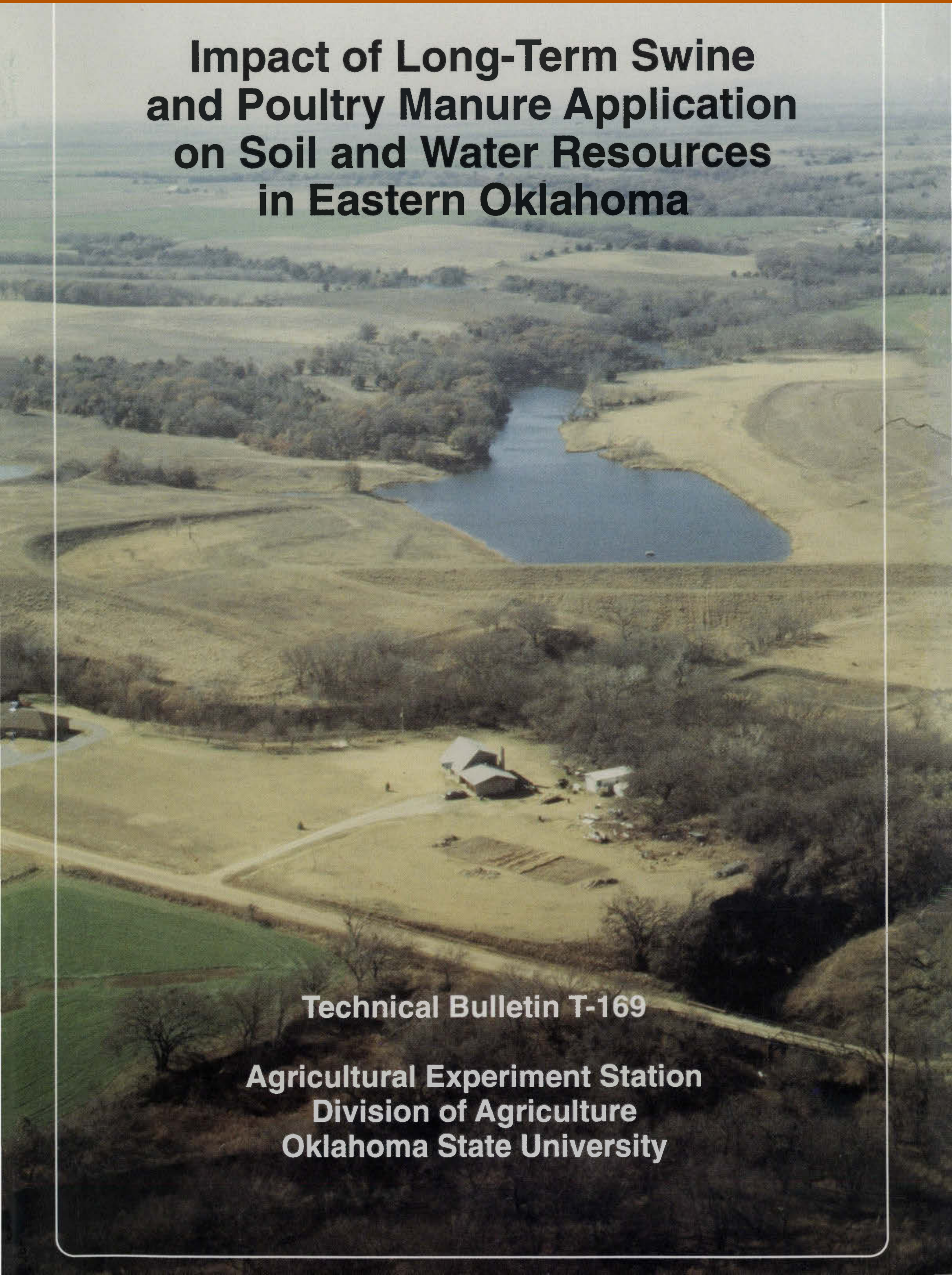
Impact of Long-Term Swine and Poultry Manure Application on Soil and Water Resources in Eastern Oklahoma



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IMPACT OF LONG-TERM SWINE AND POULTRY MANURE APPLICATION ON SOIL AND WATER RESOURCES IN EASTERN OKLAHOMA

by

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Abstract

With the rapid growth of the swine and poultry industry in eastern Oklahoma, information is needed on the impact of associated waste disposal on the areas' soil and water resources. The long-term (9 to 15 years) effect of animal waste application on the nutrient content of 3 soil series (Captina, Sallisaw, and Stigler silt loams) from Delaware county was investigated. Amounts of P, N, and K applied as manure ranged from 37 to 101, 111 to 456, and 51 to 141 kg/ha/yr, respectively. An average 2- and 9-fold increase in total (TP) and available (AP) P content (1980 and 296 kg/ha, respectively) occurred in the surface 50 cm of treated (wheat and fescue pasture) compared to untreated (native grass and forest) soil (1595 and 47 kg/ha, respectively). The increase in available P, was related to the amount of manure P added, representing a 27 kgP/ha increase for each 100 kgP/ha added in manure. In general, most of the applied manure P accumulated in inorganic plant available and hydrous Al and Fe oxide forms. The percent retention of applied manure P in soil (0 - 50 cm depth), increased as soil P sorption capacity increased. However, an associated 3- to 20-fold decrease in soil P sorption reduced the capacity of soil to sorb future manure additions. Little movement of P below 50 cm was observed. In contrast to P, no consistent increase in N or K content of surface soil was observed, although a slight accumulation was apparent in the subsoil (below 150 cm depth). Arsenic contents of the two surface horizons (approximately 0 to 50 cm depth) of all untreated and treated soils were below the 6 mg/kg. The concentration of soluble P in runoff from treated and untreated soil was predicted using a kinetic model previously developed and tested. For a 1 cm runoff event, soluble P concentration averaged 1.41 (2.28 to 0.88 mg/L) and 0.09 mg/L (0.06 to 0.15 mg/L) from treated and untreated soils, respectively. Predicted

particulate P (2.47 to 6.24 kg/ha/yr) and N (7.02 to 23.10 kg/ha/yr) losses in runoff and increased P bioavailability (15 to 59%), indicate the potential long-term supply of nutrients for accelerated eutrophication following manure applications. Although these are hypothetical runoff simulations, they emphasize the need to carefully manage repeated manure applications to minimize potential runoff losses. In terms of P, the impact of poultry and swine manure application on soil and water resources in eastern Oklahoma can, thus, be evaluated from soil texture, available P content, P sorption capacity, and amount of manure to be added.

Introduction

Agriculture is of major importance to Oklahoma economics. Inherent productivity of some soils in the state, however, is low, with these soils predominantly thin, fragile, easily erodible or of low nutrient status. Consequently, soil management is of prime importance in maintaining soil and water resources in the state. Of increasing importance in this management is the recent growth of the poultry and swine farm industry, particularly in eastern Oklahoma. For example, broiler production in Oklahoma increased 30% from 1987 (16.5 X 10^6 kg) to 1988 (21.4 X 10^6 kg) (NASS, 1989). The value of this production increased from $105 to 156 million over the same period, a 33% increase. Similar increases in production and value have also occurred for the swine industry. It is, thus, clear that both poultry and swine production is becoming increasingly important to the economic well being of Oklahoma agriculture.

Disposal of the concentrated animal waste, that accumulates in efficient production systems, is an increasing problem facing the industry. In broiler production, the concentrated manure plus absorbing material, usually pine shavings or wheat straw, is broadcast on pasture or cropland. In the case of swine manure disposal, waste solids accumulate in a lagoon, which is emptied periodically with the sludge also applied to adjacent pasture or cropland. The animal waste can be a valuable resource as an alternative source of fertilizer nitrogen (N), phosphorus (P), and potassium (K) in maintaining and restoring soil productivity (Hileman, 1967; Huhnke, 1982; Perkins et al., 1964). In fact, by improving ground cover, runoff volume and erosion may also be reduced.

Application of the animal manure at rates greater than a crop can utilize, however, has been shown to result in nitrate-N (NO_3-N) movement through the soil into ground water (Cooper et al., 1984; Liebhardt et. al., 1979; McLeod and Hegg, 1989). Although the application of poultry and swine manure results in an increased soil P availability and decreased P adsorption (Field et al., 1985; Reddy et al., 1980; Singh and Jones, 1976), less information is available on the disposition of manure P in soil and its movement in lateral and vertical soil water flow (Brown et.al., 1989; Westerman et al., 1983). This has resulted in part from public interest in NO_3-N contamination of ground water supplies.

Furthermore, information is needed at a regional or national level on the fate of this applied manure and the impact of long-term applications on soil and water resources. The need for this information is heightened by the predominance in eastern Oklahoma of fragile soils, shallow water tables, erratic weather, and potentially high economic returns for concentrated animal production systems. In addition, more detailed information is required at a local and county level, before reliable disposal recommendations and management options can be established for the benefit of both the farmer and environmentally conscious public.

This report documents the effect of long-term (up to 15 yr) poultry and swine manure application on the nutrient content of three eastern Oklahoma soils.

Materials and Methods

Materials

The classification, location, and available management history of the soils studied are presented in Table 1 and Figure 1. The cultivated soils receiving poultry and swine manure applications are representative of sites in northeast Oklahoma. All sites were on level areas (less than 3% slope), to minimize changes in soil properties due to erosion and/or deposition. Each soil was described using standard procedures of the United States Department of Agriculture, Soil Conservation Service (Soil Survey Staff, 1981). Bulk samples of about 5 liters were taken from each horizon and sieved in the field to remove rock fragments of greater than 1.9 cm in diameter. The rock fragments were further sieved into greater than 7.6 cm and from 7.6 to 1.9 cm size groups and weighed. Soil material less than 1.9 cm in diameter was transported to the laboratory for further particle size and chemical analysis. Soil samples were air dried prior to particle size analysis (Gee and Bauder, 1986), subsequently ground to pass a 2 mm sieve, and stored in sealed containers for chemical analysis. Three additional naturally occuring soil clods were taken from each horizon and coated with saran for bulk density determination (Blake and Hartge, 1986).

Annual manure application rates presented in Table 1, were provided by the land owner at each site. For Captina and Stigler soils, the volume of swine manure applied, varied from year to year (Table 2). The P, N, and K content of applied swine manure was also provided by the land owner.

Table 1. Historic land use and management of the soils studied in Delaware county.+

Soil	Land use	Duration	T‡ value	Manure application	-Nutrients applied- N	P	K
				yr (t/acre/yr)	kg/ha/yr		
Captina silt loam	Mature oak forest	-	0.1	No manure	0	0	0
(Fine-silty, siliceous, mesic Typic Fragiudult)	Fescue pasture¶	15	0.1	Poultry manure at 5.6 Mg/ha/yr (2.5 ton/acre/yr), plus fertilizer N (200 kg/ha/yr)	456	87	04
	Fescue pasture	9	0.1	Swine manure at 61.1 m^3/ha/yr (6529 gal/acre/yr)	308	101	141
Sallisaw silt loam	Native grass pasture	-	0.1	No manure	0	0	0
(Fine-loamy, siliceous, thermic Typic Paleudalf)	Fescue pasture	15	0.1	Swine manure at 47.8 m^3/ha/yr (5112 gal/acre/yr)	241	81	111
Stigler silt loam (Fine, mixed, thermic Acquic Paleudalf)	Mature oak forest	-	0.1	No manure	0	0	0
	Conventionally tilled wheat	9	1.8	Swine manure, 22.1 m^3/ha/yr (2364 gal/acre/yr)	111	37	51

+Conversion factors for m^3/ha/yr to gal/acre/yr and kg/ha/yr to lbs/acre/yr are x 107 and x 0.893, respectively.
‡Soil loss value.
¶Fescue pasture was intermittently grazed and cut for hay.

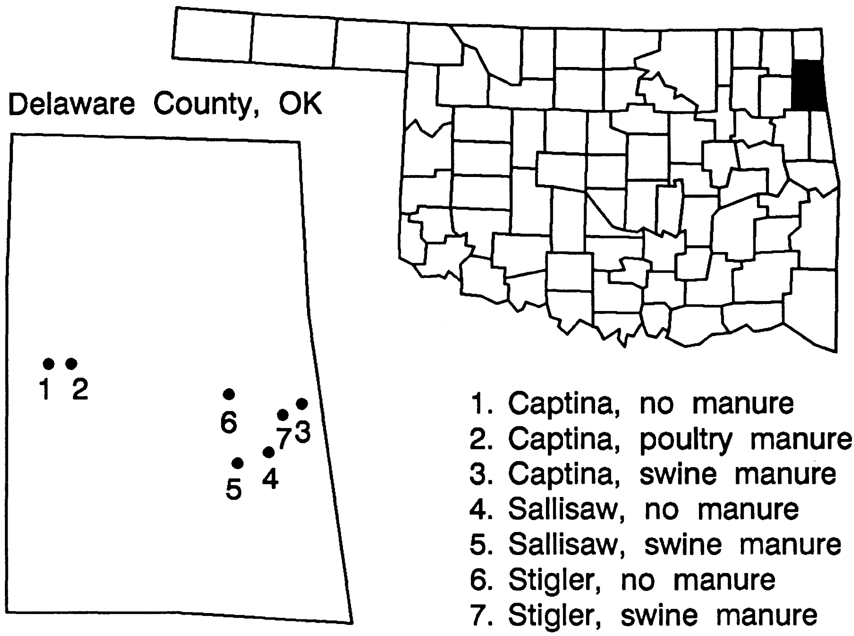

Figure 1. Location of the soils sampled in Delaware County, Oklahoma.

Table 2. Annual swine manure application for Captina and Stigler soils.

Year	Captina				Stigler			
	Volume	N	P	K	Volume	N	P	K
	m^3/ha/yr	---kg/ha/yr--			m^3/ha/yr	--kg/ha/yr---		
1980	170.3	858	238	393	0	0	0	0
1981	40.6	205	67	94	0	0	0	0
1982	ND+	ND	ND	ND	ND	ND	ND	ND
1983	26.1	131	43	60	84.8	427	141	196
1984	50.0	252	83	115	63.0	318	105	146
1985	64.5	325	107	149	0	0	0	0
1986	32.6	164	54	75	14.5	73	24	33
1987	31.9	161	53	74	0	0	0	0
1988	72.5	365	120	167	14.5	73	24	33
Average	61.1	308	101	141	22.1	111	37	51
Total	488.4	2464	808	1128	176.8	888	296	408

+Data not available.

In the case of poultry manure, however, actual nutrient contents of that applied, were not available. Consequently, an average of values reported in the literature for N, P, and K (45.8, 15.5, and 18.5 g/kg, respectively, Table 3) in poultry manure composed of bedding material (pine wood shavings) and exposure to poultry (25 weeks), similar to that applied to the Captina soil, was used to calculate nutrient applications (Table 1).

