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Agriculture and Natural Resources

Using Bermudagrass Forage Systems to Mine Phosphorus from High Soil-Test Phosphorus Soils

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Introduction

In Arkansas, many pasture soils have excessively high levels of phosphorus (**P**) because of repeated applications of poultry litter or other animal manures. Recently, this situation has received increased attention because P in surface runoff from these pastures can contribute to the eutrophication of lakes, rivers and reservoirs. Phosphorus is generally considered to be the limiting nutrient in the eutrophication of streams and lakes, and small increases in the concentration of P in the water can result in excessive algae growth.

Soil-test P (**STP**) at sites amended with broiler litter or other manures tends to increase rapidly when these pastures are grazed continuously. This occurs because most of the P within the grazed forage is recycled onto the pastures by grazing ruminants. Under this type of management, P is removed from the site primarily within the body of marketed animals. Unfortunately, there are only about 3.4 pounds of P within the body of a weaned 500-pound calf (Ball et al., 2002). Even if two calves per acre are harvested annually, this would only amount to an annual P removal of about 7 pounds/year. Generally, broiler litter contains about 27 pounds P/ton (Table 1), and application rates of two or more tons/year are very common. There is a positive P balance in the soil of 47 or more pounds P/year, and STP levels escalate quickly.

Another factor that contributes to the buildup of P in the soil is the use of litter or animal manures to meet the nitrogen (**N**) requirements of forage plants. Traditionally, this has been the basis for recommended application rates. Litter (or other animal manures) applied on this basis will contain more P than is needed to support maximum forage production and, consequently, P accumulates in the soil (Table 2). Several key concepts should be evident from Table 2. Forages contain much higher concentrations of N (and also K) than P. This creates a greatly imbalanced demand to meet requirements for growth. Applying litter to meet only the P needs of the forage will create a large N deficit that must be made up with commercial fertilizer sources

Table 1. Average Nutrient Values for Manure Samples Collected From Arkansas Producers

Manure Type	N	P_2O_5	P	K	Units
Broiler litter[1]	59	61	26.6	45	lbs/ton
Dairy manure[2]	6	4	1.8	---	lbs/1000 gal
Swine manure[2]	14	13	5.7	---	lbs/1000 gal

[1] Based on 1,705 producer samples submitted to the University of Arkansas Agricultural Diagnostics Laboratory in 2002-03.
[2] Data obtained from Daniels et al. (1998).

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Table 2. Examples of Litter Required to Provide Adequate N and P Relative to that Removed Within the Hay (Data illustrates the mechanism for accumulation of P in soils when litter is applied to meet N requirements for growth.)

Nutrient	Forage	Average DM Yield[1]	Nutrient Concentration in Hay[2]	Total Nutrients Harvested Within Hay	Broiler Litter Required for Zero Balance[3]	Excess P	N Deficit
		tons/acre	%	pounds/acre	tons/acre	pounds P/acre	pounds N/acre
N	Bermudagrass	4.0	1.98	158	3.6[4]	74	---
	Fescue	3.5	1.79	125	2.8	54	---
	All hays	3.1	1.92	119	2.7	54	---
P	Bermudagrass	4.0	0.28	22	0.8	---	111
	Fescue	3.5	0.30	21	0.8	---	78
	All hays	3.1	0.29	18	0.7	---	78

[1] Based on Ball et al. (2002).
[2] Percentages taken from Davis et al. (2002).
[3] Based on values taken from Table 1.
[4] Number is inflated to account for 25% volatilization of N compounds after spreading. No other adjustments are made for mineralization, denitrification, leaching, etc.

containing no P. This creates an additional expense for the producer, greatly limits the amount of litter that can be distributed on any given land area and may result in additional hauling and/or removal costs.

For these reasons, many soils in Arkansas already contain excessively high levels of STP. Some states have established or are considering the establishment of arbitrary threshold limits for application. One arbitrary limit that has been debated for Arkansas is 300 pounds P/acre, as determined by Mehlich III extraction. With this type of regulation, producers may not be allowed to use animal manures as soil amendments when STP exceeds the arbitrarily established threshold limit. In cases where STP is already high, one long-term technique that can be used to reduce these levels is removing all forage harvested at the site as hay or silage (mining). Unlike grazing situations, hay or silage produced on these sites can be removed to other locations for feeding, preventing the recycling of P onto the same site. This approach can also be an effective way to redistribute P loads from high STP areas to P-deficient soils. Unfortunately, this is not a quick-fix solution, but requires diligence over a period of many years to meet the desired goals of the producer.

Previous Work

An Arkansas Cooperative Extension Service project conducted in Washington, Pope and Howard counties has been reported previously (Sandage and Kratz, 1999; Table 3). Three producer sites with existing sods of bermudagrass and high STP were fertilized with commercial sources of N fertilizer at a rate of about 150 pounds N/acre annually and harvested as hay throughout the summer months. Winter annuals (wheat and/or annual ryegrass) were sod-seeded in the fall, grazed throughout the late-fall and early-winter and then harvested as hay in the late-spring. All hay produced was removed to a low STP site for feeding. Levels of STP on these high STP sites were reduced by an average of 119 pounds/acre over the three-year study or an average of about 40 pounds/acre/year. Phosphorus chemistry in the soil is complex. It should be emphasized (for a variety of reasons) that there is not necessarily a 1:1 relationship between the P removed within the hay and the amount that STP is reduced each year.

