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Using Hairy Vetch to Manage Soil Phosphorus Accumulation from Poultry Litter Applications in a Warm-season Vegetable Rotation

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Abstract. **Hairy vetch (*Vicia villosa* Roth) cover crops were grown in a rotation with sweet corn (*Zea mays* var. *rugosa* Bonaf.) and muskmelon (*Cucumis melo* L. Reticulatus group) to evaluate the legume's ability to remove excess P from soils when poultry litter was used as a fertilizer. Fertilizer treatments were: 1) litter to meet each crop's recommended preplant N requirements (1×); 2) litter at twice the recommended rate (2×); and 3) urea at the 1× rate as the control. Following the vegetable crops, hairy vetch was planted on half of each replication, while the other half was fallowed. The vetch was removed from the field in a simulated haying operation in the spring. Soil samples were taken at 0–15 cm and 15–30 cm depths at the onset of the study and after each crop to monitor plant nutrient concentrations. The vetch sometimes raised soil test N concentrations at the 0–15 cm depth. Soil test P concentrations at the 0–15 cm sampling depth in the vetch system were consistently lower numerically, but not statistically, relative to comparable plots in the fallow system. Soil test P at the 0–15 cm depth was usually increased by litter at the 2× rate relative to the urea control, regardless of cropping system. Yields of both vegetable crops were similar among all cover crop and fertilizer treatments.**

Poultry litter contains most mineral elements essential for plant growth and adds organic matter to the soil, making it a potential alternative source of fertilizer for horticultural crops (Edwards and Daniel, 1992; Sims and Wolf, 1994). Research in greenhouses and in the field has shown mixed results on the effectiveness of poultry manure or litter as a fertilizer for fruits and vegetables. Corn has been successfully grown with poultry litter or manure (Brown et al., 1994; Harper et al., 1980; Shortall and Liebhardt, 1975; Wood et al., 1996). Muskmelons grown on plots where poultry manure was broadcast in winter to a small grain cover crop that was later plowed under produced greater yields than plants grown with an inorganic fertilizer (Rahn, 1949).

Field applications of poultry litter have traditionally been based on the N needs of the crops being produced. Poultry litter is low in N, so large quantities may be needed to supply enough N to meet crop demands. Application of a large amount of litter can cause a buildup of soil P (Edwards and Daniel, 1992; Kingery et al., 1994; Sharpley et al., 1993), because plants tend to take up less P than is provided in litter. The ratio of N : P uptake for crops grown in the Southern Plains region of the United States is 8:1, while the average N : P ratio in litter is 3:1 (Edwards and Daniel, 1992). Excessive P near the soil surface is subject to rainfall runoff (Edwards and Daniel, 1993; Nichols et al., 1994), and may be carried to surface bodies of water where it may accelerate eutrophication. Concentrations of P must be managed if poultry litter is to be used as a long-term fertilizer in agricultural production.

Eastern Oklahoma has a substantial poultry industry and considerable commercial vegetable production. Much of this vegetable production is on river bottom land that has been cropped for many years; the Vegetable Research Station in Bixby, Okla. is representative of such land. These sandy soils tend to be adequate to high in P, but low in N and would benefit from organic matter addition. Poultry litter could be a useful fertilizer in this situation if the P accumulation was controlled. Poultry litter cannot readily be applied at the recommended P fertilization rate on such soils because little or no added P is likely to be needed (Sharpley et al., 1993). Therefore, our research has taken the approach of using litter to meet preplant N needs while seeking alternatives to control the buildup of P in the soil.

Legumes tend to take up P at relatively high rates, and so may deplete soil P (Griffith, 1974). Daniel (1934) analyzed the plant nutrient content of 23 grasses and 10 legumes and found that legumes contain an average of 1.74 times as much P as grasses. Hairy vetch had the highest average P concentration (0.315%) of the 10 legume species tested by Daniel (1934). Bray-P values in the 0–15 cm soil sampling depth were lower under legume cover crops than grass covers (Wilson et al., 1982). Winter legumes lowered soil pH and extractable P in the 0–7.5 cm soil sampling depth and redistributed K to the soil surface (Hargrove, 1986). Cover crops absorb nutrients while actively growing, and if significant biomass accumulates, the cover crops could affect the distribution and forms of plant nutrients in soils (Lal et al., 1991).

Earhart (1995) proposed that vegetable crops be rotated with legume cover crops to control soil P accumulation from poultry litter applications. This study was initiated to determine the ability of hairy vetch cover crops to reduce soil P concentrations in a warm-season vegetable rotation where poultry litter was used for preplant fertilization of the vegetable crops.

