VADOSE ZONE WATER AND CROP RESPONSE TO POULTRY LITTER APPLICATION ON RECLAIMED SURFACE MINE LAND[1]

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Abstract. Reclaimed mined land has low organic matter and nutrient levels. Poultry litter could supply both but its effects on vadose zone water quality must be addressed. Poultry litter rates of 0, 9, 18, or 27 Mg ha^{-1} yr^{-1} or 202 kg ha^{-1} of N fertilization were evaluated on tall fescue, alone and with birdsfoot trefoil, on mined land in a randomized complete block design. Lysimeters were installed on selected treatments to collect vadose water for ammonium, nitrate and orthophosphate analysis and fecal coliform counts. The 27 Mg ha^{-1} litter rate and the 202 kg ha^{-1} fertilizer rate resulted in the highest DM yields of 1.3 and 1.7 Mg ha^{-1} respectively compared with 0.2 Mg ha^{-1} for the control on three harvests during 1999. However, the higher litter application rates decreased legume proportion in the mixture. Water analyses showed elevated levels of nitrate for fertilizer plots and phosphate for litter plots. Initial results indicate that large increases in yield result from poultry litter and fertilizer application.

Introduction

In Kentucky two distinct coalfields exist, the western and the eastern coalfields. Eastern Kentucky is greatly dependent economically on coal production. Under the Federal Surface Mining Control and Reclamation Act of 1977, all surface mined land must be reclaimed and returned to its original production level. The exception is mountaintop removal areas. Mountaintop removal areas can be developed and reclaimed for recreational, forest, wildlife habitat, wetlands or grazing purposes. Successful reclamation implies the establishment of plant communities as well as a self-sustaining ecosystem. Spoils resulting from the surface mining of coal have yields limited by low nutrient levels, especially N, and low organic matter. Seedling establishment in this overburden does not generally present a problem although long term persistence does (Reeder and Sabey, 1987; Woodmansee et al., 1978).

The mining process disrupts the N cycle and N mineralization by microbes (Reeder and Sabey, 1987) thus reducing soil N available for plants. After an ecosystem is disturbed, it requires a period of time in which to recover and develop a new soil-plant-microorganism cycle in which plants and microbes grow, die and are finally mineralized. Accumulation of organic matter also occurs during this period. Only after this has been accomplished can soil productivity improve. In some cases spoil material can be a source of mineral or mineralizable N because these materials have a wide variability in N content, from 11µg/g of total N to more than 4,000 µg/g depending on the composition of the spoil material (Reeder and Sabey, 1987). This N is not as readily mineralizable as soil organic matter, so that it can not supply the N needed by plants for growth. Mineralization potential of indigenous N is higher in soils than in mine spoils (Reeder and Berg, 1977a; b; Reeder, 1985; Reeder and Sabey, 1987). Power et al., (1974) found that exchangeable NH_4 in certain shales could be readily nitrified but the extent of mineralization of small amounts of organic N in the same shales was minimal. Lower rates of N mineralization should be expected due to the fact that N in geologic materials can be present in forms not available for microbial metabolism (Reeder and Berg, 1977a). In order for disturbed lands to achieve a healthy, working ecosystem, accumulation of biomass and nutrients must occur (Woodmansee et al., 1978). Petersen et al. (1978) also determined that mine soils derived from coarse spoils require fertilization to support vegetation due to low levels of available nutrients in these soils. Long term fertility of these soils can be achieved by accumulation of the adequate pool of active nutrients. Mixing forage grasses with N-fixing plants can help alleviate this problem. Palmer and Chadwick (1985) found that the use of legumes in mined lands provided more mineralizable and hydrolizable N than did fertilizers.

