1
12	17.1	1.1	16.0	93.6
27	17.8	1.2	16.6	93.2
15	41.0	3.3	37.7	92.0
13	39.3	3.2	36.1	91.9
10	36.6	3.3	33.3	91.0
21	10.2	1.0	9.2	90.2
22	11.7	1.2	10.5	89.8
2	52.5	5.5	47.0	89.5
4	33.7	4.2	29.5	87.5
1	11.0	1.4	9.6	87.3
3	53.1	7.4	45.7	86.1
24	46.7	7.3	39.4	84.4
6	21.1	7.5	13.6	64.4

Tab. 4.2 Total amount of lime and fertilizer application calculated according to farm manager's crop arrangement plan before soil test and the adjusted arrangement plan after soil test

	Lime	N	P_2O_5	K_2O
	—Ton—	———	Lb	———
Before soil test	179	148979	28421	35898
After soil test	9	149598	23961	32242
Difference	170	-619	4461	3656

Fig. 4. 1 Location of study site in Muskogee, Oklahoma

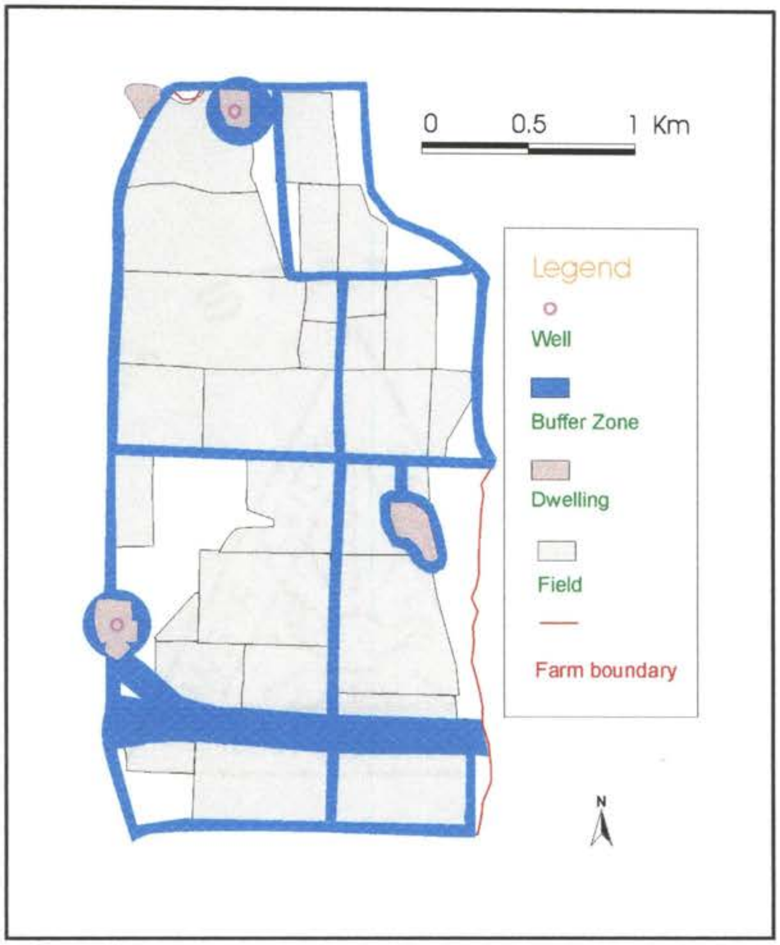

Fig. 4. 2 Map of buffer zones for the study site

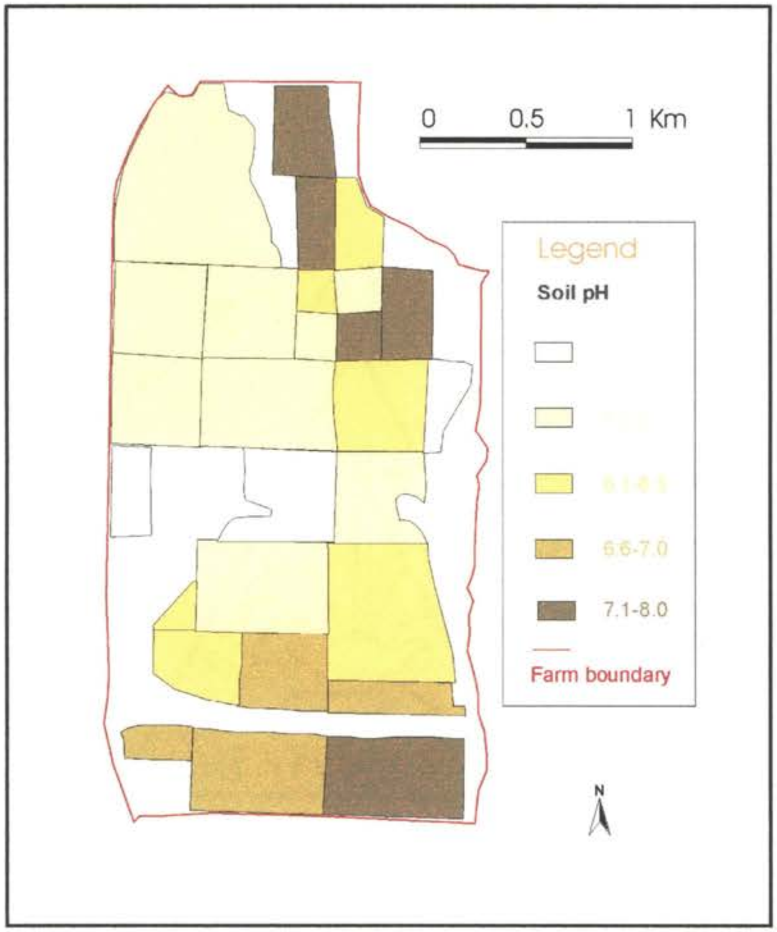

Fig. 4. 3 Thematic map of soil pH for the study site