Materials and Methods

A 3-year field experiment was conducted at the Vegetable Research Station in Bixby, Okla., on a Severn very fine sandy loam [coarse-silty, mixed (calcareous), thermic Typic Udifluvent]. A split-plot arrangement was used in a randomized complete-block design with four replications. The main plot treatment was cover crop: after each vegetable crop was harvested, hairy vetch was planted on half of each replication, with the other half left fallow. The sub-plot treatments consisted of poultry litter at a rate sufficient to meet each crop's recommended preplant N requirements (1×); litter at twice the recommended rate (2×); and urea (46% N) at the 1× rate as the control. Thus, each replication contained six plots, each measuring 5.4 m × 8.0 m. Each replication was separated by a 2-m alley, and there was a 3-m alley in the center of the field. The same field was used each year, and plot integrity was maintained for the duration of the study.

Partially composted litter was obtained from on-farm piles at three poultry farms in the northeastern Oklahoma area. Before application, the litter was analyzed for pH, electrical conductivity, percent water, and total N, P, K, and Ca by the Univ. of Arkansas' Agricultural Services Laboratory in Fayetteville (Table 1).

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Table 1. Elemental composition of three poultry litter lots applied in a 3-year experiment, Bixby, Okla.[z]

Application time	pH	EC[y] (dS·m^{-1})	H_2O (%)	N (%)	P (%)	K (%)	Ca (%)
9 Apr. 1996	7.3	13.4	29.3	2.93	1.27	2.35	2.61
20 May 1997	7.4	14.2	18.6	3.13	1.61	2.94	2.60
23 Apr. 1998	6.6	11.6	19.7	3.11	1.12	1.75	2.47

[z]Analyses performed by Univ. of Arkansas, Fayetteville. Values are reported on an "as-is" basis, since litter was applied "as is."
[y]EC = electrical conductivity.

Table 2. Amounts of poultry litter and N, P, and K applied with six cropping systems in a 3-year experiment, Bixby, Okla.[z]

	Vetch			Fallow		
Variable	Urea	Litter 1×	Litter 2×	Urea	Litter 1×	Litter 2×
			Sweet corn, 1996			
Litter (kg·ha^{-1})	0	1644	3288	0	1644	3288
N (kg·ha^{-1})	118	118	166	118	118	166
P (kg·ha^{-1})	0	21	42	0	21	42
K (kg·ha^{-1})	0	39	78	0	39	78
			Muskmelon, 1997			
Litter (kg·ha^{-1})	0	859	1718	0	1503	3006
N (kg·ha^{-1})	83	83	110	103	103	150
P (kg·ha^{-1})	0	14	28	0	24	48
K (kg·ha^{-1})	0	25	50	0	44	88
			Sweet corn, 1998			
Litter (kg·ha^{-1})	0	1118	2235	0	1334	2668
N (kg·ha^{-1})	105	105	140	111	111	152
P (kg·ha^{-1})	0	12	24	0	15	30
K (kg·ha^{-1})	0	20	40	0	23	46
			Total			
Litter (kg·ha^{-1})	0	3621	7241	0	4481	8962
N (kg·ha^{-1})	306	306	416	332	332	468
P (kg·ha^{-1})	0	47	94	0	60	120
K (kg·ha^{-1})	0	84	168	0	106	212

[z]Litter values reported on an "as is" basis. Nitrogen values include topdressings of urea made to vegetable crops as follows: the sweet corn received 70 kg·ha^{-1} of N on 21 May 1996 and on 1 June 1998, while the muskmelons received 56 kg·ha^{-1} of N on 19 June 1997. Plots fertilized with urea did not receive supplemental P or K. Plots fertilized with poultry litter received supplemental P and K only as provided by the litter.

Total amount of litter applied and the rates of N, P, and K applied with the experimental cropping systems were recorded (Table 2). Fertilizer materials were broadcast by hand and incorporated to a depth of 5–8 cm with a tractor-powered rototiller.

Before any crops were planted, soil samples were collected from each plot at two depths: 0–15 cm and 15–30 cm, and analyzed for pH, nitrate-N, P, K, Ca, Mg, Fe, B, and Zn. Five soil cores were removed from each plot and mixed to form a composite sample. Baseline samples were taken on 12 Mar. 1996, before the first vegetable crop (sweet corn) was planted. Soil samples also were collected before and after each legume cover crop and vegetable crop. Sampling periods will be abbreviated as follows: T1 = 12 Mar. 1996; T2 = 7 Oct. 1996; T3 = 7 May 1997; T4 = 9 Oct. 1997; T5 = 15 Apr. 1998; and T6 = 12 Oct. 1998. Timing of sample collections was as consistent as possible, but varied depending on the weather, field conditions, and crop phenology. The elements Ca, Mg, Fe, B, and Zn were evaluated only at T1, T3, and T5, as they were not the main focus of the study.