Methods

Phosphorus

Total P (TP) content of soil was determined by perchloric acid digestion (Olsen and Sommers, 1982) and inorganic P (IP) by acid (0.5 *M* H_2SO_4) extraction (Walker and Adams, 1958). Organic P (OP) was calculated as the difference between TP and IP. Plant available P (AP) content was determined by the Bray-I procedure, where 1 g of soil was extracted with 20 mL of 0.03 *M* NH_4F and 0.025 *M* HCl for 5 min (modified after Bray and Kurtz, 1945). Bioavailable P was that extracted by 0.1 *M* NaOH in 17 hr at a solution/soil ratio of 500:1 (Dorich et al., 1985).

All extracts were centrifuged (27,160 g for 5 min) and filtered (0.45 μm). The concentration of P was determined colorimetrically on filtered samples by the molybdate-blue method (Murphy and Riley, 1962). Acid and alkali filtrates were neutralized prior to P determination. The amount of P sorbed, X (mg/kg), from one addition of 1.5 g P/kg soil (added as K_2HPO_4) was determined after end-over-end shaking for 40 h at a water to soil ratio of 100:1. The P sorption index was calculated using the quotient X/log C, where C is solution P concentration (mg/L) (Bache and Williams, 1971). This quotient was highly correlated with P sorption maxima calculated from a Langmuir sorption plot for a wide range of soils (Bache and Williams, 1971). It, thus, reflects the number of unsatisfied P sorption sites on a soil and amount of added P that becomes relatively unavailable through sorption by soil material.

Soil IP and OP was fractionated according to the procedure described by Hedley et al. (1982). This involved sequential extraction with 0.5 *M* $NaHCO_3$ (pH 8.5); 0.1 *M* NaOH following sonification to disrupt soil aggregates; and finally, 0.1 *M* HCl. Each extraction was of 16-h duration and the solution to soil ratio was 60:1. The IP content of each extract was determined and subsequently referred to as bicarbonate IP, hydroxide IP, sonicate IP, and acid IP, respectively. In addition, the OP content of the bicarbonate, hydroxide, and sonicate extracts was calculated as the difference between TP and IP content. Total P content of each extract was determined by perchloric acid digestion. These organic fractions are subsequently referred to as bicarbonate OP, hydroxide OP, and sonicate OP, respectively.

Table 3. Nutrient content of poultry and swine manure.

Organic C	Total N	Total P	K	Reference
Poultry manure+ (g/kg)				
	43.0	16.3	21.3	Carreker et al., 1973
428	50.8	16.9	19.3	Gilbertson et al., 1979
377	43.3	16.4	19.1	Westerman et al., 1988
435	46.1	12.5	14.1	SCS, 1955
413	45.8	15.5	18.5	Average
Swine manure (g/L)				
29.1	7.01	1.62	2.41	Gilbertson et al., 1979
23.1	4.32	1.44	2.19	scs, 1985
	5.04	1.66	2.31	Present study
26.1	5.46	1.57	2.30	Average

+Pine shaving material used as bedding material with an approximate 25 week exposure.

The sequential extraction procedure removes IP and OP of increasing chemical stability in terms of soil P fertility. Hedley et al. (1982) and more recently Tiessen et al. (1984), reported that bicarbonate IP is the most biologically available IP form, while hydroxide IP is associated with amorphous and some crystalline Al and Fe phosphates. Sonicate IP is likely located within soil aggregates which are broken down with sonification. Acid IP is mainly relatively stable Ca- bound P. Bicarbonate OP is easily mineralized and may contribute to plant available P. Hydroxide OP and sonicate OP constitute chemically and physically protected organic forms that are involved in long-term soil P transformations.

Nitrogen

Total N (TN) was determined by a semimicro Kjeldahl procedure (Bremner and Mulvaney, 1982) and inorganic N forms (NO_3-N and ammonium-N, NH_4-N) were determined using procedures described by Bremner (1965). Autoclave - distillable N (a measure of mineralizable N) was determined using the procedure described by Smith and Stanford (1971).

Other properties

Soil pH was measured with a glass electrode using a 1:1 water to soil ratio (wt/wt), followed by addition of $CaCl_2$ and pH again determined in a final solution (0.01 *M* $CaCl_2$) and soil ratio of 2:1 (SCS, 1984). Organic C was determined by the dichromate - wet combustion method of Raveh and Avnimelech (1972) and carbon dioxide production using a nonenrichment procedure described by Russel and Stanford (1954). Total arsenic content of the surface two horizons of each untreated and treated soil was determined by the Oklahoma State Department of Health by atomic absorption. Exchangeable calcium (Ca), sodium (Na), magnesium (Mg), and potassium (K) content of each soil sample was determined by extraction with neutral 1.0 *M* NH_4OAc and flame photometry (Pratt, 1965). All analysis were conducted in duplicate and the following results presented as means.

Results

Physical Properties

No consistent effect of waste application on soil physical properties was observed (Table 4 and 5), although the bulk density of the Captina soil following both poultry and swine manure application was lower than the untreated soil (Table 5).

Table 4. Soil profile descriptions.[+]

Horizon	Depth (cm)	*Color moist	Structure	Texture	Consistence	Boundary	θm** %	Special Features
						Captina (no manure), 89-OK-41-2(1-9)		
A	18	10YR4/2	1,f,gr	SiL	fr	cl,w	25	Loess; M, f, m + c roots.
Bt1	46	10YR5/4	1,m,sbk	SiL	fr	g,w	22	Loess; M, f, m + c roots; F, thin discont. Clay coatings on peds + rocks; 5% rocks.
2Bt2,b	69	7.5-10YR5/4	2,m,sbk	VGSiCL	fr	cl,s	28	Colluvium; Co, f + m roots; Co, thin cont. clay coatings on peds + rocks; Co, f, d 5YR5/6 mottles; 60% rocks.
2Bt3,b	89	10YR6/4	1,m,abk	VGSiC	fi	cl,s	18	Colluvium; Co, f + m roots; M, thin cont. clay coatings on peds + rocks; M, m, pt 5YR5/6 + 10YR6/3 mottles; 85% rocks.
3Btx4,b	104	10YR7/1	2,f,abk	EGSiC	vfi	cl,s	15	Residuum; F, f roots; M, thick cont. clay coatings on peds + rocks; M, m, pt 5 + 10YR5/6 mottles; 80% rocks.
3Btx5,b	124	7.5YR5/6	3,c,pr	EGSiC	vfi	a,s	11	Residuum; M thick cont. clay coatings on peds + rocks; M, m, dt 5YR5/6 + 7/2 mottles; 95% rocks.
3Bt6,b	152	7.5YR5/6	1,m,abk	EGSiC	fi	cl,s	18	Residuum; Co, thin cont. clay coatings on peds + rocks; M, m, dt 5YR5/6 + 7/2 mottles; 85% rocks.
3Bt7,b	191	10YR4/6	1,m,sbk	VGC	fi	cl,s	23	Residuum; M, thin cont. clay coatings on peds + rocks; F, f roots; M, m, pt 5YR7/1 mottles; 60% rocks; free H_2O.
3Bt8,b	224	10YR5/6	2,c,pr/ 2,m,sbk	SiL	fi	a,w	20	Residuum; M, thick cont. clay coatings on peds + rocks; M, f, dt 10YR7/1 mottles; weathered shale.
3R,b	225+	2.5YR8/2 -2.5Y5/2	ma		vh			Residuum; chert; 10R4/6 + 2.5Y7/6 rock exterior.
						Captina (poultry manure), 89-OK-41-4(1-10)		
Ap1	10	10YR4/2	1,m,sbk	SiL	fr	a,s	20	Loess; M, f roots.
Ap2	23	10YR7/2	1,c,sbk	SiL	fr	a,s	18	Loess; Co,f roots.
Bt1	51	10YR5/4	2,m,sbk	SiL	fr	cl,w	16	Loess; Co, f roots; F, thin discont. clay coatings on rocks; Co, m, dt 7.5-10YR5/6 mottles; 3% rocks.
2Bt2	74	10YR4/2	3,f,sbk	VGSiC	fr	cl,s	22	Colluvium; F, f roots; F thin discont. clay coatings on peds + rocks; M, c, pt 5-7.5YR5/6 mottles; 50% rocks.
3Btx3,b	104	10YR5/8	3,f,sbk	EGSiC	fr	a,s	15	Residuum; Co, thick discont. clay coatings on peds + rocks; M, c, dt 7.5YR5/ mottles; 95% rocks.
3Btx4,b	130	10YR6/2	2,f,abk	EGSiC	fi	cl,s	29	Residuum; M, thin cont. clay coatings on peds + rocks; Co, m, dt 7.5YR6/2 mottles; 90% rocks.

Table 4. Soil profile descriptions.+ (Con't)

Horizon	Depth* (cm)	Color moist	Structure	Texture	Consistence	Boundary	θm** %	Special Features
					Captina (poultry manure), 89-OK-41-4(1-10) (Con't)			
3Bt5,b	168	7.5YR5/6	2,f,abk	EGC	fi	a,s	28	Residuum; M, thin cont. clay coatings on peds + rocks; Co, m, dt 7.5YR5/6 stratified w/ 10YR7/2 mottles; 90% rocks.
3BC1,b	188	10YR4/6	2,f,abk	EGSiC	fi	g,s	29	Residuum; Co, thin cont. clay coatings on peds + rocks; Co, m, dt 10YR4/6 mottles; 80% rocks.
3BC2,b	206	10YR7/2	ma	GSiC	vfi	g,s	20	Residuum; Co, thin cont. clay coatings on rocks; M, c, pt 10R4/6 + 5GY7/1; 30% rocks.
3BC3,b	229	10YR5/8	ma	SiCL	vfi	g,s		Residuum.
3R,b	230+		ma		h			Resdiuum; chert.
					Captina (swine manure), 89-OK-41-6(107)			
Ap	13	10YR4/3	1,f,gr	SiL	fr	cl,s	17	Loess; M, f roots.
E	25	10YR5/4	2,m,sbk	SiL	fr	cl,w	15	Loess; Co, f roots.
BE	61	10YR5/6	2,m,sbk	SiL	fr	a,i	17	Loess; Co, f + vf roots; F, thin discont. clay coatings on peds.
2Bt1	117	5YR4/6	2,f +	SiCL	fi	g,w	18	Alluvium; F, vf roots; Co, thick cont. clay coatings on m,abk peds; Co, m, dt 7.5YR6/4 + 7/2 mottles and tongues between peds.
2Bt2	168	2.5YR4/6	2,c,pr/ f,abk	SiCL	fi	cl,s	20	Alluvium; F, vf roots; M, thick cont. clay coatings on peds; Co, m, pt 7.5YR6/2 and F, f, dt 7.5YR6/4 mottles.
2Bt3	183	2.5YR4/4	3,c,pr/ f,abk	SiCL	fi	cl,w	19	Alluvium; Co, thick cont. clay coatings on peds; Co, c, pt 7.5YR6/2 mottles; 5% rocks.
2Bt4	218	2.5YR3/4	2,f + m,abk	SiCL	fi	a,w	19	Alluvium; Co, thin cont. clay coatings on peds; F, f, Mn-Fe (black) concretions; 15% rocks.
3R	219+		ma					Residuum; chert.
					Sallisaw (no manure), 89-OK-41-1(1-8)			
A	3	10YR4/4	2,f,gr	SiL	fr	cl,s	11	Alluvium; M, f roots.
Ad	18	10YR4/3	1,m,sbk + f,pl	SiL	fi	cl,s	11	Alluvium; Co, f roots.
BA	36	7.5-5YR4/4	2,c,sbk	SiL	fr	a,s	15	Alluvium; Co, f roots.

Table 4. Soil profile descriptions.[+] (Con't)

Horizon	Depth[*] (cm)	Color moist	Structure	Texture	Consistence	Boundary	θm[**] %	Special Features
								Sallisaw (no manure), 89-OK-41-1(1-8) (Con't)
Bt1	53	5YR4/6	2,m,sbk	SiCL	fr	g,s	18	Alluvium; F, f roots; Co, thin cont. clay coatings on peds.
Bt2	79	7.5-5YR4/6	1,c,pr/ 2,m,sbk	SiCL	fr	g,s	19	Alluvium; F, f roots; M, thick cont. clay coatings on peds.
Bt3	119	7.5YR4/6	2,c,pr/ m,sbk	SiCL	fi	g,s	20	Alluvium; F, f roots; Co, thick cont. clay coatings on prisms; Co, f-m, dt 7.5YR5/4 mottles; F, f Mn-Fe (black) coatings on peds.
Bt4	152	7.5YR4/4	2,c,pr/ 1,m,sbk	SiCL	fi	a,s	21	Alluvium; VF, f roots Co thin discont. clay coating on peds; M,f-m, dt 7.5YR5/4 mottles; gleyed prism faces; 3% rocks.
C1	203	7.5YR4/6	ma	EGSiL	l	a,s		Alluvium; VF, f roots stratified stones + gravels (5-20 cm beds); 98% rocks.
C2	249	7.5YR4/6	ma	EGSiL	l			Alluvium; VF, f roots; stones (subangular chert); 98% rocks.
								Sallisaw (swine manure), 89-OK-41-5(1-11)
Ap	15	7.5YR4/4	2,f,gr	SiL	fr	a,s	10	Alluvium; M, m roots; 7% rocks.
Ad	25	7.5YR4/4	1,fsbk	SiL	fi	cl,s	9	Alluvium, M, f + m roots.
Bt1	51	5YR4/4	1,m,sbk	SiL	fr	cl,s	15	Alluvium; Co, f roots; F thin discont. clay coatings on peds.
Bt2	79	5YR4/4	2,m,sbk	SiCL	fr	c,w	21	Alluvium; F, f roots; Co, thin discont. clay coatings on peds 5% rocks.
Bt3	102	2.5YR4/6	2,f,sbk	GSiCL	fr	a,s	21	Alluvium; F, f roots; M, thick cont. clay coatings on peds; M, m, pt 10YR6/4 mottles; 25% rocks.
Bt4,b	183	5YR4/6	1,f,sbk	EGSiCL	fi	cl,s	24	Alluvium; F, f roots; M, thick cont. clay coatings on peds; 70% rocks.
Bt5,b	198	5YR4/6	1,c,pr/ m,sbk	SiCL	fr	g,w	25	Alluvium; Co, thin cont. clay coatings on peds; 5% rocks; organic staining in old root channels (black; could be buried soil).
Bt6,b	244	5YR4/6	1,c,pr/ 1,m,abk	SiCL	fr	cl,w	24	Alluvium; F, thin discont. clay coatings on peds; 5% rocks; organic staining in old root channels.
Bt7,b	259	5YR4/6	2,f,abk	SiCL	fi	cl,w		Alluvium; F, thin discont. clay coatings on peds; 10% rocks.
BC,b	287	5YR4/4	1,f,sbk	GSiCL	fi	a,w	25	Alluvium; 20% rocks.
C,b	356+	2.5Y4/6	ma	SiCL	fi		22	Alluvium; 60% rocks.