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The application of manure is a common practice in agriculture because of the amount of nutrients that it contains. The rapid expansion of the poultry industry in Kentucky makes disposal of poultry litter, a combination of manure and bedding materials, a necessity. Lucero et al. (1995) indicate that the application of the right rate of poultry litter to pastures can successfully serve as a fertilizer source for the renovation and production of such pastures. They found that, with similar rates of N, poultry litter application resulted in equal or higher dry matter yields than those with N and P fertilizer. Long term application of poultry litter increases organic matter and total N in soils and accumulation of total N, extractable soil P, K , Ca and Mg also occurred with the use of poultry litter (Kingery et al., 1993; 1994). Kingery et al. (1993) found that a pool of mineralizable N was established when poultry litter was used. Long term use and/or heavy application rates create potential problems such as lowering of C/N ratio due to accumulation of mineralizable N in pastures, excess P concentration, increased concentrations of toxic elements (Kingery et al., 1993; 1994; Pope, 1991) and contamination of surface and groundwater due to leaching and runoff from fields where litter has been applied (Kingery et al., 1993). Toxic elements such as Cu, As, Se and Zn can be found in poultry waste and require close monitoring to avoid land application of a toxic waste and subsequently contamination of surface and vadose water and toxicity to certain crops. Salt build-up from repeated applications of poultry litter can reduce soil water availability and destroy soil structure, thus preventing good germination and plant growth (Wells, 1996).

Litter application rates are commonly based on N requirements of the crop. This causes an overapplication of phosphorus in most cases because the ratio of total N and phosphate (Rasnake et al., 1987; Simpson, 1991) in litter is usually near 1:1. The accumulation of nutrients in soils can also be of concern to grazing animals due to increased plant uptake and accumulation, especially N (Kingery et al., 1993).

Land reclaimed after coal mining can be used for forage production. Tall fescue (*Festuca arundinacea* Schreb.) is one of the most common perennial grasses used in the southeastern United States. It has been used in many reclamation projects, alone or in combination with other grasses or legumes because of its tolerance to low pH (4.5 or above) and drought (Bennet et al., 1978). It is deep rooted, long lived perennial that is propagated by seeding. Birdsfoot trefoil (*Lotus corniculatus L.)* is a winter hardy perennial legume with a well developed taproot system. It can grow in a wide variety of soils that are "poorly drained, droughty, infertile, acid or even alkaline" (Bennett et al, 1978). It produces non-bloating, nutritious forage and once established can compete in mixtures with grasses. The use of legumes represents an efficient way to accumulate N during land reclamation because more mineralizable and soluble N has been found in land where N-fixing legumes are present rather than organic fertilizer (Palmer and Chandwick, 1985). Growing tall fescue along with a legume also provides a wider distribution of forage availability throughout the growing season (Matches, 1979).

Tall fescue has been subject to numerous studies in which poultry litter was applied with favorable effects on crop production (Kingery et al., 1993; Shreve et al., 1995). However, deleterious effects on the environment can result from the oversupply and overaccumulation of nutrients. Due to the potential adverse effects of poultry litter on soils, water, and grazing cattle guidelines must be developed on the optimum rate of application to maximize productivity and minimize environmental degradation. The purpose of this study was to evaluate vadose water and crop response to poultry litter application on surface mined land for the purpose of growing forage.

Materials and Methods

The field study was initiated in May, 1998 on surface mine spoil resulting from coal mining on the University of Kentucky's Robinson Forest. Robinson Forest lies in the Southeastern part of Kentucky and it is included in the Appalachian coal field region. This region runs from Pennsylvania to Alabama (Barnes et al., 1998). Mountain top removal is a common method for mining coal in this area due to its topographic features. The resulting spoils are mixtures of sandstone, crushed shales and rocks, with little topsoil. The study site was located in Perry county, Kentucky (elevation 387 m; latitude 37°25'48"; longitude 83°10'48"). The chemical characteristics of the spoil were measured prior to treatment application in 1998 and again in 1999 (Table 1 and 2).

Table 1. Soil test for April 1998 prior to treatment application.

P	K	Ca	Mg	Zn	pH	PA
-----	-----	kg/ha	-----	-----		
146	298	2921	1301	10.6	7	0.2

Table 2. Soil test for April 1999 prior to treatment application.