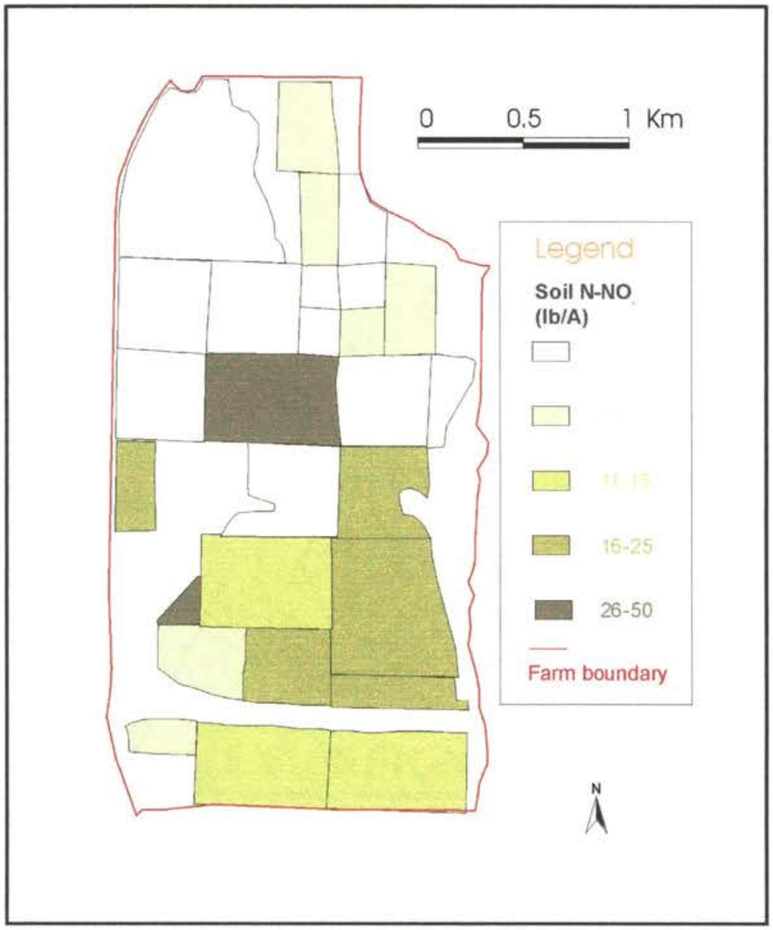

Fig. 4. 4 Thematic map of soil nitrate for the study site

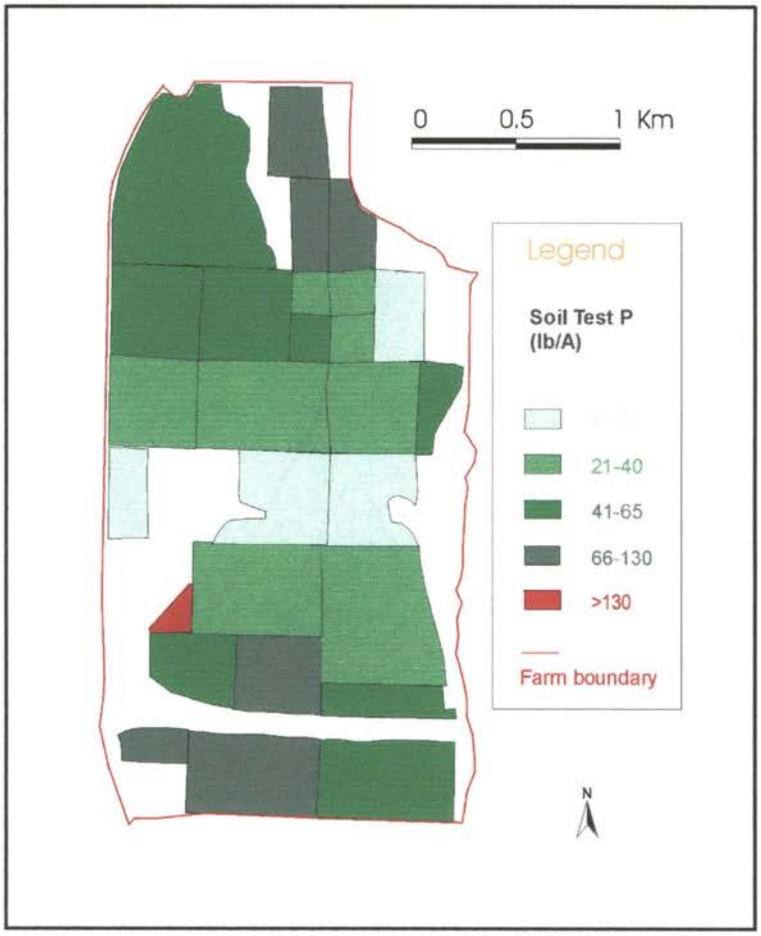

Fig. 4. 5 Thematic map of soil test P for the study site

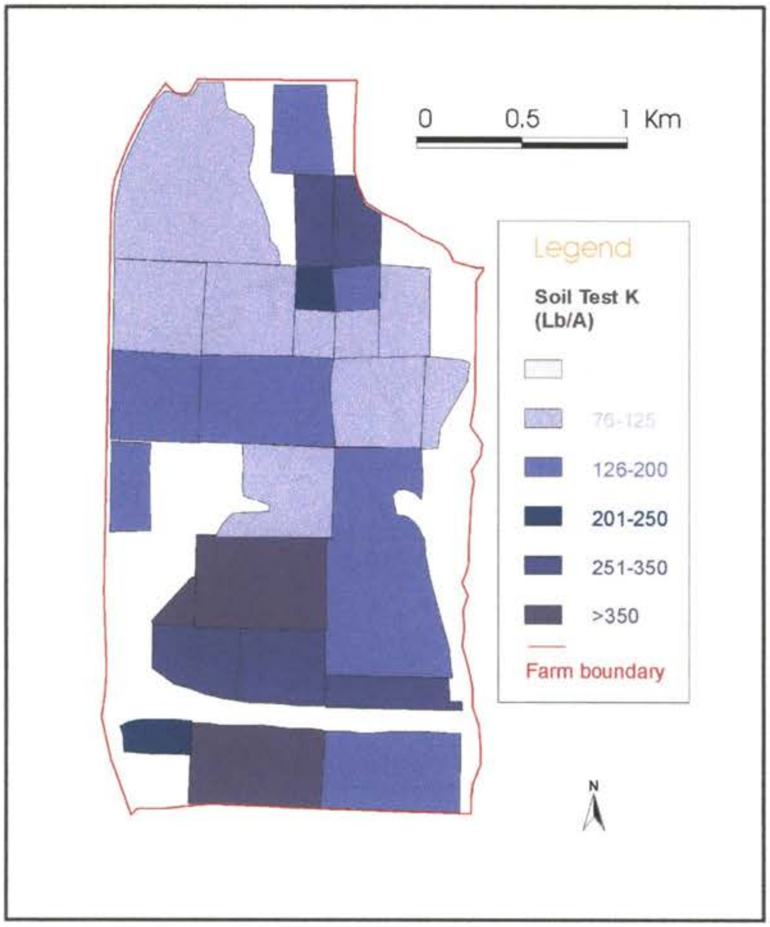

Fig. 4. 6 Thematic map of soil test K for the study site

Fig. 4. 7 Thematic map of crop arrangement plan before (A) and after (B) soil test for the study site