Table 4. Soil profile descriptions.[+] (Con't)

Horizon	Depth* (cm)	Color moist	Struc-ture	Tex-ture	Consis-tence	Boun-dary	em** %	Special Features
					Stigler (no manure), 89-OK-41-3(1-8)			
A	15	10YR3/2	1,f,sbk	SiL	fr	cl,s	37	Loess; M, f - m + c roots.
E	30	10YR4/3	2,f,sbk	SiL	fr	cl,s	23	Alluvium; M, f - m + c roots.
2Bt1	53	10YR6/4	2,f,sbk	SiCL	fr	cl,s	22	Alluvium; M, f + m roots; F, thin discont. clay coatings on peds.
2Bt2	69	10YR5/4	2,f+m, abk	SiC	fi	g,w	21	Alluvium; Co, f + m roots; Co, thin nearly cont. clay coatings on peds.
2Bt3	91	10YR5/3	3,m,sbk	SiC	fi	a,i	23	Alluvium; Co, f roots; Co, thin cont. clay coatings on peds; Co, m, ft 7.5YR5/6 mottles; F, f + m, Mn-Fe (black) concretions + coatings.
2Bt4	142	7.5YR5/4	2,c,pr/ 1,m,abk	SiCL	fi	g,s	22	Alluvium; F, f roots; M, thick cont. clay coatings on peds; F, f, dt 7.6YR5/6 mottles; Co, m, Mn-Fe (black) concretions + coatings; Co, c, 7.5YR5/4 tongues.
2Bt5	211	5YR5/6	1,m,pr	SiCL	vfi	cl,s	22	Alluvium; F, f roots; M, thick cont. clay coatings on peds; Co, m, pt 5YR6/2-7.5YR5/6 mottles; Co, f + m Mn-Fe (black) concretions + coatings.
2Bt6	244	7.5-10YR5/6	1,m,abk	C	vfi		26	Alluvium; M, f, root cavities filled or coated w/5YR6/2 clay; M, m, pt 7.5YR5/8 + 6/2 mottles; Co, f + m Mn-Fe (black) concretions + coatings; 15% rocks.
3R	245+		ma				18	Residuum; coarse grained chert.
					Stigler (swine manure), 89-OK-41-7(1-8)			
Ap	8	10YR4/2	2,f,gr	SiL	fr	cl,s	13	Loess; M, f roots.
E	33	10YR4/2	1,f,gr	SiL	fr	cl,s	16	Loess; Co, f roots.
BE	46	10YR5/4	2,f + m,sbk	SiL	fr	cl,s	16	Loess; F, f roots; Co, f, dt 7.5YR5/6 mottles; VF, thin discont. clay coatings on peds.
2Bt1	66	10YR4/1	2,f + m,abk	C	fi	cl,w	31	Alluvium; F, vf roots; Co, thin discont. clay coatings on peds; Co, m, pt 5YR4/6, 2.5YR4/8, + 10YR7/2 mottles.
2Bt2	86	10YR4/2	2,f + m,abk	C	fi	cl,w	30	Alluvium; F, vf roots; Co, thin discont. clay coatings on peds; M, m, pt 2.5YR4/8 + Co, m, dt 5YR4/6 mottles.
2Bt3	150	10YR5/6	1,m,abk	C	fi	g,w	20	Alluvium; F, thin discont. clay coatings on peds; F, f, dt 5YR5/6 mottles; F, c 10YR5/2 tongues (higher clay content).
2Bt4	173	10YR5/6	1,m + f,sbk	C	fi	cl,w	23	Alluvium; F, thin, discont. clay coatings on peds; F, f, dt 5YR5/6 mottles; F, c 10YR5/2 vertical columns; Co, m, Mn-Fe (black) coatings + soft concretions.

Table 4. Soil profile descriptions.[+] (Con't)

Horizon	Depth* (cm)	Color moist	Structure	Texture	Consistence	Boundary	θ_m** %	Special Features
								Stigler (swine manure), 89-OK-41-7(1-8) (Con't)
3C	201	5YR4/6	1,f,sbk	SiCL	fr	a,w		Residuum; F, thin discont. clay coatings on rocks; Co, f + m, dt 2.5YR4/8 mottles; 10YR5/2 rock exteriors; F, f, Mn-Fe (black) soft concretions; 70% rocks.
3R	202+	ma						Residuum; fractured chert.

[+]Soil Survey Staff (1981); 1 = weak, 2 = moderate, 3 = strong, f = fine, m = medium, c = coarse, gr = granular, sbk = subangular blocky, abk = angular blocky, pr = prismatic, ma = massive, pl = platy, fr = friable, fi = firm, h = hard, l = loose, cl = clear, g = gradual, a = abrupt, s = smooth, w = wavy, i = irregular, M = many, Co = common, F = few, ft = faint, dt = distinct, pt = prominent.

*Depth from ground surface to the bottom of the horizon.

**θ_m = gravimetric water content when sampled.

Table 5. Particle size analysis, bulk density (B.D.), and gravimetric water content (Θm) air-dry at room temperature for the soils studied.

Horizon	Depth (cm)	% Rock Fragments, diameter (cm)			% Soil (<2.0 mm diameter fraction)								Texture	B.D. (g/cm^3)	Θm (%)
		>7.6	7.6-1.9	>0.2	VCS 2.0 - 1.0	CS 1.0 - .5	MS .5 - .25	FS .25 - .1	VFS .1 - .05	S 2.0 - .05	Si .05 - .002	C .002>			
Captina (no manure), 89-OK-41-2(1-9)															
A	18	0	0	0	1.5	1.7	1.3	1.1	3.0	8.6	77.3	14.1	SiL	1.36	1.8
Bt1	46	0	0	0	5.1	2.2	1.1	1.1	2.9	12.3	65.3	22.2	SiL	1.43	2.5
2Bt2,b	69	58	18	76	3.9	1.5	0.7	1.1	2.5	9.6	42.7	47.5	SiC	1.61	5.1
2Bt3,b	89	37	37	74	12.3	4.2	1.1	1.1	2.5	21.1	37.0	41.5	C	1.07	4.4
3Btx4,b	104	28	43	71	18.9	5.3	1.6	1.7	2.8	30.1	36.1	33.8	CL	1.47	2.9
3Btx5,b	124	8	36	43	10.8	7.5	2.0	2.1	4.7	26.9	45.0	28.0	CL	1.63	1.9
3Bt6,b	152	3	17	20	9.2	3.8	1.6	1.9	4.2	21.0	35.4	44.0	C	1.76	2.9
3Bt7,b	191	16	5	22	1.9	1.5	1.1	1.6	2.9	8.9	41.7	49.3	SiC	1.72	3.6
3Bt8,b	224	0	0	0	0.8	0.7	0.4	0.5	1.1	3.3	51.1	44.6	SiC	1.89	3.6
Captina (poultry manure), 89-OK-41-4(1-10)															
Apl	10	0	0	0	1.9	1.0	1.0	1.3	3.3	8.2	73.1	18.6	SiL	1.05	2.8
Ap2	23	0	0	0	2.0	0.6	0.6	0.8	2.8	6.7	74.1	19.2	SiL	1.52	1.6
Bt1	51	0	0	0	3.0	1.0	0.6	0.7	2.4	7.6	71.1	21.3	SiL	1.35	1.6
2Bt2,b	74	68	14	82	6.0	1.6	0.7	0.7	1.7	10.6	36.7	52.7	C	1.68	5.0
3Btx3,b	104	50	18	68	16.6	4.5	0.9	0.8	1.6	24.3	35.0	40.7	C	1.48	3.0
3Btx4,b	130	46	13	59	4.2	1.4	0.6	1.0	2.7	9.8	19.4	70.7	C	1.33	4.8
3Bt5,b	168	33	18	52	2.2	1.2	0.8	1.8	4.1	10.1	17.4	72.5	C	1.33	4.9
3BC1,b	188	33	25	58	4.5	2.6	1.3	1.4	1.8	11.5	19.7	68.7	C	1.32	5.3
3BC2,b	206	12	11	23	1.9	1.9	1.4	1.3	1.2	7.7	42.4	49.7	SiC	1.82	3.4

Table 5. Particle size analysis, bulk density (B.D.), and gravimetric water content (θm) air-dry at room temperature for the soils studied. (Con't)

Horizon	Depth cm	% Rock Fragments diameter (cm) >7.6	7.6-1.9	>0.2	% Soil (<2.0 mm diameter fraction) VCS 2.0 - 1.0	CS 1.0 - .5	MS .5 - .25	FS .25 - .1	VFS .1 - .05	S 2.0 - .05	Si .05 - .002	C .002>	Tex-ture	B.D. (g/cm^3)	θm %
							Captina (swine manure), 89-OK-41-6(1-7)								
Ap	13	0	0	0	0.7	1.0	1.3	2.6	5.5	11.1	78.2	10.5	SiL	1.09	1.8
E	25	0	0	0	0.7	1.0	1.4	2.5	5.3	10.7	77.2	12.0	SiL	1.39	1.7
BE	61	0	0	0	1.0	1.3	1.4	2.2	4.5	10.2	68.3	21.4	SiL	1.46	2.1
Bt1	117	0	0	0	0.9	0.5	0.7	1.9	4.5	8.5	53.8	37.5	SiCL	1.68	3.6
Bt2	168	0	0	0	2.1	0.9	0.7	1.9	4.6	10.1	46.5	43.3	SiC	1.75	3.4
Bt3	183	0	0	0	9.4	2.1	0.9	2.1	4.1	18.5	34.8	46.6	C	1.82	3.7
Bt4	218	0	0	0	15.5	6.6	2.6	2.8	3.2	30.6	30.0	39.3	CL		3.7
							Sallisaw (no manure), 89-OK-41-1(1-8)								
A	3	0	0	0	0.2	0.1	0.2	2.2	9.7	12.4	76.1	11.2	SiL		1.4
Ad	18	0	0	0	0.1	0.1	0.2	2.0	9.8	12.1	75.1	12.7	SiL	1.41	1.1
BA	36	0	0	0	0	0	0.1	1.7	8.8	10.7	73.2	16.0	SiL	1.47	1.4
Bt1	53	0	0	0	0	0.1	0.1	1.6	7.2	9.0	68.0	22.9	SiL	1.56	2.1
Bt2	79	0	0	0	0.1	0.1	0.2	1.3	5.8	7.3	67.2	25.4	SiL	1.60	2.5
Bt3	119	0	0	0	0	0.1	0.1	1.0	4.9	6.1	69.2	24.6	SiL	1.54	2.5
Bt4	152	0	0	0	2.3	0.7	0.5	1.5	5.6	10.5	65.3	24.0	SiL	1.54	2.4

Table 5. Particle size analysis, bulk density (B.D.), and gravimetric water content (Θm) air-dry at room temperature for the soils studied. (Con't)

Horizon	Depth	% Rock Fragments diameter (cm)			% Soil (<2.0 mm diameter fraction)								Tex-	B.D.	Θm
					VCS	CS	MS	FS	VFS	S	Si	C			
	cm	>7.6	7.6-1.9	>0.2	2.0 -	1.0 -	.5 -	.25 -	.1 - .05	2.0 -	.05 -	.002>	ture	(g/cm^3)	%
					Sallisaw (swine manure), 89-OK-41-5(1-11)										
Ap	15	0	0	0	3.0	1.7	1.6	1.9	2.7	10.8	76.4	12.9	SiL	1.49	1.5
Ad	25	0	0	0	0.9	1.2	1.5	1.8	2.5	7.8	77.3	13.3	SiL	1.46	1.4
Bt1	51	0	0	0	1.0	0.9	1.1	1.6	2.4	7.0	69.6	23.5	SiL	1.68	2.2
Bt2	79	0	0	0	0.8	1.2	1.5	2.1	3.0	8.4	63.0	28.7	SiCL	1.64	2.4
Bt3	102	15	11	26	2.0	1.7	1.6	2.1	3.0	10.3	61.8	28.0	SiCL	1.69	2.3
Bt4,b	183	46	24	70	7.2	5.9	4.2	3.3	2.2	22.6	42.1	35.3	CL	1.02	2.6
Bt5,b	198	0	1	1	1.2	1.2	1.9	2.7	2.8	9.7	62.7	27.5	SiL	1.55	2.6
Bt6,b	244	3	4	7	2.9	2.5	2.4	2.8	2.7	13.1	56.5	30.5	SiCL	1.57	3.3
Bt7,b	259	(not sampled - too thin)													
BC,b	287	11	8	19	1.8	2.2	2.7	2.9	2.7	12.2	55.2	32.8	SiCL	1.41	3.1
C,b	356+	44	28	71	5.8	5.0	3.6	2.9	2.0	19.9	43.5	36.8	SiCL		4.2
					Stigler (no manure), 89-OK-41-3(1-8)										
A	15	0	0	0	0.7	0.7	0.7	0.9	1.4	4.1	81.3	14.5	SiL	1.28	2.6
E	30	0	0	0	2.1	2.3	1.2	1.1	1.3	8.0	75.4	16.7	SiL	1.36	1.6
2Bt1	53	0	0	0	2.2	1.6	1.0	1.2	0.2	5.6	76.3	18.1	SiL	1.47	1.7
2Bt2	69	0	0	0	2.3	1.3	1.0	1.4	0.9	6.8	70.1	23.2	SiL	1.55	2.2
2Bt3	91	0	0	0	1.3	1.0	0.8	1.5	2.0	6.5	61.8	31.8	SiCL	1.63	3.5
2Bt4	142	0	0	0	0.5	0.6	0.7	1.6	2.4	5.6	66.5	28.0	SiCL	1.66	2.4
2Bt5	211	0	0	0	1.9	0.8	0.7	1.5	0.6	6.4	67.6	25.9	SiL	1.71	2.3
*	211	0	0	0	0.5	0.7	0.7	1.5	1.1	4.1	60.7	35.1	SiCL		3.7
2Bt6	244	0	0	0	5.2	1.7	0.9	1.6	0.7	9.9	61.2	27.1	SiCL	1.77	2.3

Table 5. Particle size analysis, bulk density (B.D.), and gravimetric water content (Θm) air-dry at room temperature for the soils studied. (Con't)

Horizon	Depth	% Rock Fragments diameter (cm)			% Soil (<2.0 mm diameter fraction)								Tex-	B.D.	Θm
	cm	>7.6	7.6-1.9	>0.2	VCS 2.0 - 1.0	CS 1.0 - .5	MS .5 - .25	FS .25 - .1	VFS .1 - .05	S 2.0 - .05	Si .05 - .002	C .002>	ture	(g/cm^3)	%
							Stigler (swine manure), 89-OK-41-7(1-8)								
Ap	8	0	0	0	1.8	0.7	0.6	1.1	2.2	6.3	61.7	32.0	SiCL	1.22	1.7
E	33	0	0	0	0.5	0.6	0.6	1.2	2.6	5.3	64.4	30.3	SiCL	1.35	1.7
BE	46	0	0	0	9.7	2.1	0.9	1.1	1.8	15.5	52.5	32.1	SiCL	1.37	1.7
2Bt1	66	0	0	0	0.2	0.1	0.1	0.4	0.7	1.5	19.5	79.1	C	1.71	7.1
2Bt2	86	0	0	0	1.0	0.3	0.3	0.8	0	2.3	27.8	70.0	C	1.76	6.7
2Bt3	150	0	0	0	3.6	1.4	0.9	1.7	3.7	11.2	46.9	42.0	SiC	1.70	2.6
2Bt4	173	0	0	0	6.0	2.6	1.6	2.1	2.5	14.7	30.2	55.3	C	1.67	4.9

*Sample taken from ped coating.