Soil samples were analyzed by the Oklahoma State Univ. Soil, Water and Forage Analytical Laboratory in Stillwater, using calcium sulfate extraction of nitrate-N; the Mehlich III extraction for P, K, Ca, and Mg; diethylenetriaminepentaacetic acid (DTPA) extraction of Fe and Zn; and hot water extraction of B. Phosphate (phospho-molybdate blue) and nitrate (cadmium reduction) were analyzed colorimetrically using flow injection instrumentation. Solutions containing the other elements were analyzed using inductively coupled plasma emission spectroscopy (Zhang et al., 1998).

The fertilizer 1× treatment rates were determined by averaging the residual soil test N values at the 0–15 cm sampling depth in the eight control plots for the sampling times before vegetable crop establishment (T1, T3, and T5). Supplemental fertilizer (urea or poultry litter) was applied at rates based on total percent N that, when combined with the residual N levels, brought preplant soil test N to the recommended level for each crop. These calculated rates for the poultry litter were doubled to create the litter 2× rates.

Two warm-season vegetable crops were grown: 'Bodacious' sweet corn and 'Magnum .45' muskmelons. Commercial insect, weed, and disease control methods were followed according to Oklahoma Cooperative Extension Service recommendations. Sprinkler irrigation was used as needed to prevent drought stress. Fallow areas were tilled shallowly (5–8 cm) as needed to control weeds. After harvests of cover crops or vegetable crops, plots were disked and worked with a field cultivator to a depth of 12–15 cm.

Sweet corn, 1996. Fertilizer materials were applied and incorporated on 9 Apr. 1996. Control plots contained an average of 7 kg·ha^{-1} residual soil N. Preplant urea and litter 1× rates added 48 kg·ha^{-1} N, while the litter 2× rate added 96 kg·ha^{-1} N. The sweet corn was direct seeded on 10 Apr. at an in-row spacing of 10 cm between seeds, in eight rows 0.9 m apart per plot. The herbicide 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide (metolachlor) was applied at 1.1 kg·ha^{-1} on 13 Apr. for weed control. Seedlings were thinned on 1 and 9 May to one plant every 30 cm. The corn was topdressed with 70 kg·ha^{-1} N from urea on 21 May. Representative leaf samples (the midrib of the first leaf above the primary ear at tasseling) were taken from six plants per plot on 14 June to determine foliar N concentration.

The corn was hand-harvested on 26 June. Data were taken from 15 plants per row in the center of the middle two rows in each plot, for a total sampling area of 8.1 m^2 per plot. Ears were graded in the husk into marketable (≥13 cm of mature kernels), immature, and cull groups, then counted and weighed. Culls primarily had irregular cob fill; we did not cull based on insect damage. Subsamples of 10 marketable ears per plot were husked and measured for average diameter at the base of the cob and average ear length.

Muskmelons, 1997. Soil samples taken following the first hairy vetch crop and before muskmelon establishment (T3) showed an average of 29 kg·ha^{-1} residual soil N in control plots following vetch, and an average of 9 kg·ha^{-1} residual soil N in control plots following fallow. These differences were so marked that it was necessary to fertilize vetch plots differentially from fallow plots, thereby creating six cropping systems. For plots following vetch, preplant urea and litter 1× rates added 27 kg·ha^{-1} N, while the litter 2× rate added 54 kg·ha^{-1} N. For plots following fallow, preplant urea and litter 1× rates added 47 kg·ha^{-1} N, while the litter 2× rate added 94 kg·ha^{-1} N. Fertilizer materials were applied and incorporated on 20 May.

The herbicide *N*-ethyl-*N*-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl) benzenamine (ethalfluralin) was applied at 1.3 kg·ha^{-1} on 21 May for weed control. Muskmelon seedlings (42 d from seeding in the greenhouse, two plants per peat pot) were transplanted into the field on 23 May. Furrows were opened at a between-row spacing of 2 m, with four rows per plot. One pot was set every 60 cm within a row, with 12 total pots per row. 'Starship' muskmelons were planted at the ends of each data row and in guard rows; thus, data rows contained ≈20 plants of 'Magnum .45'. Each plant received ≈200 mL of a starter solution providing 1079N–949P–895K (mg·L^{-1}), respectively, plus *O,O*-diethyl *O*-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate (diazinon) at 287 mg·L^{-1} for soil insect control. All plants

were topdressed with 56 kg·ha^{-1} N from urea on 19 June. Ten leaves per plot were sampled for elemental analyses on 17 July.

Eight selective hand harvests were made from 21 July through 8 Aug. Fruits were separated into marketable and cull groups, then counted and weighed. At the fourth harvest (30 July), five relatively uniform, marketable fruit per plot were sampled for soluble solids with a refractometer.