Fig. 4. 8 Thematic map of lime requirement according to farm manager's crop arrangement plan (A) and the adjusted crop arrangement after soil test (B) for the study site

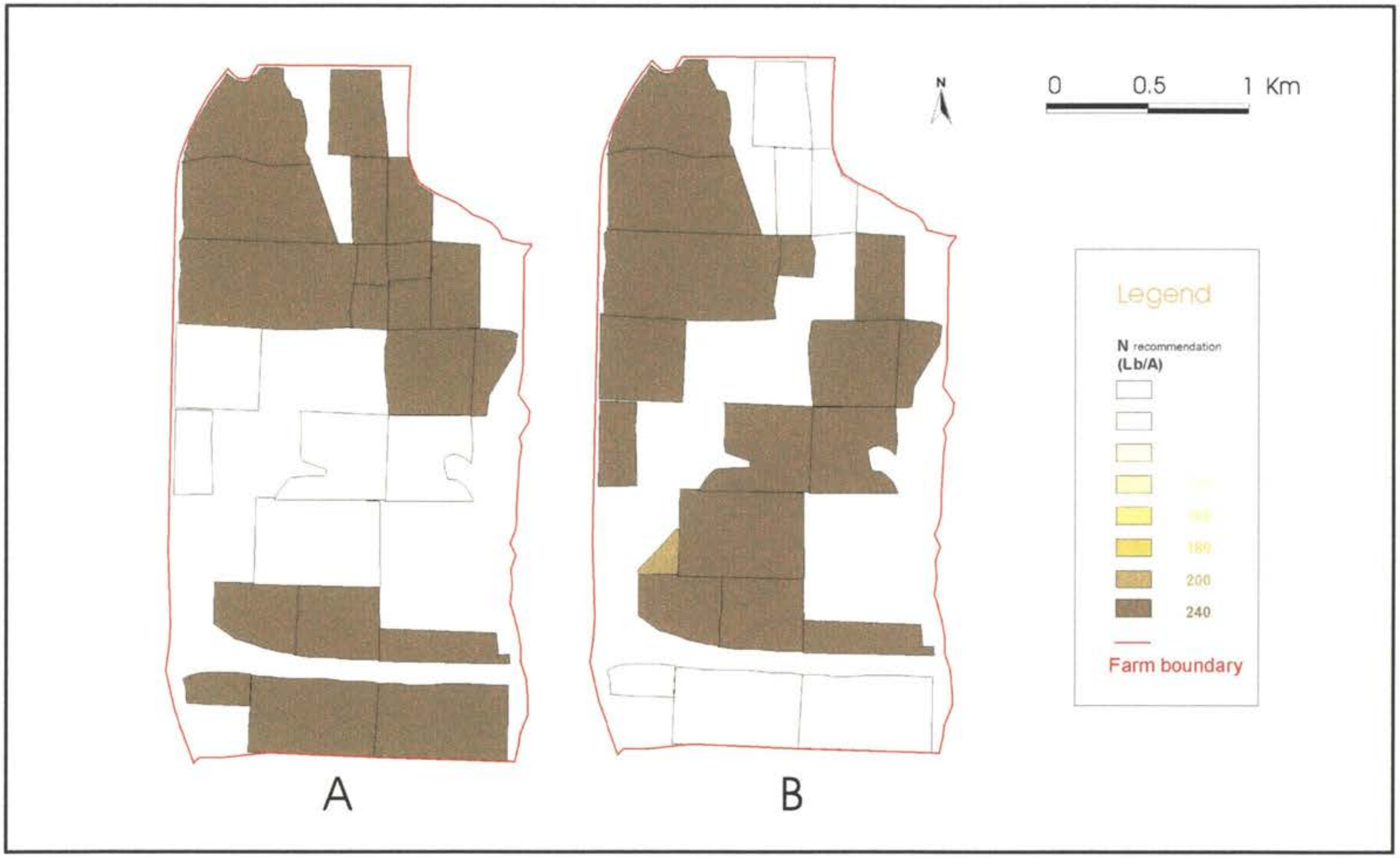

Fig. 4. 9 Thematic map of nitrogen fertilizer recommendation according to the manager's crop arrangement (A) and the adjusted crop arrangement (B) for the study site