Several soil series contained either buried soils or lithologic discontinuities (change in soil parent material with depth). In Tables 4 and 5 buried soils and lithologic discontinuities are denoted in the horizon name by a "b" suffix or arabic number prefix, respectively. Buried soils and lithologic discontinuities had a significant influence on the C, N, and P content with increasing depth in the untreated Captina soil and Captina soil treated with poultry manure. Buried soils were found at a depth of 46 and 51 cm, respectively. Correspondingly, at these depths there was an increase in organic C, all forms of N, and all forms of P except available P. Within the Sallisaw soil treated with swine manure buried soil horizons were found at a depth of 102 cm. All forms of P were greater than the horizon directly above the buried soil but organic C and all forms of N were either equal to or lower within the buried soil compared to the horizon directly above. Additions of swine manure may have increased the organic C and N content in this Sallisaw soil which masks the effect of the buried soil especially within the upper 50 cm. Eolian additions such as loess (silt sized particles) or dust (silt and clay size particles) are important processes that bury soils in Oklahoma. Also, alluvium (sediments from stream deposits can bury soils that border stream and river systems. When sampling soils for evaluation of manuring effects, all buried soil horizons should be identified because of the originally high contents of organic C, N, P and other elements commonly associated with organic matter (Olson, 1989).

Chemical Properties

Phosphorus

Amounts: Total P, IP, and AP content of the surface horizons of treated soils was greater than untreated soil (Table 6). This increase was only evident, however, in approximately the surface 50 cm. Consequently, most of the applied P remained in the root zone and little movement of P occurred below 50 cm. The amount of P in each 10 cm depth, of soil was calculated from bulk density (Table 5) and P concentration (Table 6) and is presented to a 125 cm depth for TP, IP, and AP in Figures 2, 3, and 4, respectively. The accumulation of P in the surface 50 cm of soil is clearly evident.

Following both poultry and swine manure application, IP constituted a greater proportion of TP than in untreated soils (Fig. 5). For example, the 25, 22, and 33% of TP as IP in the surface 10 cm of untreated Captina, Sallisaw, and Stigler soils, respectively, increased to 66, 69, and 61%, respectively, following swine manure application and to 89% in Captina treated with poultry manure. Accumulation of manure P in these soils was, thus, primarily in an inorganic form, indicating its rapid sorption by soil

Table 6. Total P, inorganic P, organic P, and available P content, C:P ratio and P sorption index of the soils studied.

Horizon	Depth	Total P	Inorganic P	Organic P	Available P	P sorption index	C:P ratio
	cm	---------------mg/kg--------------					
Captina (no manure)							
A	0-18	273	87	186	4.5	391	56.5
Bt1	18-46	195	52	143	3.7	446	20.5
2Bt2,b	46-69	225	51	174	1.7	1310	27.5
2Bt3,b	69-89	170	74	96	0.6	1317	18.2
3Btx4,b	89-104	269	87	182	1.7	869	8.6
3Btx5,b	104-124	217	66	151	3.1	481	1.8
3Bt6,b	124-152	186	37	149	3.1	523	2.7
3Bt7,b	152-191	156	22	133	0.6	416	6.4
3Bt8,b	191-224	256	26	230	1.0	432	2.7
Captina (poultry manure)							
Ap1	0-10	1103	900	202	278.8	48	49.9
Ap2	10-23	234	121	113	21.7	141	50.5
Bt1	23-51	163	73	90	17.5	257	30.1
2Bt2,b	51-74	262	106	155	5.5	1504	35.9
3Btx3,b	74-104	389	96	292	3.0	535	5.9
3Btx4,b	104-130	221	66	155	1.1	807	6.3
3Bt5,b	130-168	136	25	111	0.7	690	8.1
3BC1,b	168-188	147	19	128	0.7	582	6.8
3BC2,b	188-221	145	16	129	0.4	363	4.8
Captina (swine manure)							
Ap	0-13	566	344	222	120.5	20	39.9
E	13-25	211	91	119	14.4	86	40.4
BE	25-61	164	57	108	4.9	323	21.3
Bt1	61-117	151	48	104	1.3	861	11.2
Bt2	117-168	207	56	151	1.3	495	6.8
Bt3	168-183	265	101	164	1.7	512	6.0
Bt4	183-218	737	138	599	2.5	607	1.4
Sallisaw (no manure)							
A	0-3	226	54	172	6.02	218	74.6
Ad	3-18	198	43	155	3.5	128	35.8
BA	18-36	213	50	163	4.4	128	20.7
Bt1	36-53	196	104	92	12.7	238	13.2
Bt2	53-79	225	117	108	16.5	123	10.2
Bt3	79-119	250	157	92	29.6	206	7.6
Bt4	119-152	236	179	57	28.5	227	6.8
Sallisaw (swine manure)							
Ap	0-15	436	265	171	147.4	51	41.8
Ad	15-25	283	103	180	39.3	119	36.0
Bt1	25-51	168	45	123	4.8	252	26.1
Bt2	51-79	173	56	117	3.9	333	15.1

Table 6. Total P, inorganic P, organic P, and available P content, C:P ratio and P sorption index of the soils studied. (Con't)

Horizon	Depth	Total P	Inorganic P	Organic P	Available P	P sorption index	C:P ratio
	cm	---------------mg/kg--------------					
Bt3	79-102	159	57	102	3.6	282	10.7
Bt4,b	102-183	243	127	16	10.6	343	7.0
Bt5,b	183-198	229	134	95	21.5	499	3.5
Bt6,b	198-244	269	164	105	23.1	530	3.3
BC,b	259-287	270	200	71	26.5	530	3.3
C,b	287-356	319	220	99	29.7	516	4.4
Stigler (no manure)							
A	0-15	352	115	237	14.5	212	124.8
E	15-30	196	62	134	6.2	242	31.6
2Bt1	30-53	207	89	118	8.0	230	16.4
2Bt2	53-69	180	55	126	3.0	405	11.1
2Bt3	69-91	204	55	149	2.9	642	12.2
2Bt4	91-142	194	77	116	6.1	460	5.2
2Bt5	142-211	222	100	122	6.3	325	3.2
3Bt6	211-244	210	80	130	2.8	268	3.8
Stigler (swine manure)							
Ap	0-8	336	139	197	82.3	81	67.6
E	8-33	225	98	126	24.1	159	74.5
BE	33-46	160	32	128	3.8	325	35.0
2Bt1	46-66	170	28	142	2.5	1792	55.9
2Bt2	66-86	160	25	136	1.9	1336	53.6
2Bt3	86-150	154	61	93	3.0	280	11.7
2Bt4	150-178	194	50	144	1.4	547	23.2

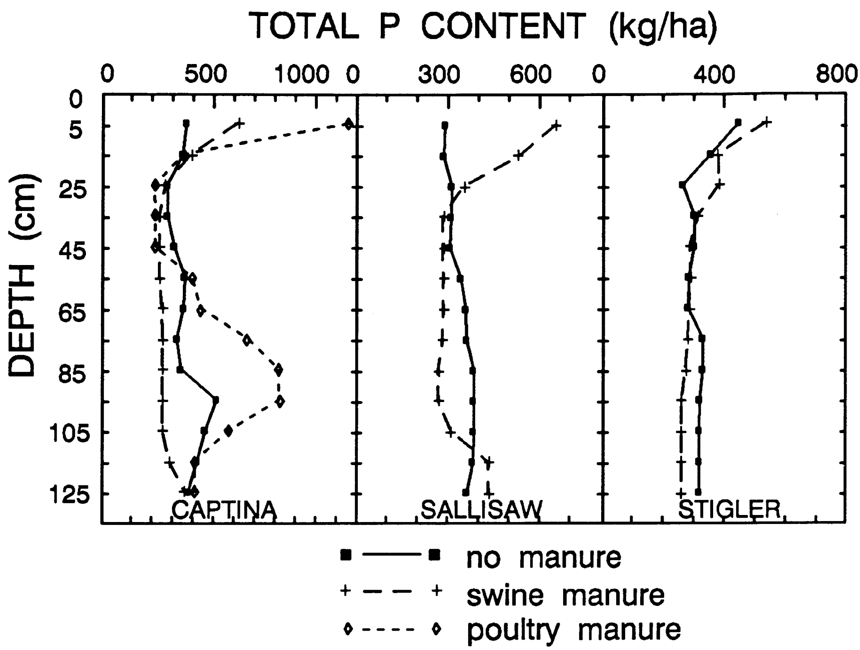

Figure 2. Total P content of untreated and treated soils.

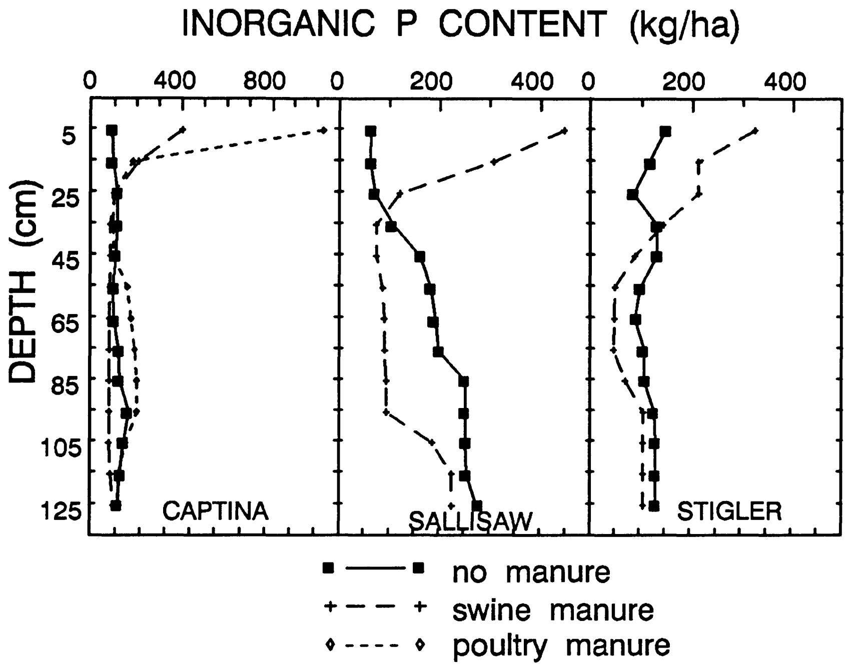

Figure 3. Inorganic P content of untreated and treated soils.

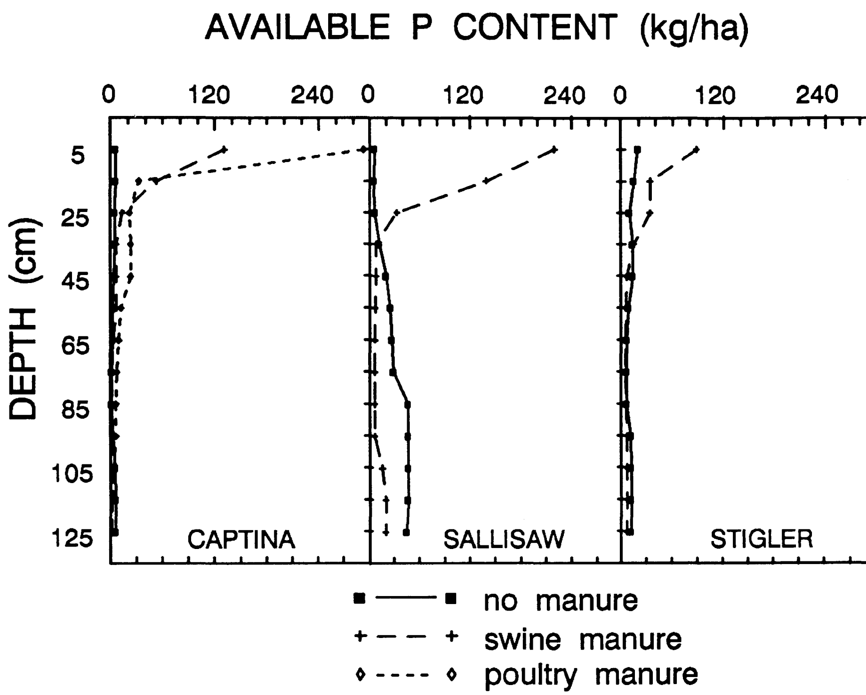

Figure 4. Available P content of untreated and treated soils.

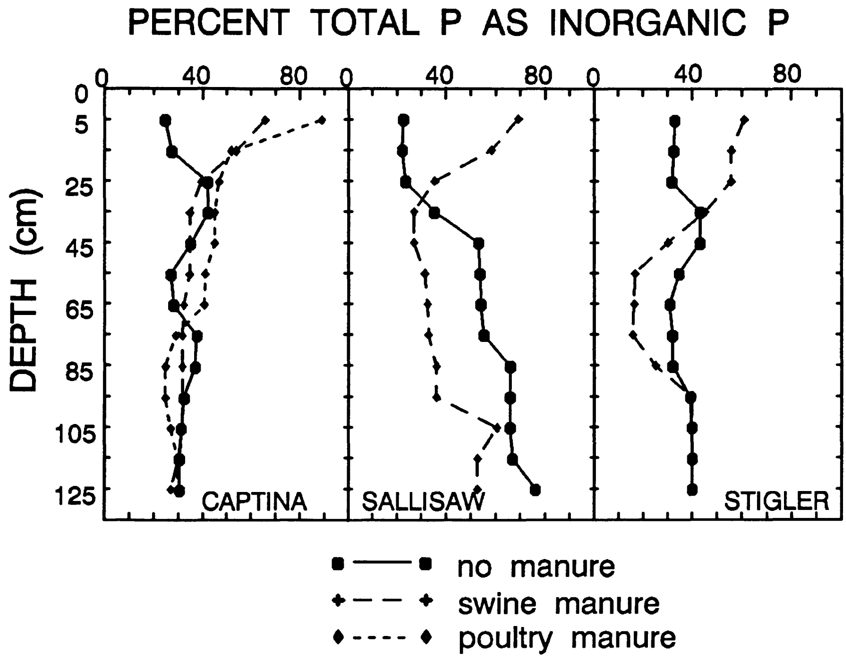

Figure 5. Proportion of total P as inorganic P in untreated and treated soils.

material. Of this accumulated IP, a greater proportion was present in a plant available form, as represented by Bray P (Fig. 6). The proportion of P as AP in untreated Captina (7%), Sallisaw (9%), and Stigler (13%) soils, increased 5 fold for Captina (33%) and Sallisaw (49%) and 2 fold for Stigler (27%) soils treated with swine manure and 4 fold for the Captina soil (28%) treated with poultry manure. This represents a dramatic increase in the amount of P potentially available for plant uptake. However, it also represents an important source of P to surface runoff waters from these soils. No difference in OP content of treated and untreated soil was apparent (Table 6), thus, any OP in manure was mineralized following application. This is consistent with the low C:P ratio of both poultry (27:1) and swine manure (17:1) (Table 3). It is generally assumed that for C:P ratios of 200:1 or less, P mineralization occurs, and if the ratios are 300:1