Species	Litter	P	K	Ca	Mg	Zn	pH
		--------------------kg/ha-----------------					
TF	0	113	232	2556	1164	12	6.8
TF	9 Mgha^{-1} PL	195	289	2801	1335	16	7.4
TF	18 Mgha^{-1} PL	386	349	3034	1259	29	7.4
TF	27 Mgha^{-1} PL	300	332	2628	1146	23	7.4
TF	202 kgha^{-1} N	128	218	2067	987	9	7.0
TF/BFT	0	153	234	2581	1267	11	7.1
TF/BFT	9 Mgha^{-1} PL	248	322	2658	1214	20	7.3
TF/BFT	18 Mgha^{-1} PL	316	345	3000	1328	25	7.4
TF/BFT	27 Mgha^{-1} PL	380	382	3176	1379	25	7.0
TF/BFT	202 kgha^{-1} N	173	267	2740	1270	14	7.4

TF= Tall fescue
BFT= Birdsfoot trefoil

The study area had originally been seeded using a standard reclamation mixture for this region. On initiation of the study it was reseeded according to two vegetation approaches for forage production, tall fescue monoculture or a mixture of tall fescue and birdsfoot trefoil. Tall fescue was broadcast over all plots on a prepared seedbed. Birdsfoot trefoil was then drilled using a small plot seeder. The empty drill was also used to consolidate the soil after broadcasting grass in the monoculture plots. Phosphorus and K were applied according to soil test recommendations along with application of N to encourage uniform establishment. The study was set as a randomized complete block design with four replications arranged to account for differences in slope. Plots measure 2.44 x 6.10 m, except for those with lysimeter pans which measured 3.66 x 6.10 m. The treatments consisted of three different levels of poultry litter, a control with no N, or ammonium nitrate fertilizer (Table 3). The N fertilizer rate

Table 3. Treatments.

	Grass	Legume	Litter	Fertilizer N
			-Mg/ha--	kg/ha--
1	X		0	
2	X		9	
3	X		18	
4	X		27	
5	X			202
6	X	X	0	
7	X	X	9	
8	X	X	18	
9	X	X	27	
10	X	X		202

provided an equal amount of N as the medium level of poultry litter.

Lysimeter pans were installed 0.6 m beneath the soil surface to collect water from treatments 1, 3 and 5 corresponding to the control, medium rate of poultry litter and ammonium nitrate fertilizer treatments for the grass monoculture.

Manure was applied only once in 1998, in July, at half of the annual rate. In 1999, manure was applied in two split applications (May and July). Stacked manure was transported to the experimental site where it was broadcast over the plots. Poultry litter from each application was analyzed for nutrient concentration (Table 4).

Water sampling and analysis

Water was pumped out of the lysimeter pans biweekly. The volume of water was recorded and a subsample retained for analysis. Microbial counts for fecal coliform bacteria were conducted within 24 hours of sample collection using a membrane filtration system. Volumes of 10 and 100 ml were filtered collected within 24 hours of sample collection using a membrane filtration system and placed on Difco mFC dehydrated medium. Samples were then incubated for approximately 24 hours at 44.5 °C (APHA, 1998). Colonies were then counted. Ammonium concentration in water samples was determined colorimetrically at 630 nm using a modification of the Berthelot reaction (Chaney and Marbach, 1962). This modification used two reagents, one containing phenol and nitroprusside and the other containing sodium hydroxide and sodium hypochlorite. Nitrate was determined as nitrite using a Technician Autoanalyzer System II (Industrial method No. 100-70W/B, Technicon, 1978). Nitrate was quantitatively reduced to nitrite using a copperized-cadmium reductor. Nitrite ions were then reacted with an acidified solution containing N (1-Naphthyl) ethylene diamine dihydrochloride (NED) and sulfanilamide and determined colorimetrically at 540 nm. Orthophosphate was determinated colorimetrically at 630 nm using a manual method developed by Van Veldhoven and Mannaerts (1987). The sample was first reacted with acidified ammonium molybdate then Malachite green in polyvinyl alcohol was added to produce a colored reaction product.