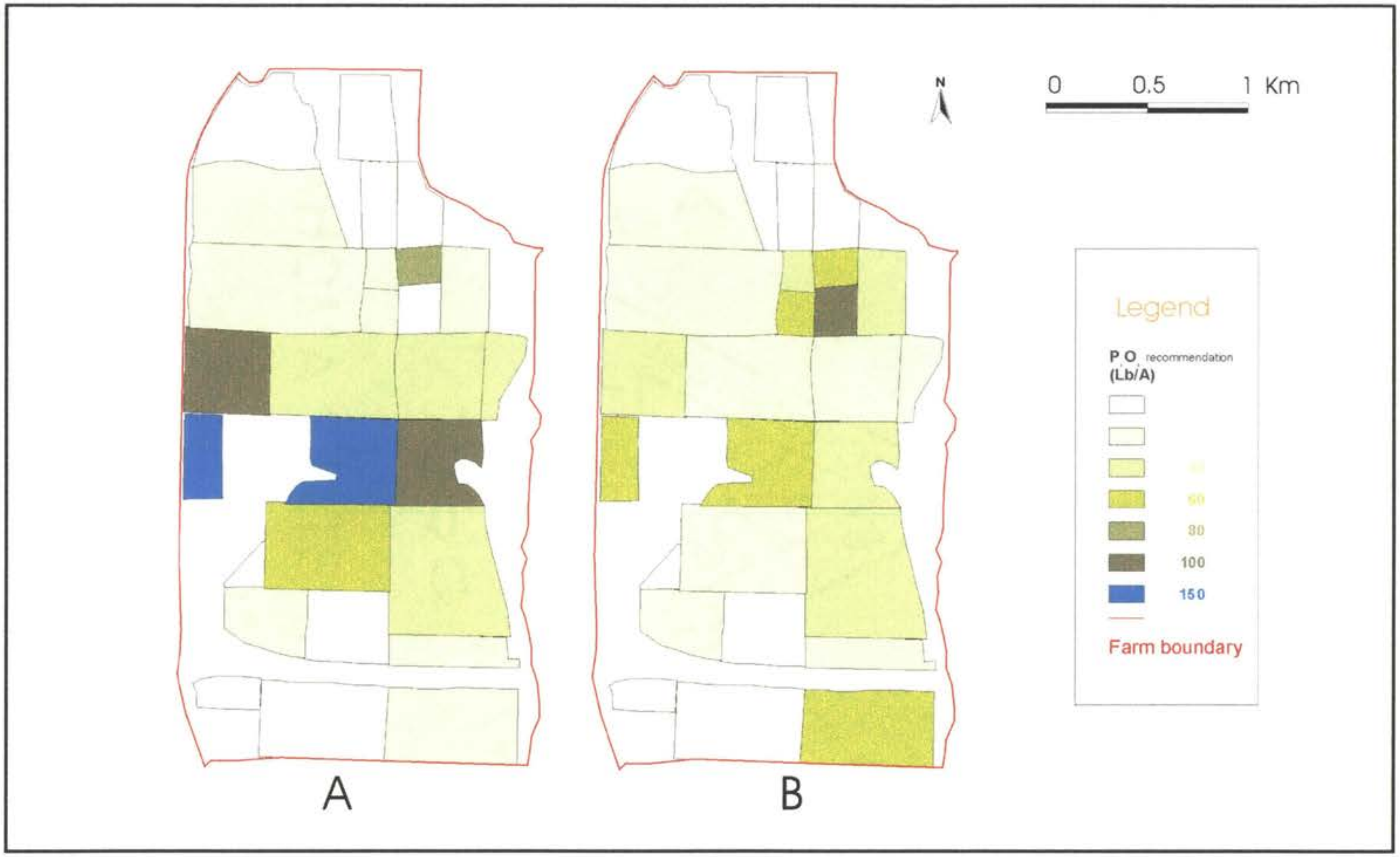

Fig. 4. 10 Thematic map of phosphorus fertilizer recommendation according to the manager's crop arrangement (A) and the adjusted crop arrangement (B) for the study site