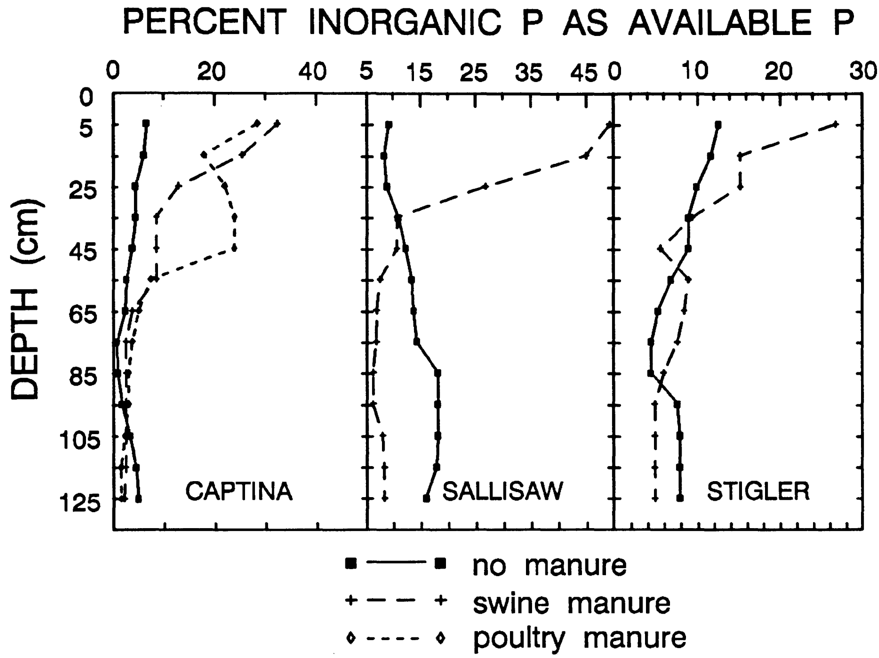

Figure 6. Proportion of inorganic P as available P in untreated and treated soils.

or more immobilization occurs (Dalal, 1977; Fuller et al., 1956). Soil C:P ratio decreased following both poultry and swine manure application (Table 6). It was apparent, however, that the decrease was greater for swine compared to poultry manure application, due in part to the narrower C:P ratio of swine (17:1) than poultry manure (27:1) (Table 3).

Due to the large amount of P added to these soils, the capacity of the soil to sorb further additions of P, represented by P sorption index (PSI), decreased with manure application (Table 6 and Fig. 7). This decrease was mainly evident in approximately the surface 50 cm. The large decrease in PSI following swine manure application to Captina and Sallisaw (19.6 and 4.3 fold, respectively) compared to Stigler (2.6 fold), may result in part from the larger amounts of P added to Captina and Sallisaw than Stigler soils during the study period (Table 1).

Disposition: The sequential fractionation of soil P into forms of differing lability, allow an evaluation of the disposition of P in added manure (Table 7). In general, most of the applied manure P accumulated in inorganic bicarbonate and hydroxide fractions, representing weakly bound plant available (physical and chemical) P and P associated with hydrous Al and Fe oxides, respectively. Smaller amounts of IP accumulated in the acid fraction, representing formation of relatively stable Ca-bound P, even though the pH ($CaCl_2$) of all soils ranged from 3.8 to 5.8. In exception to this, was the 13-fold increase in acid IP in the surface horizon of Captina treated with poultry manure compared to the untreated Captina (Table 7). This exception may be attributed to the greater concentration of Ca in poultry (20 g/kg) than swine manure (6g/kg) (Carreker et al., 1973; Gilbertson et al., 1979). As discussed earlier for total OP content, manure application had little influence on the disposition of OP in fractions ranging in chemical and physical stability.

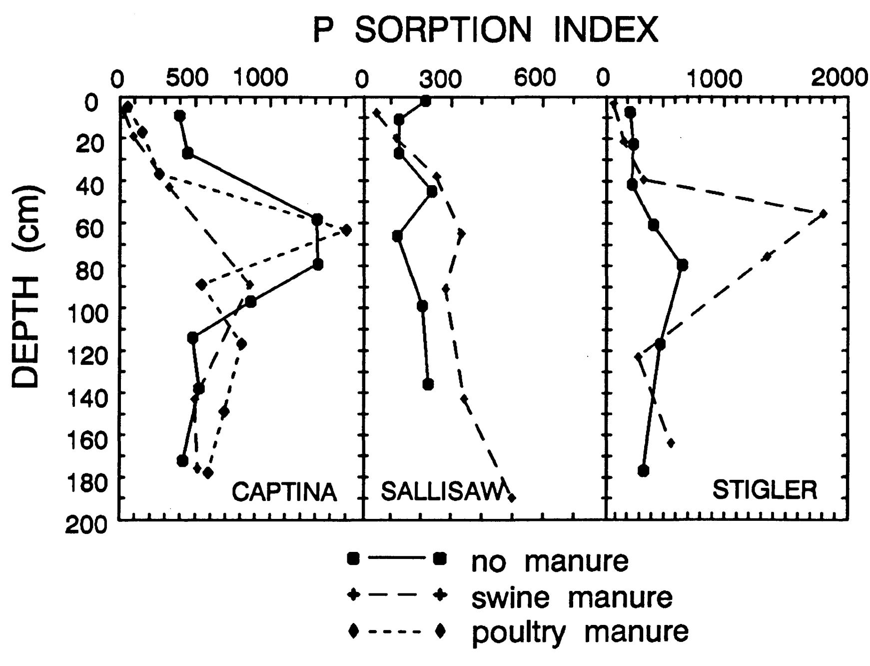

Figure 7. P sorption index of untreated and treated soils.

Table 7. Inorganic and organic P fractionation of the soils studied.

Horizon	Depth	Inorganic P				Organic C		
		Bic.+	Hyd.	Son.	Acid	Bic.	Hyd.	Son.
	cm	mg/kg						
Captina (no manure)								
A	0-18	13.0	55.3	10.0	8.6	14.7	33.1	5.6
Bt1	18-46	10.1	22.3	16.4	3.1	5.2	29.8	5.9
2Bt2,b	46-69	6.7	36.4	6.0	2.3	4.5	10.8	7.0
2Bt3,b	69-89	5.0	48.9	14.2	6.0	1.0	6.6	2.3
3Btx4,b	89-104	9.0	55.7	15.8	6.6	0.8	8.8	2.9
3Btx5,b	104-124	10.0	42.4	9.0	4.5	0.1	8.5	1.1
3Bt6,b	124-152	7.5	19.0	7.4	3.4	1.0	9.6	4.7
3Bt7,b	152-191	4.1	11.3	4.9	1.9	0.0	3.3	1.0
3Bt8,b	191-224	3.6	13.7	6.1	2.2	0.1	2.7	0.8
Captina (poultry manure)								
Ap1	0-10	354.0	396.2	38.0	112.3	17.7	59.2	10.3
AP2	10-23	39.4	54.3	12.3	14.6	1.6	31.4	9.2
Bt1	23-51	21.9	38.5	8.8	3.9	5.0	11.8	5.1
2Bt2,b	51-74	8.0	75.2	19.7	3.5	6.0	0.5	5.8
3Btx3,b	74-104	9.6	57.9	18.1	10.8	0.6	10.0	7.1
3Btx4,b	104-130	6.8	44.8	10.8	3.8	0.9	10.9	0.9
3Bt5,b	130-168	4.0	13.9	4.7	2.0	0.9	6.2	0.6
3BC1,b	168-188	3.5	10.0	3.6	1.9	0.4	3.0	2.1
3BC2,b	188-221	3.5	7.6	3.0	1.4	0.2	2.1	1.1
Captina (swine manure)								
Ap	0-13	97.1	156.0	33.3	57.5	21.3	31.3	8.0
E	13-25	20.3	45.5	15.0	10.5	7.9	31.4	5.4
BE	25-61	9.3	35.7	7.3	4.2	3.8	13.6	4.9
Bt1	61-117	5.4	31.1	8.8	2.4	0.8	9.0	6.4
Bt2	117-168	5.8	31.3	13.5	5.4	1.0	4.9	2.3
Bt3	168-183	10.2	63.6	21.7	5.1	1.1	3.9	3.5
Bt4	183-218	21.1	81.6	31.3	4.1	2.0	19.7	2.2
Sallisaw (no manure)								
A	0-3	11.5	25.4	5.2	12.3	18.6	56.4	16.1
Ad	3-18	6.2	16.9	7.1	13.0	11.9	54.1	10.2
BA	18-36	6.6	18.6	8.0	16.4	9.3	34.0	7.7
Bt1	36-53	20.4	48.1	13.0	22.5	5.0	15.8	2.5
Bt2	53-79	21.8	55.5	15.1	24.6	3.7	12.9	1.8
Bt3	79-119	28.9	81.0	17.3	29.9	4.0	10.2	1.2
Bt4	119-152	36.7	90.3	20.0	31.8	4.0	14.8	5.1
Sallisaw (swine manure)								
Ap	0-15	95.8	114.9	14.8	39.3	26.4	60.1	16.0
Ad	15-25	25.9	50.9	10.3	15.9	19.4	57.1	10.3
Bt1	25-51	8.5	15.5	7.1	14.0	13.9	33.3	3.5
Bt2	51-79	8.7	24.8	7.7	14.9	6.9	15.4	1.0
Bt3	79-102	9.9	24.5	7.7	14.6	4.0	14.7	0.8

Table 7. Inorganic and organic P fractionation of the soils studied. (Con't)

Horizon	Depth	Inorganic P				Organic C		
		Bic.[+]	Hyd.	Son.	Acid	Bic.	Hyd.	Son.
	cm	mg/kg						
Bt4,b	102-183	18.8	74.2	15.7	18.4	3.1	6.4	0.6
Bt5,b	183-198	21.3	83.7	14.9	14.4	3.0	9.1	0.0
Bt6,b	198-244	25.8	103.7	18.7	15.6	3.0	10.2	1.2
BC,b	259-287	31.0	132.0	19.7	16.8	2.5	10.3	1.0
C,b	287-356	37.2	142.0	22.7	18.0	3.0	13.9	0.2
Stigler (no manure)								
A	0-15	22.6	55.5	13.9	23.1	16.0	65.8	8.1
E	15-30	10.1	33.3	6.2	12.4	8.5	42.9	5.0
2Bt1	30-53	16.0	47.6	12.4	12.8	3.3	12.3	2.3
2Bt2	53-69	6.5	32.3	7.2	8.7	3.6	13.1	4.2
2Bt3	69-91	6.7	31.6	9.3	7.5	2.9	10.9	2.4
2Bt4	91-142	17.2	31.9	9.7	18.7	0.4	12.0	6.5
2Bt5	142-211	18.4	54.1	8.9	18.8	1.1	5.3	7.3
3Bt6	211-244	14.9	45.7	13.5	6.2	0.3	4.5	1.1
Stigler (swine manure)								
Ap	0-8	90.4	118.1	29.4	51.3	19.7	93.0	10.6
E	8-33	50.1	65.6	8.6	29.2	13.3	62.0	8.8
BE	33-46	26.0	37.7	5.6	12.4	10.0	37.0	3.2
2Bt1	46-66	1.5	17.0	6.7	2.4	7.6	38.0	4.0
2Bt2	66-86	2.0	14.4	6.2	2.1	5.8	27.6	1.2
2Bt3	86-150	10.9	38.9	6.7	4.4	0.8	12.4	2.6
2Bt4	150-178	7.8	29.4	10.2	2.7	0.7	5.3	1.4

[+] Bic., Hyd., and Son. represent bicarbonate, hydroxide, and sonicate extractable P.

Carbon and nitrogen

The effect of manure application on the C and N content of the 3 soils studied was less consistent than for P (Table 8 and Fig. 8). Organic C content of the surface soil horizon increased 3.6 fold with poultry manure application. For swine manure, the increase in organic C was only 1.5 and 1.1 fold for Captina and Sallisaw soils, while for Stigler a 2- fold decrease was observed (Table 8). The different response of the Captina soil to poultry and swine manure may result from a greater organic C content of poultry (435 g/kg dry manure) than swine manure (10 g/kg dry manure). The difference in response of the 3 soils to swine manure application may result from a decreased amount of manure applied to Captina, Sallisaw, and Stigler soils (Table 1).

Table 8. Organic C, total N, nitrate-N, ammonium-N, and autoclave distillable N content CO_2 production, and C:N ratio of the soils studied.

Horizon	Depth	Organic C	Total N	Nitrate N	Ammonium N	Autoclave N	CO_2 production	C:N ratio
	cm	g/kg	------------------------mg/kg------------------------					
Captina (no manure)								
A	0-18	15.4	1007	12.30	4.16	55.20	242	15.3
Bt1	18-46	4.0	471	8.23	2.97	15.20	528	8.5
2Bt2,b	46-69	6.2	810	10.60	10.20	18.30	0	7.7
2Bt3,b	69-89	3.1	576	20.40	18.40	19.30	0	5.4
3Btx4,b	89-104	2.3	442	18.40	16.60	12.30		5.2
3Btx5,b	104-124	0.4	184	10.30	8.82	4.54		2.2
3Bt6,b	124-152	0.5	328	9.07	2.16	4.90		1.5
3Bt7,b	152-191	1.0	281	6.15	1.74	2.93		3.6
3Bt8,b	191-224	0.7	290	3.86	0.00	0.00		2.4
Captina (poultry manure)								
Ap1	0-10	55.0	4083	102.60	11.10	170.30	13	13.5
Ap2	10-23	11.8	796	13.80	0.00	32.80	88	14.8
Bt1	23-51	4.9	542	27.60	1.70	15.20	110	9.0
2Bt2,b	51-74	9.4	1112	30.40	5.51	21.80	44	8.5
3Btx3,b	74-104	2.3	451	13.50	8.31	8.13		5.1
3Btx4,b	104-130	1.4	272	10.40	4.41	2.05		5.1
3Bt5,b	130-168	1.1	234	14.80	3.31	2.93		4.7
3BC1,b	168-188	1.0	257	25.40	6.15	4.32		3.9
3BC2,b	188-221	0.7	234	13.40	4.37	0.00		3.0
Captina (swine manure)								
Ap	0-13	22.6	1574	9.33	1.48	83.40	968	14.4
E	13-25	8.5	664	4.16	0.00	32.80	242	12.8
BE	25-61	3.5	416	0.00	0.00	11.20	110	8.4
Bt1	61-117	1.7	322	0.00	0.00	3.15	110	5.3
Bt2	117-168	1.4	296	3.86	0.00	0.00		4.7
Bt3	168-183	1.6	260	2.97	0.00	0.00		6.2
Bt4	183-218	1.0	161	2.37	0.00	0.00		6.2
Sallisaw (no manure)								
A	0-3	16.9	1196	8.69	2.71	62.40	682	14.1
Ad	3-18	7.1	626	4.71	1.91	33.50	132	11.3
BA	18-36	4.4	471	1.36	0.00	18.30	22	9.3
Bt1	36-53	2.6	404	2.04	0.00	8.78	44	6.4
Bt2	53-79	2.3	395	4.45	0.00	5.64	0	5.8
Bt3	79-119	1.9	342	0.00	0.00	4.17		5.6
Bt4	119-152	1.6	345	2.71	2.59	0.00		4.6
Sallisaw (swine manure)								
Ap	0-15	18.2	1460	93.90	15.60	72.50	682	12.5
Ad	15-25	10.2	927	11.50	2.46	37.00	198	11.0
Bt1	25-51	4.4	515	3.60	0.00	12.60	110	8.5
Bt2	51-79	2.6	448	5.00	0.00	7.91	0	5.8
Bt3	79-102	1.7	345	5.05	0.00	6.59		4.9