Sweet corn, 1998. Soil samples taken following the second hairy vetch crop and before establishment of the second sweet corn crop (T5) showed an average of 20 kg·ha^{-1} residual soil N in control plots following vetch, and an average of 14 kg·ha^{-1} residual soil N in control plots following fallow. For plots following vetch, preplant urea and litter 1× rates added 35 kg·ha^{-1} N, while the litter 2× rate added 70 kg·ha^{-1} N. For plots following fallow, preplant urea and litter 1× rates added 41 kg·ha^{-1} N, while the litter 2× rate added 82 kg·ha^{-1} N. Fertilizer materials were applied and incorporated on 23 April. The sweet corn was direct seeded on 24 Apr. at the same rate and spacing as in 1996. Metolachlor was applied at 1.1 kg·ha^{-1} on 29 Apr. for weed control. Seedlings were thinned on 18 May to one plant every 30 cm. The corn was topdressed with 70 kg·ha^{-1} N from urea on 1 June. Leaf samples were taken from eight plants per plot on 18 June for elemental analyses. The corn was hand-harvested on 3 July following the same procedures as in 1996.

Hairy vetch cover crops. Vetch was planted on half of each replication, with the other plots fallowed, on 9 Oct. 1996 and 17 Oct. 1997 after the soil was disced and packed. Seeds (not inoculated, as native populations of nodulating bacteria were considered adequate) were sown with a grain drill at 3.4 g·m^{-2}. There were eight rows per plot spaced 0.9 m apart. No fertilizers or herbicides were applied to the vetch crops.

The first vetch crop was harvested on 21 Apr. 1997, while the second was harvested on 3 Apr. 1998. In both years, a flail-vacuum mower was used to cut a strip ≈1.2-m wide at a height of ≈3 cm from the approximate middle of each plot. Cut material was dumped on a tarp and weighed. Subsamples were pulled from the cut material for further analyses. After harvest of the data strips, the mower cut the remaining vetch areas and removed the cut material from the field in a simulated haying operation.

Tissue analyses. Foliar samples, collected as previously described, were dried at 48 °C for ≥7 d and reweighed, then ground in a Wiley mill to pass through a no. 40 U.S. standard testing sieve (0.42 mm). The samples were analyzed by the Samuel Roberts Noble Foundation, Ardmore, Okla., or Ward Laboratory, Kearney, Neb. Except for the 1996 sweet corn crop, for which only N concentration was determined, all crops were analyzed for concentrations of N (crude protein), P, K, Ca, Mg, Mn, Fe, and Zn.

Statistical analyses. Data were evaluated with analysis of variance procedures and the MIXED procedure of the Statistical Analysis System (SAS) (SAS Institute, 1999). Vetch data were analyzed by year for effects of fertilizer treatment. Vegetable crop data were analyzed by year. The 1996 sweet corn crop was analyzed for main effects of cover crop (random effects of position in the field only, as no cover crop had yet been grown), main effects of fertilizer treatment, and interactions. The 1997 muskmelon and the 1998 sweet corn crops were analyzed for effects of cropping system (cover crop/fertilizer treatment combinations). Soils data were analyzed across the six sampling times, so these analyses included main effects of treatment (cropping system) and time, as well as interactions. For crop data, if a main effect was significant ($P \leq 0.05$), means were separated using the least significant difference (LSD) at $P \leq 0.05$. For the soils data, trend analysis was used to partition main effects of time into linear and quadratic components. Significant interactions were partitioned with SAS using the SLICE option in a LSMEANS statement, with means separated using a DIFF option and a significance level of 0.05.

Results and Discussion

Sweet corn, 1996. The 1996 sweet corn crop responded similarly to the three fertilizer treatments for all measured variables (Table 3). The 1996 sweet corn was the only vegetable crop in our study not preceded by a cover crop treatment. A test of cover crop effects to determine if there were random effects of position in the field was statistically nonsignificant.

Muskmelons, 1997. Even though N fertilization rates were adjusted to balance the vetch and fallow areas (with higher amounts of fertilizer applied to the fallow areas), N concentrations often were higher in muskmelon plants following vetch than in plants following fallow (Table 4). Differences in foliar N, however, did not translate into yield differences (Table 5). Main effects of cropping systems were not significant for the concentrations of P, K, Ca, Mg, Mn, Fe, or Zn in muskmelon leaves.

Sweet corn, 1998. Cropping systems affected foliar concentrations of N, P, Ca, Mg, and Mn in the 1998 sweet corn crop (Table 4). While there was considerable overlap among individual treatments, an F test (not presented; $P \leq 0.02$) indicated overall N concentrations were higher in corn plants following vetch (2.0%) vs. plants following fallow (1.8%), even though fertilization rates were adjusted as in 1997. Corn fertilized with poultry litter received more P than corn fertilized with urea (Table 2), and this was reflected in increased P concentrations in the foliage of litter-fertilized corn (Table 4). There was a tendency for increased foliar concentrations of Ca, Mg, and Mn in plants following vetch vs. plants following fallow, but individual treatments sometimes overlapped (Table 4). Within the vetch or fallow systems, corn fertilized with poultry litter contained similar concentrations of foliar Ca and more foliar Mn compared to corn fertilized with urea (Table 4). Harper et al. (1980) reported that conventionally fertilized corn ear leaves contained one-third higher Ca concentrations than did those fertilized with broiler litter, but their litter rates (9 and 18 Mg·ha^{-1}) were much higher than those used in our study. As with the muskmelons, however, differences in foliar elemental concentrations did not translate into yield differences in our study (Table 6). Shortall and Liebhardt (1975)

Table 3. Effects of fertilizer treatments on 'Bodacious' sweet corn, Bixby, Okla., 1996.