Plant sampling and analysis

Plots were harvested once in the summer of 1998 and three times in 1999 (May, July and October). Botanical composition and yield were determined. Botanical composition involved separating plant materials into grass, weed and legume when appropriate. Total N and P for tissue samples were determined after digestion with sulfuric acid in a Technicon Block Digestor. The digestion process converted all form of N to ammonium and all forms of P to orthophosphate. A dual Technicon System II Autoanalyzer performed both analyses simultaneously at 660 nm wavelength. The ammonium technique used was a modification of the Berthelot reaction done by Chaney and Marbach (1962). The method utilized for phosphorus was based on Fiske and Subbarow's method (1925).

Table 4. Poultry litter analysis.

	Spring 98	May 99	July 99
% moisture	17.4	27.5	25.7
N (g/kg)	28.2	25.4	25.1
P (g/kg)	18.0	48.5	53.1
K (g/kg)	38.3	48.0	40.8
Ca (g/kg)	26.2	33.3	36.1
Cu (g/kg)	0.46	0.39	0.34
Zn (g/kg)	0.68	0.39	0.35
Mg (g/kg)	----	7.48	8.00
Mn (g/kg)	----	0.50	0.73
Fe (g/kg)	----	2.07	2.73
NO_3N (g/kg)	----	0.35	3.64
NH_4N (g/kg)	----	0.54	0.93

Nitrate determination in plant tissue was done following the same method as for the water samples (Industrial method No. 100—70W/B.)

Analysis of variance was done using the General Linear Models (SAS Institute) to identify treatment effects. Individual treatment means were compared using the PDIFF option of SAS (SAS, 1996). Water quality results were analyzed statistically using repeated measures.

Results and Discussion

Environmental Characteristics

Rainfall during 1999 was low and below normal for the spring in this region but well below average during the summer months. The state of Kentucky suffered a severe drought during the summer.

Water Quality

Statistical analyses performed on water quality parameters indicated significant effects for poultry litter and fertilizer on PO_4 (Fig 1) and NO_3 concentrations (Fig 2) in vadose water but not on NH_4 concentrations (Fig 3).

Results showed that poultry litter application increases PO_4 levels in vadose water, while NH_4NO_3 fertilizer increases NO_3 levels in vadose water. Reeder and McGinnies (1989) stated that the potential for nitrate leaching is increased in mine land soils made of unconsolidated spoil material with low water holding capacity. Solubilization of P applied in poultry litter would explain higher P levels in vadose water for the litter treatments. For all the parameters studied there was a significant effect of time and of the interaction of time and litter ($p=0.05$).

Figure 1. Total phosphate concentration in vadose water samples collected from lysimeter pans between July 1998 and December 1999.

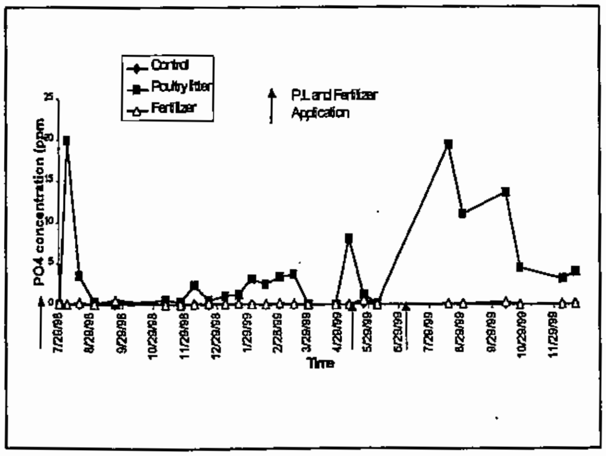


Figure 2. Total nitrate concentration in vadose water collected from lysimeter pans between July 1998 and December 1999.