Table 8. Organic C, total N, nitrate-N, ammonium-N, and autoclave distillable N content CO_2 production, and C:N ratio of the soils studied. (Con't)

Horizon	Depth	Organic C	Total N	Nitrate N	Ammonium N	Autoclave N	CO_2 production	C:N ratio
	cm	g/kg	----------	----------	mg/kg	----------	----------	
Bt4,b	102-183	1.7	313	3.31	0.00	0.00		5.4
Bt5,b	183-198	0.8	255	2.59	0.00	0.00		3.1
Bt6,b	198-244	0.9	272	3.60	0.00	0.00		3.3
BC,b	259-287	0.9	304	11.30	1.70	0.00		3.0
C,b	287-356	1.4	407	9.14	6.53	6.59		3.4
Stigler (no manure)								
A	0-15	43.9	2297	34.50	5.09	130.30	1098	19.1
E	15-30	6.2	562	5.09	2.37	22.80	22	11.0
2Bt1	30-53	3.4	462	5.17	1.40	16.70	44	7.4
2Bt2	53-69	2.0	416	3.39	0.00	7.17	0	4.8
2Bt3	69-91	2.5	492	0.00	0.00	10.00		5.1
2Bt4	91-142	1.0	389	0.00	0.00	6.08		2.6
2Bt5	142-211	0.7	322	0.00	0.00	0.00		2.2
3Bt6	211-244	0.8	269	0.00	0.00	0.00		3.0
Stigler (swine manure)								
Ap	0-8	22.7	1241	3.18	1.78	53.40	548	18.3
E	8-33	16.7	1080	5.17	3.31	43.30	242	15.5
BE	33-46	5.6	597	2.54	1.78	16.80	22	9.4
2Bt1	46-66	9.5	1207	6.44	2.88	15.70	44	7.9
2Bt2	66-86	8.6	1009	6.28	3.22	17.00		8.5
2Bt3	86-150	1.8	334	8.52	1.65	3.37		5.4
2Bt4	150-178	4.5	360	10.60	1.78	4.39		12.5

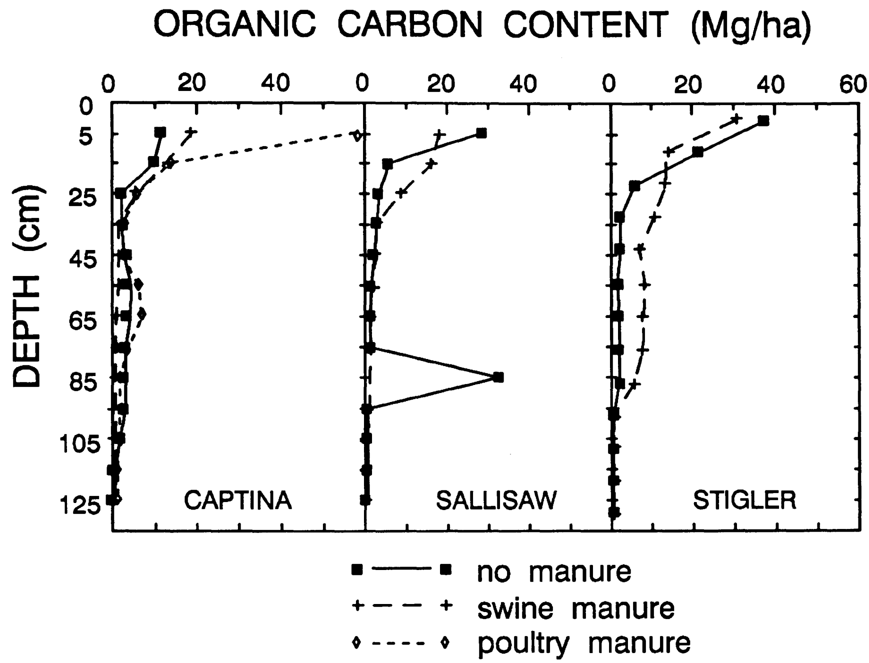

Figure 8. Organic carbon content of untreated and treated soils.

The accumulation of TN, NO_3-N, NH_4-N and autoclave- distillable N was similar to that of organic C, with the greatest accumulation occurring in the Captina soil treated with chicken manure (Table 8 and Fig. 9 and 10). No consistent effect of swine manure application on N content of each soil was apparent. Although the TN, NO_3-N, and NH_4-N content of Stigler soil treated with swine manure was lower than for the untreated soil, contents in the Sallisaw soil increased slightly. An accumulation of TN (Fig. 9), NO_3-N (Fig. 10), and autoclave-distillable N, (representing mineralizable N), was evident below 150 cm in Sallisaw and Stigler soils treated with swine manure.

Potential microbial activity, as represented by CO_2 production, was measured in the surface 4 horizons only, and was found to be decreased by poultry manure application (Table 8). Swine manure application had no consistent effect on microbial activity. C:N ratios of the manure treated

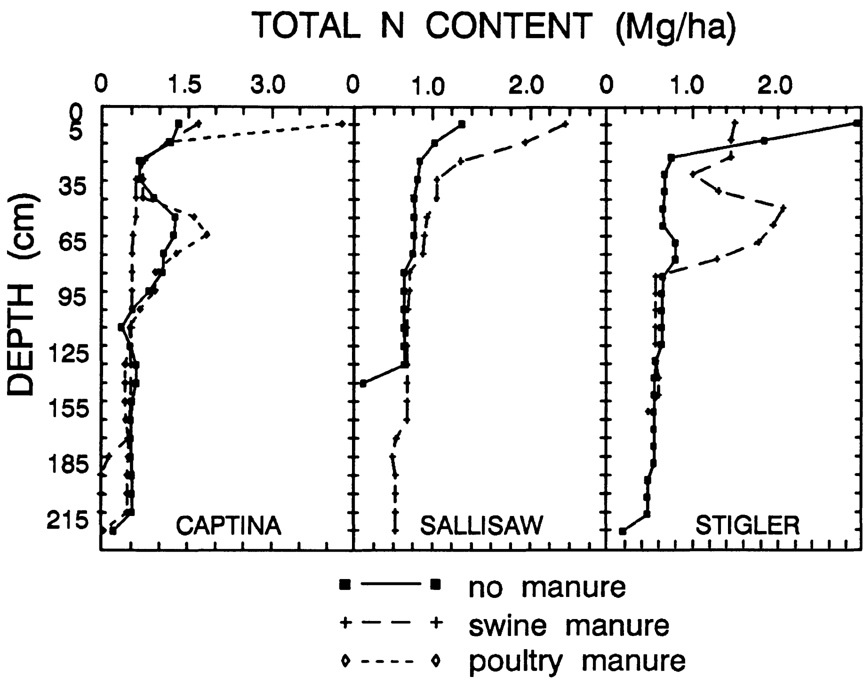

Figure 9. Total N content of untreated and treated soils.

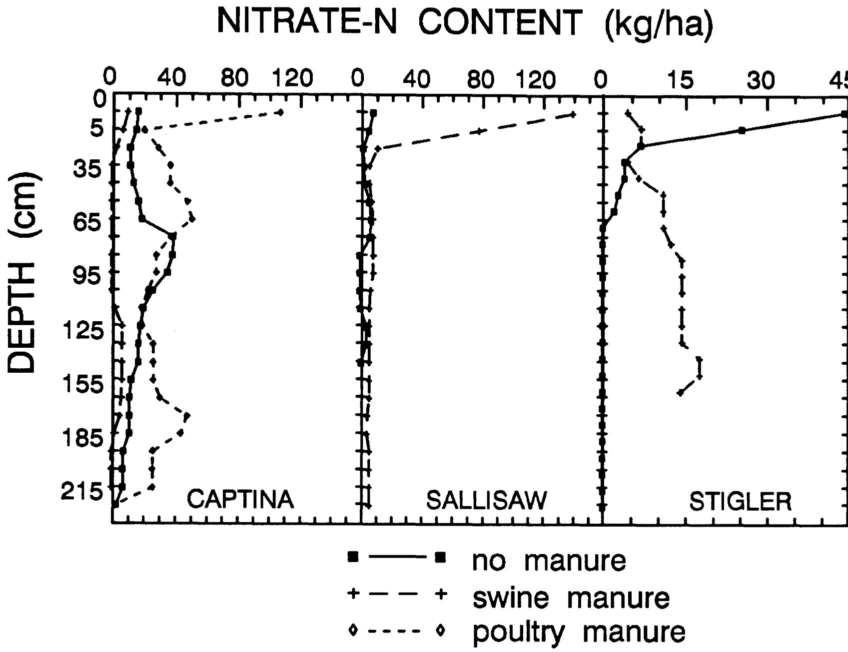

Figure 10. Nitrate-N content of untreated and treated soils.

soils were similar to untreated soils, even though the average C:N ratio of poultry manure (9.0) was approximately twice that of swine manure (4.8) (Table 3).

Soil pH, arsenic, and cations

Soil pH of the surface 50 cm of the Captina soil treated with poultry manure application was greater than that of the untreated soil (Table 9 and Fig. 11). A similar trend was observed for Captina and Sallisaw soils receiving swine manure, although the pH increase was not as great as for poultry manure. In contrast, the Stigler soil treated with swine manure had a lower pH than the untreated soil (Table 9).

Total arsenic contents of the two surface horizons (approximately 0 to 50 cm depth) of all untreated and treated soils were below 6 mg/kg and, thus, posed no threat to soil and water resources at these sites.

Table 9. pH and exchangeable cation content of the soils studied.

Horizon	Depth	pH		Exchangeable cations			
		Water	$CaCl_2$	Ca	Na	Mg	K
	cm	mg/kg					
Captina (no manure)							
A	0-18	5.04	4.00	1477	121	442	910
Bt1	18-46	5.11	4.11	2046	113	1004	654
2Bt2,b	46-69	4.98	3.95	3915	140	2154	640
2Bt3,b	69-89	5.07	3.84	1552	229	1521	369
3Btx4,b	89-104	5.14	3.91	1036	180	933	298
3Btx5,b	104-124	5.48	4.04	983	198	677	203
3Bt6,b	124-152	5.58	4.06	3646	521	1216	269
3Bt7,b	152-191	5.86	4.12	8598	929	2340	328
3Bt8,b	191-224	6.02	4.20	10134	966	2344	335
Captina (poultry manure)							
Ap1	0-10	6.26	5.75	12663	169	1829	4709
Ap2	10-23	6.35	5.36	5166	109	645	1612
Bt1	23-51	5.34	4.51	2744	132	543	1050
2Bt2,b	51-74	4.75	4.00	4119	380	989	1911
3Btx3,b	74-104	5.81	4.01	2787	1017	989	322
3Btx4,b	104-130	5.87	4.20	7599	2181	2119	362
3Bt5,b	130-168	5.78	4.12	9425	2339	2439	347
3Bc1,b	168-188	5.82	4.09	9930	2417	2492	395
3Bc2,b	188-221	6.08	4.09	8888	1678	2193	341
Captina (swine manure)							
Ap	0-13	5.86	5.15	5199	88	685	218
E	13-25	6.33	5.34	3480	148	350	148
BE	25-61	5.83	4.50	3288	206	729	205
Bt1	61-117	5.54	3.95	678	397	736	335
Bt2	117-168	5.94	4.05	2108	852	2050	321
Bt3	168-183	6.03	4.17	2272	1117	2063	292
Bt4	183-218	6.19	4.33	2035	764	1710	204
Sallisaw (no manure)							
A	0-3	5.36	4.47	2524	75	407	231
Ad	3-18	5.82	4.79	3087	82	199	197
BA	18-36	6.15	5.18	4432	89	175	226
Bt1	36-53	6.38	5.36	6291	88	330	366
Bt2	53-79	6.41	5.40	6528	116	378	591
Bt3	79-119	6.48	5.46	6637	118	458	600
Bt4	119-152	6.29	5.22	6538	87	486	546
Sallisaw (swine manure)							
Ap	0-15	5.40	4.83	3226	188	805	1608
Ad	15-25	5.61	4.62	2900	122	417	333
Bt1	25-51	6.31	5.14	5263	318	575	323
Bt2	51-79	6.32	5.43	6904	223	1240	363
Bt3	79-102	6.45	5.61	5105	172	1261	650
Bt4,b	102-183	5.97	4.88	5075	137	2119	945

Table 9. pH and exchangeable cation content of the soils studied. (Con't)

Horizon	Depth	pH		Exchangeable cations			
		Water	$CaCl_2$	Ca	Na	Mg	K
	cm	mg/kg					
Bt5,b	183-198	5.34	4.11	2029	119	1432	726
Bt6,b	198-244	5.28	4.05	2020	120	1392	743
Bc,b	259-287	5.23	4.10	2563	128	1762	681
C,D	287-356	5.22	4.20	3819	159	1787	687
Stigler (no manure)							
A	0-15	6.02	5.34	9052	154	1171	989
E	15-30	5.45	4.22	2235	135	690	431
2Bt1	30-53	5.46	4.30	2783	78	844	370
2Bt2	53-69	5.17	3.96	1708	95	870	213
2Bt3	69-91	5.15	3.89	2256	116	1360	316
2Bt4	91-142	5.41	3.99	1635	183	1253	234
2Bt5	142-211	5.65	4.07	2183	369	1613	223
3Bt6	211-244	5.75	4.19	2646	500	1692	208
Stigler (swine manure)							
Ap	0-8	5.82	4.76	5259	153	438	314
E	8-33	5.94	4.78	5322	268	217	213
BE	33-46	5.64	4.06	2246	420	92	167
2Bt1	46-66	6.12	3.96	5070	2847	653	442
2Bt2	66-86	6.26	4.05	5870	3596	826	430
2Bt3	86-150	6.19	4.13	3879	2122	782	194
2Bt4	150-178	6.20	4.09	6165	2551	1389	320

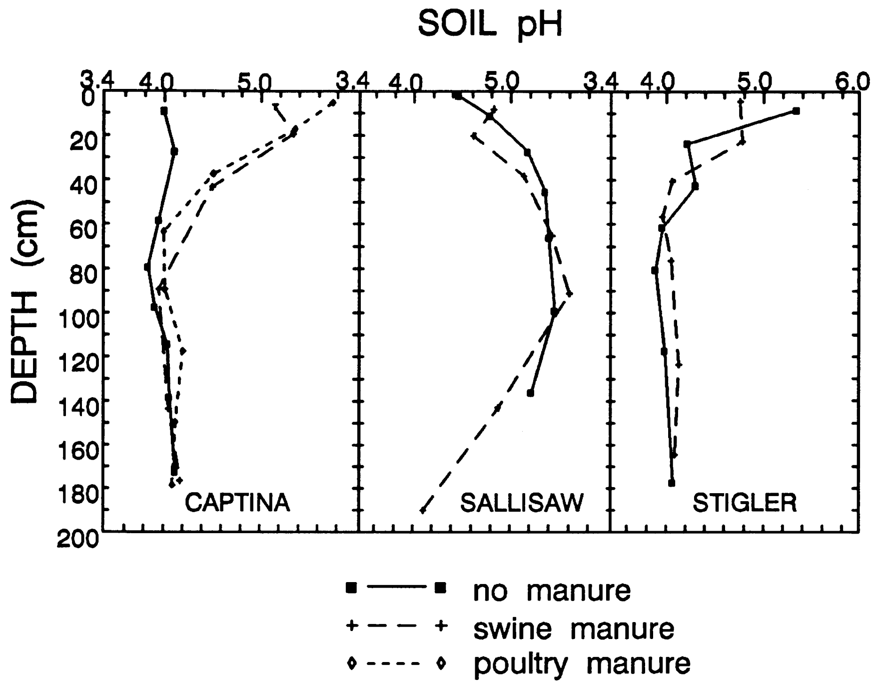

Figure 11. pH (in 0.01 *M* $CaCl_2$) of untreated and treated soils.