Fertilizer treatment	Unhusked ears: Marketable (Mg·ha^{-1})	Unhusked ears: Marketable (g/ear)	Unhusked ears: Total (Mg·ha^{-1})	Husked marketable ears: Avg diam[z] (cm)	Husked marketable ears: Avg length (cm)	Husked marketable ears: Foliar N (%)
Urea	9.3	301	13.3	3.9	18	2.0
Litter 1×	10.0	306	13.4	4.0	18	1.7
Litter 2×	10.4	309	14.0	4.0	18	1.8
Significance	NS	NS	NS	NS	NS	NS

[z]Measured at base of cob.
NSNonsignificant at $P \leq 0.05$.

Table 4. Foliar element concentrations of muskmelon (1997) and sweet corn (1998) in response to cover crop and fertilizer treatments, Bixby, Okla.[z]

Variable	Vetch: Urea	Vetch: Litter 1×	Vetch: Litter 2×	Fallow: Urea	Fallow: Litter 1×	Fallow: Litter 2×
			Muskmelon			
N (%)	5.3 ab	5.5 a	5.2 ab	5.0 bc	4.4 d	4.7 cd
P (%)	0.46	0.48	0.50	0.45	0.48	0.44
K (%)	1.9	2.1	2.3	2.2	2.4	2.5
			Sweet corn			
N (%)	2.1 a	2.0 ab	1.9 abc	2.0 ab	1.7 c	1.8 bc
P (%)	0.22 e	0.28 cd	0.32 bc	0.23 de	0.34 b	0.42 a
K (%)	2.7	2.7	2.7	2.8	2.7	3.0
Ca (%)	0.51 a	0.50 a	0.47 ab	0.46 abc	0.40 c	0.41 bc
Mg (%)	0.27 a	0.24 ab	0.20 bc	0.22 b	0.16 c	0.15 c
Mn (mg·kg^{-1})	54 a	40 b	36 bc	40 b	32 cd	27 d

[z]Within crops, if significant differences exist, letters indicate mean separation in rows by LSD, $P \leq 0.05$. Cropping system had no significant ($P \leq 0.05$) main effects on foliar concentrations of Ca, Mg, and Mn in muskmelons, or Fe and Zn in either crop, so data are not presented.

Table 5. Effects of cover crop and fertilizer treatments on 'Magnum .45' muskmelon, Bixby, Okla., 1997.

Cropping system	Marketable fruit Wt (Mg·ha^{-1})	Wt (kg/fruit)	Soluble solids (%)	Total fruit wt (Mg·ha^{-1})
		Vetch		
Urea	27.0	1.6	9.8	33.4
Litter 1×	27.6	1.7	10.2	34.2
Litter 2×	29.0	1.8	10.5	37.4
		Fallow		
Urea	28.1	1.6	10.0	32.2
Litter 1×	27.3	1.6	9.5	33.6
Litter 2×	24.7	1.6	9.4	31.9
Significance	NS	NS	NS	NS

NSNonsignificant at $P \leq 0.05$.

Table 6. Effects of cover crop and fertilizer treatments on 'Bodacious' sweet corn, Bixby, Okla., 1998.

Cropping system	Unhusked ears Marketable (Mg·ha^{-1})	Marketable (g/ear)	Total (Mg·ha^{-1})	Husked marketable ears Avg diam[z] (cm)	Avg length (cm)
			Vetch		
Urea	7.9	258	9.2	3.7	16
Litter 1×	9.6	278	10.9	3.9	17
Litter 2×	8.9	275	11.0	3.8	16
			Fallow		
Urea	7.4	265	9.5	3.8	15
Litter 1×	8.2	258	9.4	3.6	16
Litter 2×	8.3	269	10.0	3.8	16
Significance	NS	NS	NS	NS	NS

[z]Measured at base of cob.
NSNonsignificant at $P \leq 0.05$.

and Wood et al. (1996) also found no yield differences between corn fertilized with poultry manure or litter and corn grown with commercial inorganic fertilizers.