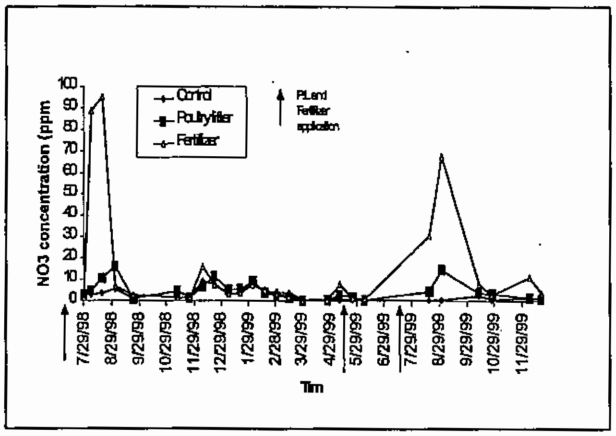
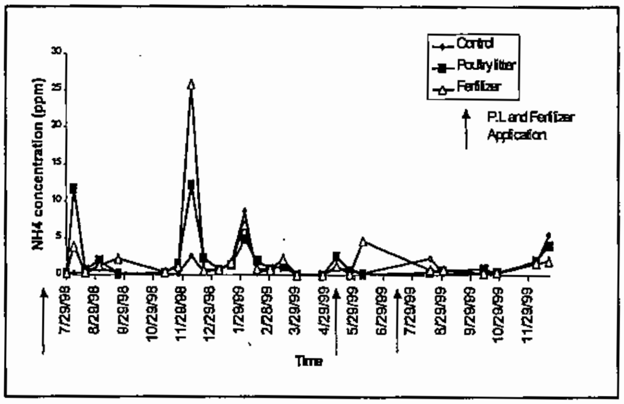
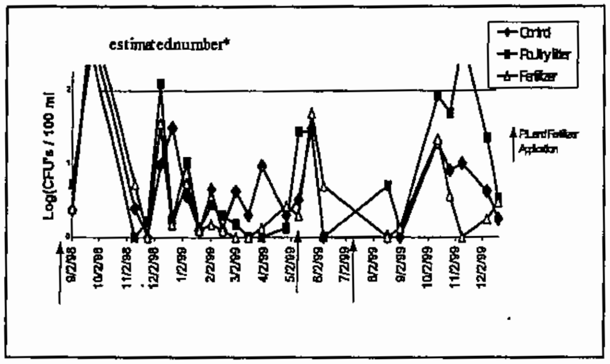


Figure 3. Total ammonium concentration in vadose water collected from lysimeter pans between July 1998 and December 1999.



Fecal Coliform bacteria counts showed greater variation over time than other quality analyses (Fig 4).

Figure 4. Fecal coliform bacteria counts from vadose water samples collected between September 1998 and December 1999.



*Indicates that bacteria numbers were too numerous to count.
** Line represents the critical bacteria level for recreational water.

Fecal coliform bacteria numbers were consistently below the statutory limits set by the State Division of Water of 200 CFU's/100 ml. Contamination of samples may be responsible for the higher numbers counted on September 1998 and December 1998. These data seem to indicate that fecal bacteria in poultry litter can significantly affect water quality months after the litter is applied when adequate rainfall occurs following an extended dry period. However, other research suggests that survival of these bacteria for extended periods would not be expected.

Forage Yield and Composition

All variables studied showed significant harvest effects. This is most probably caused by the drought experienced during the summer months in Kentucky that reduced yields dramatically for the second harvest and third harvest. While the May harvest yields averaged nearly 1700 kg ha^{-1}, the July harvest averaged under 300 kg ha^{-1} and the October harvest just over 700 kg ha^{-1}.

There was no significant effect on yield of the interaction of harvest by species by treatment but there was a significant effect of the species by treatment interaction. For harvest 1, there was an increase in yield due to increased litter rate (Fig 5). However, for harvest 2, there was no significant trend with increased fertility rate (Fig 6). Harvest 3 showed again a positive yield increase with increased litter rate (Fig 7). However, the mixture plots lost their

Fig 5. Effect on 1999 yields of treatment by species interaction for harvest 1.