Exchangeable cation content of surface soil (approximately 0-25 cm) following manure application, was greater than untreated soil for all treatments, except for Stigler (Table 9 and Fig. 12). In the case of Stigler, however, cation movement through the soil was evident from increased exchangeable Ca, Na, and K levels below 30 cm depth, in treated compared to untreated soil. The magnitude of this increase was in particular, greatest for Na (Table 9).

Discussion

Soil Resources

Animal waste application had no significant effect on soil physical properties and no consistent effect on soil pH. More dramatic changes in nutrient content, however, were observed.

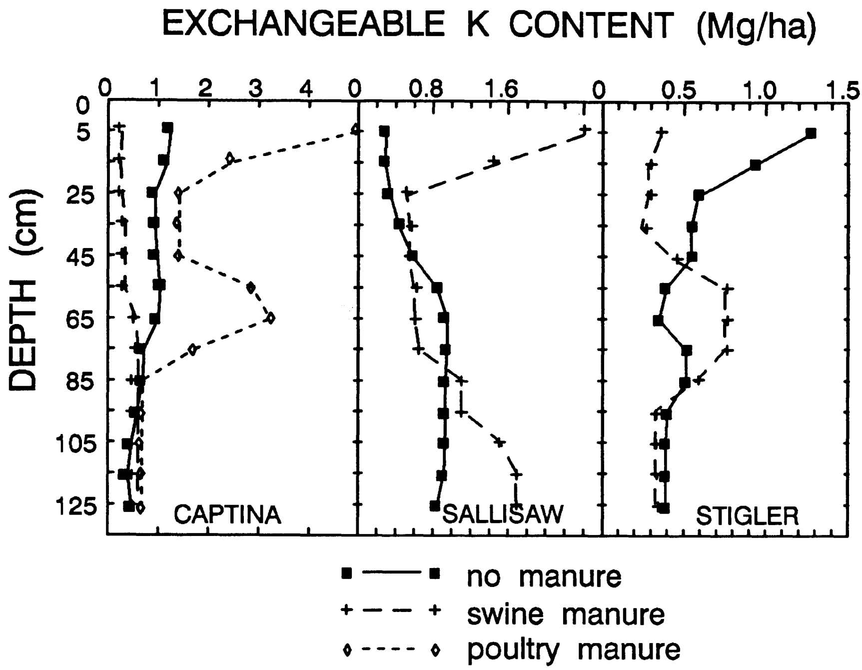

Figure 12. Exchangeable K content of untreated and treated soils.

Amounts of P, N, and K added in poultry and swine manure during the study period and amounts in the surface 0-50 cm of untreated and treated soils were calculated and are presented in Table 10. Although P accumulated in the surface 0-50 cm of each treated soil, N accumulation only occurred in the Captina soil treated with poultry manure and Sallisaw soil plus swine manure (Table 10). As for N, exchangeable K accumulated in the Captina soil treated with poultry manure and Sallisaw soil treated with swine manure. The lack of a constant accumulation of N or K in the surface soil compared to P, may in part result from the potentially greater soil mobility and removal in harvested forage of N and K than more rapidly sorbed P.

Although the increase in TP content of the surface 50 cm of manure treated soil was not related (at the 5% level of significance) to the total amount of P applied (r^2 =0.69), AP accumulated during the study period was closely related to the total amount of P applied (Fig. 13). This

Table 10. Amount of P, N, and K applied in poultry and swine manure during the study period and in the surface 50 cm of untreated and treated soil.

Soil	Treatment	Amount applied			Soil content+					
		P	N	K	TP	IP	AP	TN	NO_3-N	K
		kg/ha			kg/ha/50 cm					
Captina	No manure	0	0	0	1593	532	27	4873	70	5257
	Poultry manure	1305	6840	1360	2167	1510	395	7678	233	11638
					(574)	(978)	(368)	(3003)	(163)	(6381)
	Swine manure	808	2464	1128	1753	886	213	4856	20	1304
					(160)	(354)	(186)	(-17)	(-50)	(-3953)
Sallisaw	No manure	0	0	0	1508	473	49	3959	22	1911
	Swine manure	1215	3615	1665	2094	1029	407	6780	242	5436
					(586)	(556)	(358)	(2821)	(220)	(3525)
Stigler	No manure	0	0	0	1685	609	64	6915	85	3868
	Swine manure	296	880	408	1907	981	170	6745	29	1623
					(222)	(372)	(106)	(-170)	(-56)	(-2245)

+Number in parenthesis is the difference in content of untreated and treated soil. TP, IP, AP, and TN represent total P, inorganic P, available P, and total N, respectively.

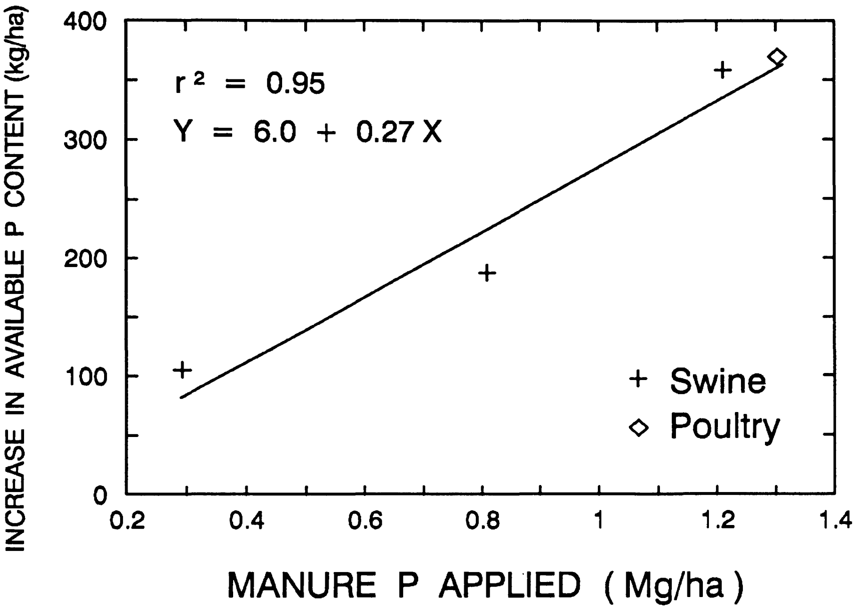

Figure 13. Relationship between the increase in available P content of the surface 50 cm soil and amount of P added in poultry and swine manure.

relationship included both poultry and swine manure applications. From the slope of this linear relationship (0.27, Fig. 13), it can be calculated that for every 100 kg P/ha added in manure to the 4 soils studied, AP content of the surface soil increased 27 kg P/ha. The intercept of the relationship between P added and AP increase (6.0 kg P/ ha, Fig. 13), equivalent to the AP content with no manure applied, is similar to the AP content of surface soil (10 kg P/ha). The fact that a significant relationship between the amount of P added and accumulation of P in the surface 0-50 cm of soil was obtained for AP but not TP, may be attributed to a differing P sorption index of the treated soils and consequent differential accumulation of P in available and unavailable forms in the soil (Table 7).

The proportion of P added during the study period retained as TP (20-75%) and AP (23-36%) varied from soil to soil (Table 10). This variation in percent retention of applied P as TP or AP, was a function of PSI of the treated soil (Fig. 14). This relationship held for both poultry and swine

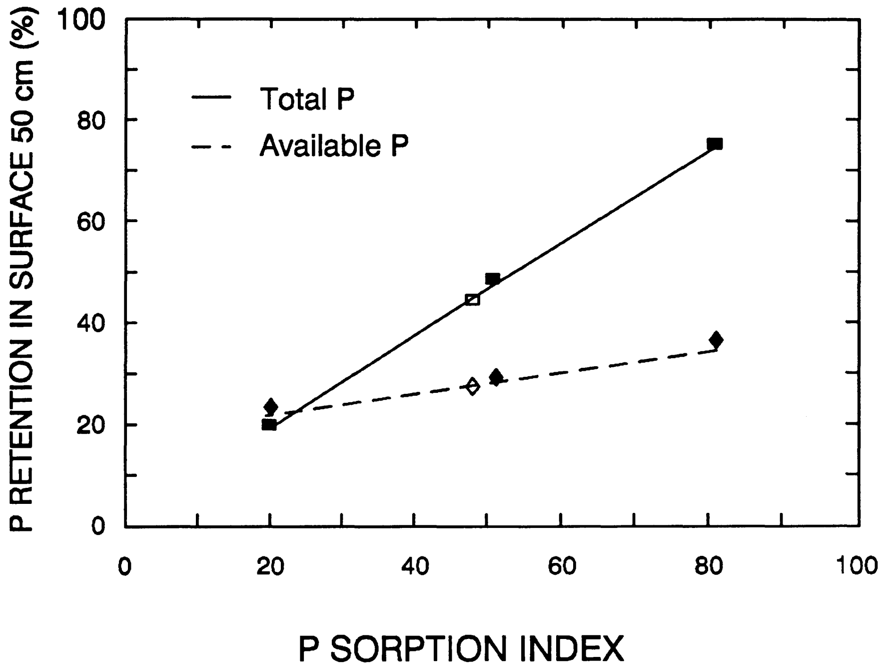

Figure 14. Relationship between the proportion of manure P retained as total and available P in the surface 50 cm soil and P sorption index. Closed and open symmbols represent swine and poultry manure, respectively.

manure applications. The effect of PSI on P retention as AP was not as great as that for TP, as represented by the lower relationship slope of the former P form (Fig. 14). This difference may be attributed to an increasing accumulation of P in more strongly bound and less plant available forms with increasing soil PSI. It is, thus, apparent that the differential accumulation of P in either AP or TP forms, as a function of soil type, may be accounted for by soil PSI.

Water Resources

Soluble Nutrients

Although P retention in the root zone of the treated soil minimizes the possibility of P reaching ground water, the potential enrichment of the soluble P concentration in surface runoff from these soils must be considered. The soluble P concentration in surface runoff from the untreated and treated soils was predicted by a model developed by Sharpley and Smith (1989), describing the kinetics of soil P desorption:

$$P_r = \frac{k \bullet AP \bullet D \bullet B \bullet t^{\alpha} \; W^{\beta}}{V} \qquad [1]$$

where P_r is the available soluble P concentration in runoff from an individual event (mg/L), AP the available P content (as Bray P, mg/kg) of surface soil (0-5 cm) before each runoff event, D the effective depth of interaction between surface soil and runoff in soluble P transport (mm), B the bulk density of soil (mg/m^3), t the runoff event duration (min), W the runoff water to soil (suspended sediment) ratio, V the total runoff during the event (mm) and k, α, and β constants for a given soil.

In the present simulations, AP and B were obtained from field measurements (Table 5 and 6, respectively) and t was set at 30 min, an approximate value for a representative event. Values of Eq.[1] constants (k, α, and β) were calculated from the ratio of percent clay/organic C content of surface soil using the following equation derived by Sharpley (1983) from an analysis of 60 U.S. soils:

$$k = 0.630 \text{ (percent clay/organic C)}^{-0.698} \qquad [2]$$

$$\alpha = 0.815 \text{ (percent clay/ organic C)}^{0.540} \qquad [3]$$

$$\beta = 0.141 \text{ (percent clay/ organic C)}^{0.429} \qquad [4]$$

Soil loss (kg/ha) for each soil was estimated from a runoff - sediment discharge rating curve, calculated for measured data from grassed and conventionally tilled wheat watersheds at El Reno, Oklahoma (Sharpley et al., 1988). Finally, the value of D was calculated from soil loss for each runoff event using the following equation obtained by regression analysis (Sharpley, 1985a):

$$\ln(D) = i(A) + 0.576 \ln(\text{soil loss}) \qquad [5]$$

where i is a function of soil aggregation (A) and has a value of -1.28 for the 4 soils studied.

The concentration of soluble P in runoff was predicted for hypothetical events representing total volumes of 0.2 to 7.0 cm to illustrate the potential impact of animal waste disposal (Fig. 15). Soluble P concentration decreased with an increase in runoff volume, due to an increasing dilution of P released from surface soil to runoff. For Captina, Sallisaw, and Stigler soils receiving swine manure, soluble P concentration decreased from 1.85 to 0.35 mg/L, 3.10 to 0.59 mg/L, and 1.73 to 0.33 mg/L and for the Captina soil treated with poultry manure from 4.51 to 0.85 mg/L. The concentrations were a respective 14-, 26-, 6-, and 33-fold greater than from untreated soils. It is clear that manure applications have the potential to dramatically increase soluble P concentrations of surface runoff, if runoff from the treated soils occurs. Runoff from these soils may, thus, have the potential to stimulate an increase in biological growth in streams and receiving impoundments.

The release of soluble soil nitrogen and transport in runoff was not predicted, as the primary constituent, NO_3-N, is generally not sorbed by surface soil material and moves downward with infiltrating soil water. Movement of NO_3-N to ground water below the treated soils appeared minimal at the time of sampling with little accumulation of N in the subsoil. A potential movement of NO_3-N to ground water remains, however, shortly after animal manure application.