Hairy vetch cover crops. The fertilizer treatments did not affect foliar concentrations of N, P, K, Ca, Mg, Mn, or Fe in hairy vetch, nor shoot fresh weight (Table 7). The only significant difference in foliar nutrient concentration occurred with Zn in the 1996–1997 crop, with less Zn in plants fertilized by litter at the 2× rate than in plants fertilized by litter at the 1× rate or by urea. We do not know why this difference occurred. Years were not compared statistically, but the relatively low shoot yield in 1997–98 reflected a shorter vetch growing season than in 1996–97. An early vetch harvest was necessary in 1998 due to the earlier planting date of the 1998 sweet corn crop relative to the 1997 muskmelon crop. Earhart (1998) reported that dry matter yields of hairy vetch were not affected by increasing rates of poultry litter application.

Soils. In general, cover crop and fertilizer treatments had few significant main effects on plant nutrient concentrations in the soil (Tables 8, 9, and 10). Sampling time effects predominated, as expected, and there were some interactions of time with cropping system treatments.

pH. A treatment × time interaction was evident for pH at the 0–15 cm soil sampling depth (Table 8). Cropping system effects were detected only at T6 (Table 9), when litter 1× and 2× plots in the fallow system had higher pH values than their respective counterparts in the vetch system. Gupta and Charles (1999) and Kingery et al. (1994) noted increased pH to a depth of 60 cm under soils with a long-term history of poultry litter application. However, in our study the trend over time was a quadratic decrease in soil pH (Table 8).

Table 7. Foliar element concentrations and shoot fresh weights of vetch cover crops in response to fertilizer treatments, Bixby, Okla.[z]

Variable	1996–97 Urea	Litter 1×	Litter 2×	1997–98 Urea	Litter 1×	Litter 2×
N (%)	3.6	3.4	3.5	1.3	1.0	1.4
P (%)	0.58	0.63	0.65	0.24	0.20	0.47
K (%)	3.8	4.0	4.2	1.4	1.2	1.6
Ca (%)	1.9	1.7	1.7	0.59	0.46	0.59
Mg (%)	0.43	0.41	0.40	0.29	0.28	0.30
Zn (mg·kg^{-1})	57 a	57 a	51 b	36	33	39
Shoot wt. (Mg·ha^{-1})	9.0	9.3	9.9	3.3	3.2	2.8

[z]Within years, if significant differences exist, letters indicate mean separation in rows by LSD, $P \leq 0.05$. There were no significant ($P \leq 0.05$) treatment effects on foliar concentrations of Mn and Fe in the vetch (data not presented). No fertilizer treatments were applied to the vetch. The fertilizer treatments were applied to sweet corn (1996) and muskmelon (1997) crops preceding the vetch.

Nitrogen. A treatment × time interaction was evident for soil test N at both the 0–15 cm and 15–30 cm soil sampling depths (Table 8). Simple effects of cropping system on N at the 0–15 cm soil sampling depth were detected at T3 and T4, but not at other times (Table 9). Plots in the vetch system were higher in soil test N at the 0–15 cm sampling depth than plots in the fallow system at T3 (7 May 1997, after harvest and residue incorporation of the first vetch crop). There were no differences due to fertilizer treatments within cover crop systems at T3. At T4 (9 Oct. 1997, after the muskmelon crop), samples from vetch plots remained higher in soil test N at the 0–15 cm sampling depth than samples from fallow plots fertilized with either urea or litter at the 1× rate. This difference occurred even though higher rates of preplant N were applied in the fallow system than in the vetch system. It appeared that vetch plots still were getting residual N benefits from the microbial breakdown of vetch residue. While the ability of hairy vetch residue to act as a N fertilizer for succeeding crops is established (Abdul-Baki et al., 1996; Hargrove, 1986), our result at T4 was unexpected given that most of the above-ground vetch biomass had been removed from the field on 21 Apr. 1997. Within the vetch system, there were no differences in N concentrations at the 0–15 cm soil sampling depth at T4, but within the fallow system, N concentrations were higher in litter 2× plots than in litter 1× plots (Table 9).

It is not surprising that treatment effects on soil test N at the 0–15 cm soil sampling depth were not detected at T5 and T6. The 1997–98 vetch crop produced less biomass than the 1996–97 crop (Table 7). Also, T5 soil samples were taken just 12 days after the 1997–1998 vetch crop was harvested, allowing little time for vetch decomposition before soil sampling. This early soil sampling date was necessary so that the 1998 sweet corn crop could be planted on time, as previously noted. Indirect evidence for vetch effects on soil test N concentrations in 1998 was seen in the data from the 1998 sweet corn crop's foliar analyses (Table 4), but we were unable to detect corresponding N differences from our soil samples.