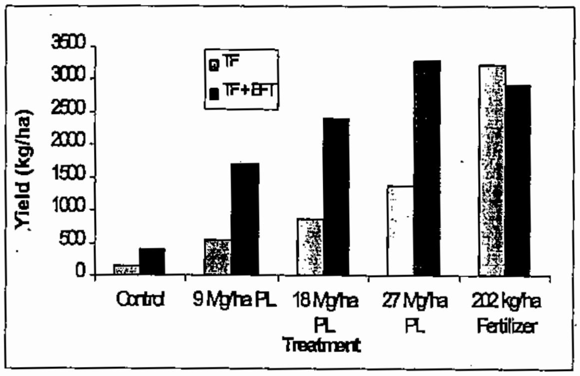


Fig 6. Effect on 1999 yields of treatment by species interaction for harvest 2.

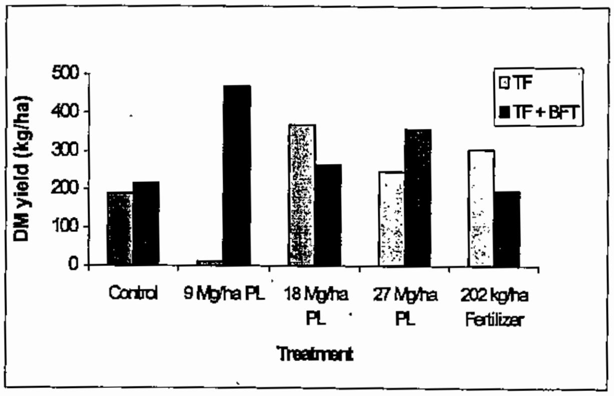
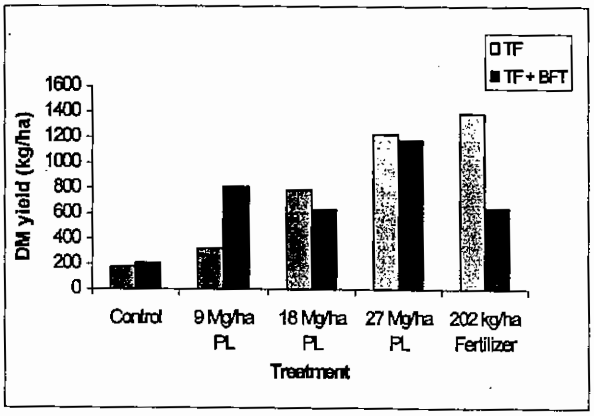


Fig 7. Effect on 1999 yields of treatment by species interaction for harvest 3.



yield advantage on the third harvest over the monoculture plots.

These yield findings are in accordance with the findings of Berg (1975) and Aldon (1978). They found that on mineland with no topsoil, N fertilization increased yields when moisture was not limiting.

Litter/fertilizer treatments significantly affected percentages of all components (grass, weed and legume). Grass percentage increased with increasing litter rate while legume percentage declined (Fig 8). Nitrogen fertilizer gave the highest percent of tall fescue and the lowest birdsfoot trefoil percentage of all treatments. Percent grass in the stand also increased from harvest 1 to harvest 3 while legume percentage declined from the May harvest to the October harvest.

Birdsfoot trefoil and weed percentages were influenced by species treatment and by harvest. Inclusion of birdsfoot trefoil with tall fescue significantly reduced weed proportion. There was no litter by species interaction. When similar rates of N were applied (treatment 3 vs. 5), ammonium nitrate fertilizer gave higher dry matter yields than poultry litter when adequate moisture was available. However, poultry litter rate gave the highest yield when moisture was limiting.

The movement of water through the soil varied widely among plots and sampling dates. This was most likely caused by a lack of soil structure and the existence of unweathered sandstones and shales that allowed for macropores to route the water down through the profile. The high degree of variability in forage productivity was probably also caused by the nature of this spoil and specifically its low water holding capacity. First harvest yields were high, illustrating the potential of this type of land for pasture production. The second and third harvests determined that this spoil is not capable of producing a good yield unless adequate moisture is available.