Particulate Nutrients

While soluble phosphorus and nitrogen are for the most part, immediately available for biological uptake (Peters, 1981; Walton and Lee, 1972), particulate P and N are less readily available and can provide a long-term source of these elements to aquatic biota (Bjork, 1972; Carignan and Kalff, 1980; Wildung et al., 1974). The loss of particulate nutrients in runoff from the untreated and treated soils were, thus, predicted. Particulate P, bioavailability of P and total N concentrations of runoff were calculated from the total P, bioavailable P and total N content of surface

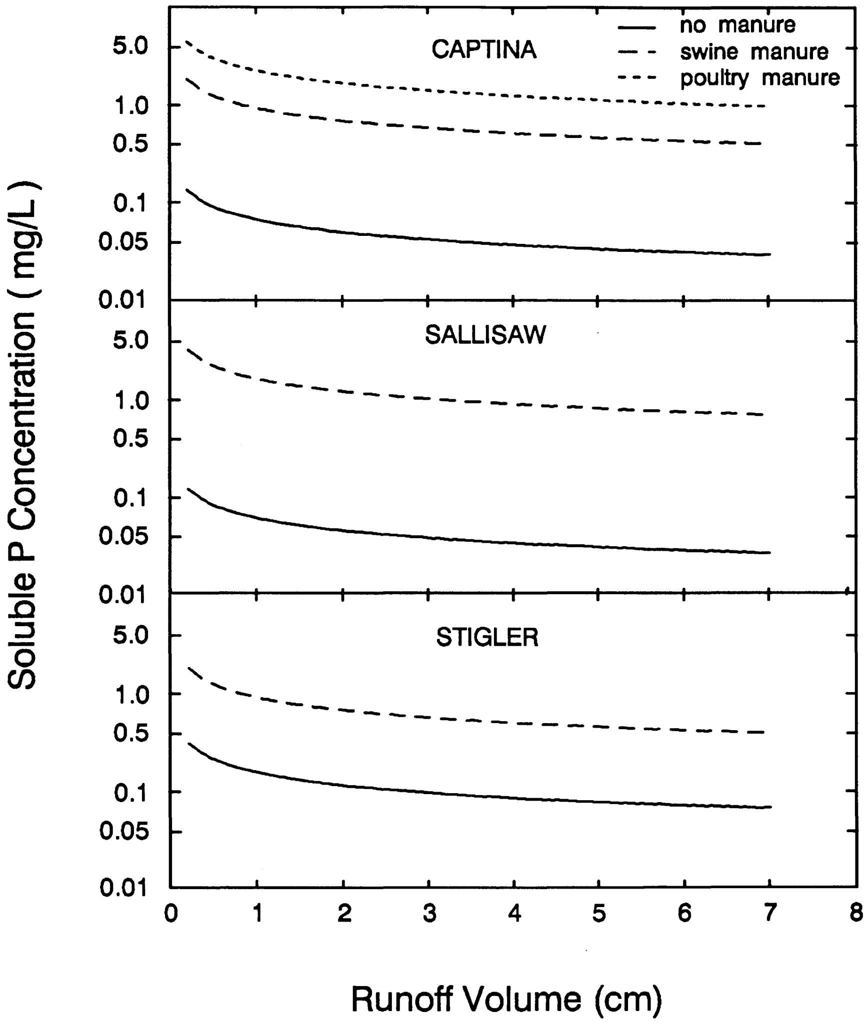

Figure 15. Relationship between predicted soluble P concentration in runoff and runoff volume for untreated and treated soils.

soil, respectively, using the enrichment ratio for each nutrient form (PER, BIOER, and NER, respectively):

$$\text{Particulate P} = (\text{Soil total P}) \bullet (\text{Sediment concentration}) \bullet (\text{PER}) \quad [6]$$

$$\text{Bioavailable P} = (\text{Soil bio P}) \bullet (\text{Sediment concentration}) \bullet (\text{BIOER}) \quad [7]$$

$$\text{Total N} = (\text{Soil total N}) \bullet (\text{Sediment concentration}) \bullet (\text{NER}) \quad [8]$$

where the units of soil total P, bioavailable P, and total N are mg/kg and g/L for sediment concentration of runoff. The enrichment ratios were predicted from soil loss (kg/ha) using the following equation developed by Sharpley (1985b):

$$\ln(\text{ER}) = 1.21 - 0.16 \ln(\text{soil loss}) \quad [9]$$

Bioavailable P contents of surface soil from Captina with no manure, poultry manure, swine manure, Sallisaw with no manure, swine manure, Stigler with no manure and swine manure were 57, 650, 286, 35, 205, 71, and 210 mg/kg, respectively.

Particulate nutrient concentrations in runoff were predicted for ten events of equal volume and soil loss and summed to give the total losses presented in Table 11. It is apparent that a large increase in the amount of particulate nutrients transported in runoff occurred even for the T value (approximately 2 ton/acre) of the cropped soils (Table 11). In addition to increased amounts, a greater proportion of particulate P transported was bioavailable (potentially available for uptake by algae) from treated compared to untreated soils (Table 11). Consequently runoff and erosion from soils treated with animal manure can contribute large amounts of nutrients to receiving water bodies and lead to sustained eutrophication problems.

Although these are hypothetical runoff situations, they clearly emphasize the need to carefully manage repeated applications of manure over a long period of time to agricultural land and to minimize the potential for runoff and erosion to occur from these soils.

Table 11. Predicted total N and P and bioavailable particulate P loss in runoff from untreated and treated soils.

Soil	Treatment	Soil loss		Total N	Total P	Bioavailable P	Percent Bio. P
		kg/ha/yr	ton/acre/yr	---------kg/ha--------			%
Captina	No manure	4480	2	5.68	1.54	0.32	21
		8960	4	10.18	2.76	0.58	
		17920	8	18.26	4.95	1.03	
	Poultry manure	4480	2	23.10	6.24	3.68	59
		8960	4	41.35	11.17	6.58	
		17920	8	74.00	19.99	11.78	
	Swine manure	4480	2	8.90	3.20	1.62	51
		8960	4	15.93	5.73	2.90	
		17920	8	28.53	10.26	5.18	
Sallisaw	No manure	4480	2	6.77	1.28	0.20	15
		8960	4	12.12	2.29	0.35	
		17920	8	21.70	4.10	0.63	
	Swine manure	4480	2	8.27	2.47	1.16	47
		8960	4	14.80	4.42	2.08	
		17920	8	26.45	7.90	3.72	
Stigler	No manure	4480	2	12.99	1.99	0.40	20
		8960	4	23.23	3.56	0.72	
		17920	8	41.63	6.38	1.29	
	Swine manure	4480	2	7.02	2.75	1.19	43
		8960	4	12.56	4.92	2.13	
		17920	8	22.50	8.81	3.81	

Conclusions

Poultry and swine manure application to three eastern Oklahoma soils, resulted in an average 2- and 9-fold increase in TP and AP content, respectively, of the surface 50 cm of soil. Overall, this represented a 27 kg P/ ha increase in AP for each 100 kg P/ha added in manure. In contrast to P, however, no consistent increase in N or K content of surface soil was observed, although a slight accumulation of N and K was apparent in the subsoil (below 150 cm depth). Further, due to the different chemical composition of poultry and swine manure, the disposition of applied P and N may differ between manure types. As only one poultry manure site was sampled, further information is needed to evaluate these differences.

At the time of sampling, the potential contribution of residual P and N to ground water for the 4 untreated soils, appeared minimal. In contrast, the potential removal in surface runoff of P and N accumulated in the surface soil must be a priority management consideration. Management options for liquid swine manure disposal may include subsurface incorporation or injection to reduce soil P concentrations in the zone of removal in surface runoff. Less options are available for solid poultry manure applications, however, which is generally broadcast or occasionally incorporated during tillage operations.

The agronomic and environmental fate of manure P applied to different soil types, can be evaluated if texture, AP content, and P sorption capacity of the soil and amount of P added is known. Use of this information will allow determination of the relative impact of poultry and swine manure applications on soil and water resources in Oklahoma.

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References

Bache, B.W., and E.G. Williams. 1971. A phosphate sorption index for soils. J. Soil Sci. 22:289-301.

Bjork, S. 1972. Swedish lake restoration program gets results. Ambio 1:153-165.

Blake, G.R., and K. H. Hartge. 1986. Bulk density. *In* A. Klute (ed.), Methods of soil analysis, Part I. 2nd ed. Agronomy 9:363-375.

Bray, R.H., and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59:39-49.

Bremner, J.M. 1965. Total nitrogen. *In* C.A. Black (ed.), Methods of soil analysis, Part 2. Agronomy 9:1149-1178.

Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen - total. *In* A.L.Page et al. (ed.), Methods of soil analysis, Part 2. 2nd ed. Agronomy 9:595-624.

Brown, M.P., P. Longabucco, M.R. Rafferty, P.D. Robillard, M.F. Walter, and D.A. Haith. 1989. Effects of animal waste control practices on nonpoint-source phosphorus loading in the West Branch of the Delaware River watershed. J. Soil Water Conserv. 44:67-70.

Carignan, R., and J. Kalff. 1980. Phosphorus sources for aquatic weeds: Water or sediments? Science 207:987-989.

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. 2:497-500.

Cooper, J.R., R.B. Renau, Jr., W. Kroontje, and G.D. Jones. 1984. Distribution of nitrogenous compounds in Rhodic Paleudult following heavy manure application. J. Environ. Quality. 13:189-193.

Dalal, R.C. 1977. Soil organic phosphorus. Adv. Agr. 29:83-117.

Dorich, R.A., D.W. Nelson, and L.E. Sommers. 1985. Estimating algal available phosphorus in suspended sediments by chemical extraction. J. Environ. Qual. 14:400-405.

Field, J.A., R.B. Renau, and W. Kroontje. 1985. Effects of anaerobically digested poultry manure on soil phosphorus adsorption and extractability. J. Environ. Qual. 14:105-107.

Fuller, W.H., D.R. Nielson, and R.W. Miller. 1956. Some factors influencing the utilization of phosphorus from crop residues. Soil Sci. Soc. Am. Proc. 20:218-224.

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. *In* A. Klute (ed.), Methods of soil analysis, Part 1. 2nd ed. Agronomy 9:383-409.

Gilbertson, C.B., F.A. Norstadt, A.C. Mathers, R.F. Holt, A.P. Barnett, T.M. McCalla, C.A. Onstad, and R.A. Young. 1979. Animal waste utilization on cropland and pastureland. USDA Utilization Research Report No. 6. 135p.

Hedley, M.J., R.E. White, and P.H. Nye. 1982. Plant-induced changes in the rhizosphere of rape (Brassica napus var Emerald) seedlings. II. Origin of the pH changes. New Phytol. 91:31-44.

Hileman, L.H. 1967. The fertilizer value of broiler litter. University Arkansas, Fayetteville. Agric. Exp. Sta. Rep. Ser. 158. p 12.

Huhnke, R.L. 1982. Land application of livestock manure. Cooperative Extension Service, Oklahoma State Univ., Extension Facts 1710.

Liebhardt, W.C., C. Golt, and J. Tupin. 1979. Nitrate and ammonium concentrations of ground water resulting from poultry manure applications. J. Environ. Qual. 8:211-215.

McLeod, R.V., and R.O. Hegg. 1984. Pasture runoff water quality from application of inorganic and organic nitrogen sources. J. Environ. Qual. 13:122-126.

Murphy, J., and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 27:31-36.

NASS, National Agricultural Statistics Service. 1989. Poultry production and value. Bulletin POU 3-1 (April). USDA, Washington, D.C.

Olson, C.G. 1989. Soil geomorphic research and the importance of paleosol stratigraphy to Quaternary investigations, Midwestern USA. Catena 16:129-142.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. *In* A.L. Page et al. (ed.), Methods of soil analysis, Part 2, 2nd Ed. Agronomy 9:403-430.

Perkins, H.F., M.B. Parker, and M.L. Walker. 1964. Chicken manure-its production, composition, and use as a fertilizer. Report NS 123, Georgia Agricultural Experiment Station, University of Georgia, Athens, GA. p 50.

Peters, R.H. 1981. Phosphorus availability in Lake Memphremagog and its tributaries. Limnol. Oceanogr. 26:1150-1161.

Pratt, P.F. 1965. Potassium. *In* C.A. Black et al. (eds.), Methods of soil analysis, Part 2. Agronomy. 9:1022-1030.

Raveh, A., and Y. Avnimelech. 1972. Potentiometric determination of soil organic matter. Soil Sci. Soc. Am. Proc. 36:967.

Reddy, K.R., M.R. Overcash, R. Kahled, and P.W. Westerman. 1980. Phosphorus absorption-desorption characteristics of two soils utilized for disposal of animal manures. J. Environ. Qual. 9:86-92.

Russel, D.A., and G. Stanford. 1954. Laboratory manual for soil fertility students. W.C. Brown, Dubuque, Iowa.

Sharpley, A.N. 1983. Effect of soil properties on the kinetics of phosphorus desorption. Soil Sci. Soc. Am. J. 47:462-467.

Sharpley, A.N. 1985a. Depth of surface soil-runoff interaction as affected by rainfall, soil slope and management. Soil Sci. Soc. Am. J. 49:1010-1015.

Sharpley, A.N. 1985b. The selective erosion of plant nutrients in runoff. Soil Sci. Soc. Am. J. 49:1527-1534.

Sharpley, A.N., and S.J. Smith. 1989. Prediction of soluble phosphorus transport in agricultural runoff. J. Environ. Qual. 18:313-316.

Sharpley, A.N., S.J. Smith, and J.R. Williams. 1988. Nonpoint source pollution impacts of agricultural land use. Lake and Reservoir Management 4:41-49.

Singh, B.B., and J.P. Jones. 1976. Phosphorus sorption and desorption characteristics of soil as affected by organic residues. Soil Sci. Soc. Am. J. 40:389-394.

Smith, S.J., and G. Stanford. 1971. Evaluation of a chemical index of soil nitrogen availability. Soil Sci. 111:228-232.

Soil Conservation Service. 1984. Procedures for collecting soil samples and methods of analysis for soil survey. USDA, Soil Survey Investigations Rep. No. 1. U.S. Govt. Printing Office, Washington, DC.

Soil Conservation Service. 1985. Livestock waste facilities handbook. 2nd edition.

Soil Survey Staff. 1981. Soil survey manual (update), draft of chapter 4, Examination and description of soils in the field. For Soil Survey Manual. USDA, SSC. Washington, D.C.

Tiessen, H., J.W.B. Stewart, and C.V. Cole. 1984. Pathways of phosphorus transformations in soils of differing pedogenesis. Soil Sci. Soc. Am. J. 48:853-858.

Walker, T.W., and A.F.R. Adams. 1958. Studies on soil organic matter. I. Influence of phosphorus content of parent material on accumulations of carbon, nitrogen, sulphur, and organic phosphorus in grassland soils. Soil Sci. 85:307-318.

Walton, C.P., and G.F. Lee. 1972. A biological evaluation of the molybdenum blue method for orthophosphate analysis. Tech. Int. Ver. Limnol. 18:676-684.

Westerman, P.W., T.L. Donnely, and M.R. Overcash. 1983. Erosion of soil and poultry manure - a laboratory study. Trans. Am. Soc. Agric. Eng. 26:1070-1078,1084.

Wildung, R.E., R.L. Schmidt, and A.R. Gahler. 1974. The phosphorus status of eutrophic lake sediments as related to changes in limnological conditions -- total, inorganic, and organic phosphorus. J. Environ. Qual. 3:133-138.