Simple effects of cropping system on N at the 15–30 cm soil sampling depth were detected at T2, T4, and T6 (that is, following each vegetable crop), but not at other times (Table 9). No cover crops had yet been grown on the land at T2, so no differences were expected between cover crop treatment plots for a given fertilizer treatment. However, samples from "future" fallow plots fertilized with urea had higher N concentrations at the 15–30 cm soil sampling depth than samples from "future" vetch plots fertilized with urea (Table 9). Also, samples from plots fertilized with litter usually had higher soil test N concentrations at the 15–30 cm sampling depth than samples from control (urea) plots at T2. At T4, samples from plots fertilized with urea in the vetch system were higher in soil test N at the 15–30 cm sampling depth than samples from any other treatment. Values from the remaining treatments were similar, except that

Table 8. Mean soil test values for pH and N, P, and K at six soil sampling times, Bixby, Okla.

Variable	Sampling times[z]						Significance[y]		
	T1	T2	T3	T4	T5	T6	Treatment	Time	Treatment × time
0–15 cm soil sampling depth									
pH	6.2	6.1	6.0	5.8	6.1	5.8	NS	L**, Q**	*
N (kg·ha^{-1})	8	16	19	46	17	11	**	L**, Q**	**
P (kg·ha^{-1})	227	188	246	254	208	235	*	L**, Q**	**
K (kg·ha^{-1})	376	365	326	360	297	367	NS	L**, Q**	NS
15–30 cm soil sampling depth									
pH	6.0	6.0	6.0	5.6	6.0	5.8	NS	L**, Q**	NS
N (kg·ha^{-1})	7	43	7	36	12	30	NS	L**, Q**	**
P (kg·ha^{-1})	203	160	214	209	178	199	NS	NS	*
K (kg·ha^{-1})	285	258	261	261	238	242	NS	L**, Q*	NS

[z]T1 = 12 Mar. 1996 (baseline); T2 = 7 Oct. 1996 (after sweet corn and before hairy vetch planting); T3 = 7 May 1997 (after hairy vetch and before muskmelon planting); T4 = 9 Oct. 1997 (after muskmelon and before hairy vetch planting); T5 = 15 Apr. 1998 (after hairy vetch and before sweet corn planting); T6 = 12 Oct. 1998 (termination, after sweet corn).
[y]Linear (L) and quadratic (Q) effects of time were tested.
NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Table 9. Details of treatment × time interactions affecting pH and soil test N and P, Bixby, Okla.[z]

Sampling time	Vetch			Fallow		
	Urea	Litter 1×	Litter 2×	Urea	Litter 1×	Litter 2×
pH, 0–15 cm soil sampling depth						
T6 (12 Oct. 1998)	5.7 c	5.8 bc	5.7 c	5.8 bc	6.0 a	5.9 ab
N (kg·ha^{-1}), 0–15 cm soil sampling depth						
T3 (7 May 1997)	29 a	28 a	31 a	9 b	9 b	10 b
T4 (9 Oct. 1997)	53 a	50 a	52 a	34 bc	38 c	46 ab
N (kg·ha^{-1}), 15–30 cm soil sampling depth						
T2 (7 Oct. 1996)	30 d	44 bc	52 a	42 c	43 bc	49 ab
T4 (9 Oct. 1997)	49 a	38 b	36 bc	28 c	31 bc	36 bc
T6 (12 Oct. 1998)	25 b	24 b	44 a	31 b	27 b	30 b
P (kg·ha^{-1}), 0–15 cm soil sampling depth						
T3 (7 May 1997)	207 c	230 bc	262 ab	240 bc	260 ab	281 a
T4 (9 Oct. 1997)	208 c	232 bc	289 a	219 c	267 ab	307 a
T5 (15 Apr. 1998)	170 b	204 ab	215 a	197 ab	224 a	236 a
T6 (12 Oct. 1998)	195 d	223 bcd	260 ab	213 cd	247 abc	271 a

[z]Letters indicate mean separation in rows by least squares, $P \leq 0.05$. No treatment effects were found at T1 (12 Mar. 1996), since no treatments had been applied.

samples from plots fertilized with litter at the 1× rate in the vetch system had higher soil test N concentrations at the 15–30 cm sampling depth than samples from plots fertilized with urea in the fallow system (Table 9). At T6, more soil test N was found at the 15–30 cm sampling depth in plots fertilized with litter at the 2× rate in the vetch system than in plots from any other treatment (Table 9). The findings for soil test N at the 15–30 cm sampling depth are not readily explained, particularly for T2. Results may simply reflect sampling and analytical variation.

Phosphorus. A treatment × time interaction was evident for soil test P at the 0–15 cm soil sampling depth (Table 8). Treatment effects on P at the 0–15 cm soil sampling depth were detected at T3, T4, T5, and T6, but not at T1 (the baseline sample, at which time no treatments had been applied) and T2 (before cover crops were grown) (Table 9). At T3, T4, T5, and T6, no differences in soil test P at the 0–15 cm sampling depth due to cover crop system were found for a given fertilizer treatment. The general trends at these four times were that values for soil test P at the 0–15 cm sampling depth were higher from litter 2× plots than from urea plots, while values from litter 1× plots were similar to those from urea plots. Exceptions occurred within fallow system plots at T5 and T4, respectively (Table 9). Also, samples from litter 2× plots had P concentrations at the 0–15 cm soil sampling depth similar to those in samples from litter 1× plots in all cases except for T4 in the vetch system (Table 9). Earhart (1998) reported that litter applications at a rate matching an inorganic fertilizer control (similar to our 1× rate) maintained soil test P concentrations in the 0–15 cm sampling depth at about the same values over five seasons, while higher rates increased P accumulation.