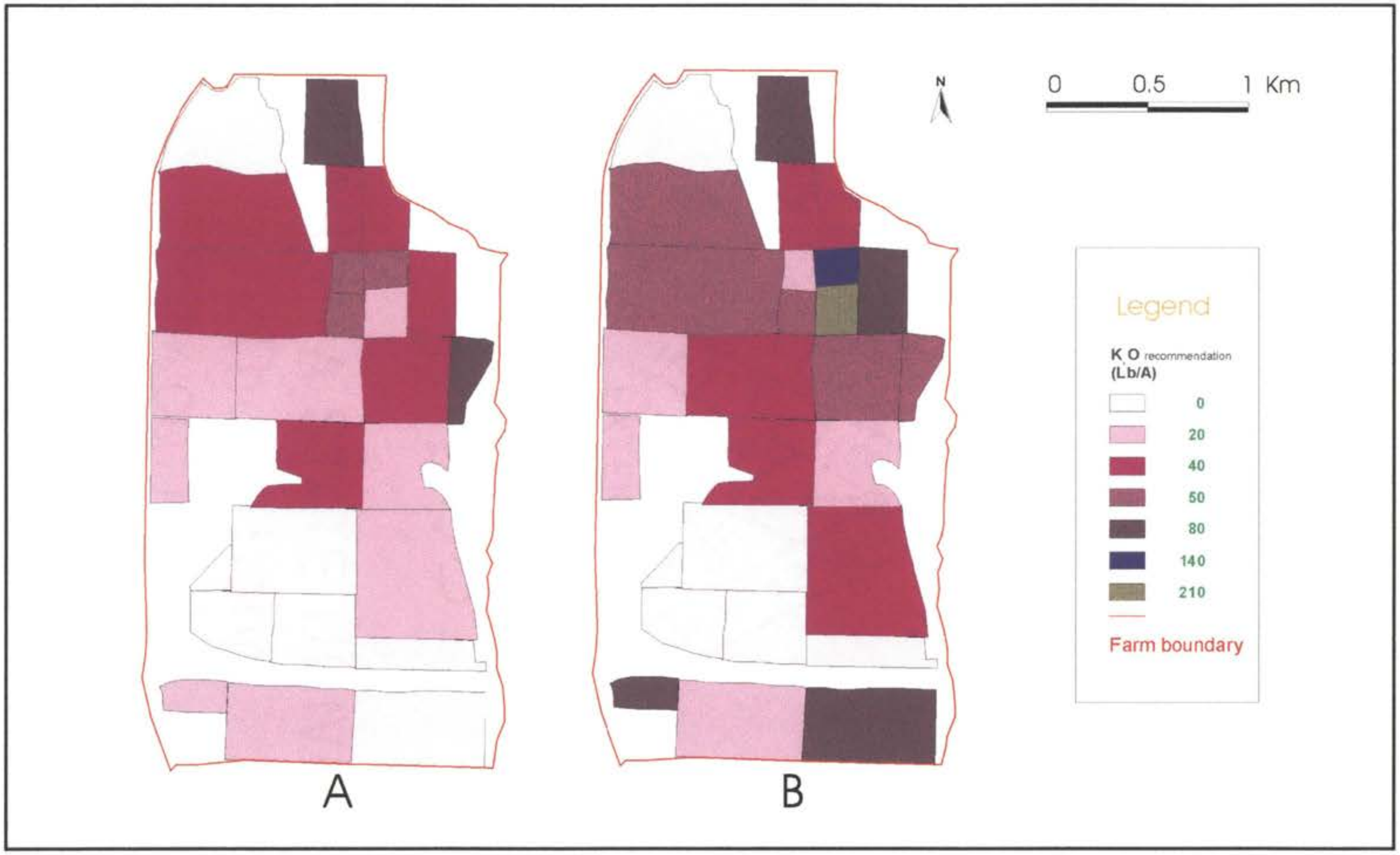

Fig. 4. 11 Thematic map of potassium fertilizer recommendation according to the manager's crop arrangement (A) and the adjusted crop arrangement (B) for the study site

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