Figure 8. Botanical percentages for litter/fertilizer treatment for the tall fescue/birdsfoot trefoil plots averaged over the three 1999 harvests.

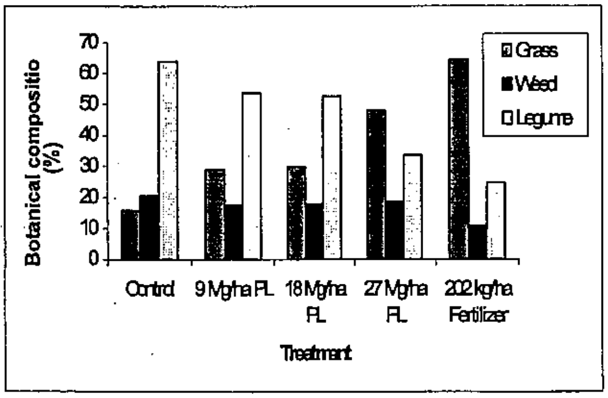
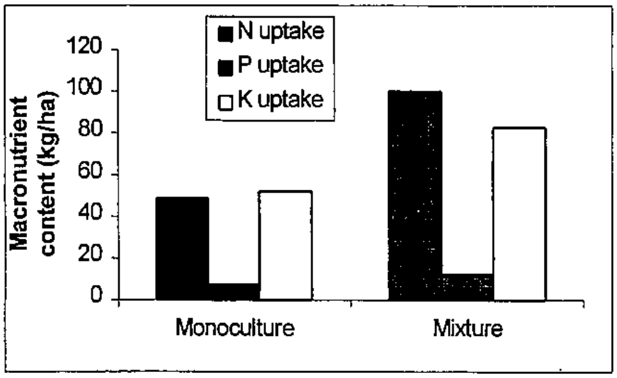


Figure 9. Total macronutrient content in plant tissue, summed over May, July and October harvests.



Nitrogen, P and K uptakes were greater for the mixture than for tall fescue alone (Fig 9). Nitrate levels in the plant tissue were consistently lower for the litter treatments. However, high nitrate concentrations were found in the fertilizer treatment, and they were at levels of concern for grazing cattle, reaching almost 7000 ppm.

Nitrogen, P and K content increased with increased litter rate, in agreement with the findings of Lucero et al. (1995). This was especially true when birdsfoot trefoil was included although the differences in content for the monoculture versus the mixture plots were not significantly different.

Of the N provided in the litter/fertilizer treatments, over 80% can be accounted for in fertilizer plots. The percentage is much lower for the litter plots (Table 5). Slow break down of litter in the spoil due to dry conditions could account for the lower uptake of nutrients by the forage species.

Summary

•Forage yield was greatly affected by litter/fertilizer treatment and by moisture availability.

•Inclusion of legume also had a positive effect on yield and reduce the weed percentage in the stand.

Table 5. Percentage of total amount of macronutrients applied in 1999 as litter/fertilizer recovered in vadose water or by plant uptake.

	Nitrogen		Phosphorus		Potassium
	Vadose Water	Crop Uptake	Vadose Water	Crop Uptake	Crop Uptake
	%				
9 Mg/ha PL	N/A	22.3 (7.0)*	N/A	5.7	26.2
18 Mg/ha PL	2.8	14.7 (7.6)*	8.7	4.7	12.8
27 Mg/ha PL	N/A	15.0 (8.2)*	N/A	4.8	21.0
Fertilizer	25.5	67.7 (64.4)*	N/A	N/A	N/A

*Represents N amount taken up in monoculture plots.

•High rates of poultry litter reduced legume proportion in tall fescue/birdsfoot trefoil mixtures.

•Fertilizer NH_4NO_3 had a significant effect on the NO3 concentration in vadose water while poultry litter had an effect on the amount of PO_4 found in vadose water.

•Much of the N applied in fertilizer can be accounted for while very little in the litter treatments.

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