While a treatment × time interaction also was detected for soil test P at the 15–30 cm soil sampling depth (Table 8), statistical tests of effect "slices" showed no significant ($P \leq 0.05$) differences between treatments at any one sampling time. The interaction occurred because the relative rankings of the treatments were not always the same at each sampling time (data not presented). Since treatments did not differ, the interaction is of little practical consequence.

The vetch did not contain high concentrations of P (Table 7) and may not have accumulated enough removable biomass in the time frame available to have a major impact on soil test P values, especially in the 1997–98 season. Earhart (1998) also used poultry litter in spring vegetable–fall legume rotations, and found that soil test P values were maintained or reduced by fall legume cover cropping.

Potassium. Cropping system treatments had no detectable effects on soil test K at the 0–15 cm or 15–30 cm soil sampling depths (Table 8). Only the main effect of time was significant for these variables, and the response was a quadratic decrease over time at both soil sampling depths (Table 8). Others (Earhart, 1995; Shortall and Liebhardt, 1975; Wood et al., 1996) have reported increased K accumulation in soils following applications of poultry litter or manure at relatively high rates.

Secondary nutrients and micronutrients. Cropping system treatments had no detectable effects on concentrations of Ca, Mg, Fe, B, or Zn at either soil sampling depth (Table 10). However, concentrations of these elements varied over time. Most responses were quadratic. Wood et al. (1996) found that poultry litter applications at 9 and 18 Mg·ha^{-1} increased concentrations of soil extractable Ca, Mg, and Zn.

Table 10. Mean soil test values for Ca, Mg, Fe, B, and Zn at three soil sampling times, Bixby, Okla.

Variable	Sampling times[z]			Significance[y]		
	T1	T3	T5	Treatment	Time	Treatment × time
0–15 cm soil sampling depth						
Ca (kg·ha^{-1})	2591	2623	2301	NS	L**, Q**	NS
Mg (kg·ha^{-1})	392	394	345	NS	L**, Q**	NS
Fe (mg·kg^{-1})	44	41	41	NS	L**, Q**	NS
B (mg·kg^{-1})	0.33	0.29	0.23	NS	L**	NS
Zn (mg·kg^{-1})	1.5	1.8	1.7	NS	L**, Q**	NS
15–30 cm soil sampling depth						
Ca (kg·ha^{-1})	2613	2773	2440	NS	L**, Q**	NS
Mg (kg·ha^{-1})	379	401	351	NS	L**, Q**	NS
Fe (mg·kg^{-1})	45	42	39	NS	L**	NS
B (mg·kg^{-1})	0.29	0.31	0.23	NS	L**, Q**	NS
Zn (mg·kg^{-1})	1.3	1.3	1.2	NS	L**, Q**	NS

[z]T1 = 12 Mar. 1996; T3 = 7 May 1997; T5 = 15 Apr. 1998.
[y]Linear (L) and quadratic (Q) effects of time were tested.
NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Conclusions

Soil test P concentrations at the 0–15 cm sampling depth in the vetch system were consistently lower numerically, but not statistically, relative to comparable plots in the fallow system. However, after the first sweet corn crop and first vetch crop, plots in the

vetch system received less poultry litter than plots in the fallow system. Also, the vetch system did not prevent significant increases in soil test P concentrations at the 0–15 cm sampling depth when poultry litter was applied at twice the recommended rate. Therefore, with our vegetable rotations and growing season, hairy vetch cover crops were not satisfactory as a means of managing soil P accumulation from poultry litter applications. Hairy vetch cover crops still could be part of a sustainable vegetable production system where poultry litter was used. There was no evidence of negative interactions between hairy vetch and poultry litter, and the vetch reduced the need for preplant N fertilization.

Yields of sweet corn and muskmelons fertilized by poultry litter at the recommended preplant N rate and at twice the recommended rate were similar to yields from fertilization with urea at the recommended preplant N rate. While the litter 2× rate resulted in demonstrable increases in soil test P at the 0–15 cm soil sampling depth, litter at the 1× rate was not shown to raise soil test P values. Longer-term studies may show increases in soil test P even with litter at the 1× rate, so poultry litter would be recommended only with caution on high-native-P soils such as those used in our studies. Research should continue on ways to efficiently utilize poultry litter in horticultural production systems.

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