Table 3. Summary of Reductions in Soil-Test P (STP) Between 1995-1998 in Grid Samples Taken From Producer Sites With High STP in Washington, Pope and Howard Counties (adapted from Sandage and Kratz, 1999)

Site	Fall 1995	Fall 1996	Fall 1997	Fall 1998	Total Reduction	Change Per Year
	- - - - - - - - - -	- - - pounds P/acre	- - -	- - - - - - - - - -		pounds P/acre/year
Washington	292	268	283	205	-87	-29
Pope	521	456	415	414	-107	-36
Howard	389	270	272	227	-162	-54
Overall Average	401	331	323	282	-119	-40

Ballard Creek Project

Overview

The concept of mining P from the soil with harvested forages was investigated further as part of the Upper Ballard Creek Watershed Education Project on two producer sites (A and B) in Washington County that already had high levels of STP (572 and 306 pounds P/acre, respectively). Each site had an existing stand of common bermudagrass. Site B had been fertilized with broiler litter over the years, while caged layer waste had been used at Site A. In this project, ammonium nitrate was split-applied at annual rates of 0, 50, 100, 150, 200, 250 and 300 pounds N/acre as shown in Table 4. Application of ammonium nitrate was timed during late-April and after the second hay harvest. A summary of annual DM yield, concentration of P in the forage, and P removal for Site A in 2000-2001 and for Site B in 2000 are presented in Tables 5 and 6, respectively. Several key concepts are immediately illustrated:

1) There were differences in soil fertility between the two sites; DM yields at Site A were substantially higher than observed at Site B. This limited P removal at Site B to roughly 60 percent of that at the more fertile Site A, and supports the established principle that P removal is driven primarily by DM yield.

2) Bermudagrass is widely known to be highly responsive to N fertilization, and yields of DM were clearly increased by N fertilization at both sites.

3) Concentrations of P in bermudagrass forage are low, which clearly limits the potential for P removal within the harvested hay. Maximum annual P removal within the bermudagrass hay was about 45 and 27 pounds P/acre at Sites A and B, respectively.

4) Concentrations of P in the bermudagrass forage decreased with N fertilization at both sites. Unfortunately, much of the potential for P removal that was gained through aggressive N fertilization and the subsequent production of additional DM was negated by decreasing concentrations of P in the forage.

5) **On a practical basis, P removal generally leveled off at annual fertilization rates of about 150 pounds N/acre, suggesting that 150 pounds N/acre is an optimum N fertilization rate for promoting P removal. Therefore, typical good forage management practices may optimize P removal. More aggressive N fertilization may increase DM yield but may not offer much benefit for P removal.**

Relationship Between DM Yield and P Removal

Historically, scientists have believed that P removal was primarily driven by DM yield because P concentrations in forages are relatively low. They do not generally vary substantially, either within or across forage species. Data collected from the Ballard Creek Project supports this concept within a broad context. DM yields at Site B were (on average) only about 66 percent of those at Site A, and the associated P removal was only about 60 percent of that observed at the more fertile site. However, closer inspection of the Ballard Creek data indicates that the mechanism for maximizing P removal from bermudagrass hay fields may be more complex than simply maximizing DM yield. Figures 1 and 2 illustrate the relationship between concentrations of P in the harvested hay and the most recent application rate of N fertilizer for harvests taken before and after July 15. At both sites, concentrations of P were stable in response to N fertilization before July 15, but declined noticeably in harvests taken after July 15.

Phosphorus is relatively immobile in the soil compared to the other macronutrients (N and K); therefore, plant uptake of P depends largely on root penetration through the soil, particularly near the soil surface. Droughty conditions, which are more likely during late summer, can reduce penetration and depth by new roots. In addition, surface roots may dry out and lose function under these stressful conditions. Therefore, the effective uptake of P can be limited considerably by droughty soil conditions.

From a P-mining perspective, a stable concentration of P in the hay is desirable because P removal is then driven entirely by DM yield. However, it appears that late-summer applications of N fertilizers may not be as effective at driving P removal as those made early in the growing season. More research work is clearly needed to identify best management practices for situations where the primary producer objective is efficient P removal.

Effects on STP

When the Upper Ballard Creek Watershed Education Project was initiated in April 2000, levels of STP at Sites A and B were 572 and 306 pounds P/acre, respectively. Throughout the project, there

Table 4. Application Scheme for Fertilization of Bermudagrass with Ammonium Nitrate (34-0-0) at the Sites A and B During 2000 and at Site A in 2001

Total N Applied[1]	First Application[2]	Second Application[3]
--------------------------- pounds N/acre ---------------------------		
0	0	0
50	50	0
100	50	50
150	100	50
200	100	100
250	150	100
300	150	150

[1] Total application for the entire growing season.
[2] April 28, 2000, and April 25, 2001.
[3] July 19, 2000, and August 29, 2001.

Table 5. Effects of N Fertilization on DM Yield, Concentrations of P and Total Removal of P in Bermudagrass Harvested at Site A Near Lincoln, Arkansas, During 2000 and 2001

Fertilization Rate	DM Yield	P	P Removal
lbs N/acre/year	lbs/acre/year	% of DM	lbs P/acre/year
0	7,253	0.49	32.9
50	8,031	0.49	37.2
100	9,127	0.45	38.7
150	10,359	0.43	42.0
200	11,436	0.42	45.3
250	11,379	0.42	44.5
300	11,677	0.42	44.6

Table 6. Effects of N Fertilization on DM Yield, Concentrations of P and Total Removal of P in Bermudagrass Harvested at Site B Near Lincoln, Arkansas, During 2000

Fertilization Rate	DM Yield	P	P Removal
lbs N/acre/year	lbs/acre/year	% of DM	lbs P/acre/year
0	4,533	0.39	17.9
50	5,197	0.41	21.0
100	6,495	0.36	24.3
150	6,399	0.38	24.9
200	7,064	0.33	23.6
250	7,648	0.34	26.7
300	8,688	0.29	25.4

Figure 1. Concentrations of P in Bermudagrass Forage Harvested From Site A Before and After July 15

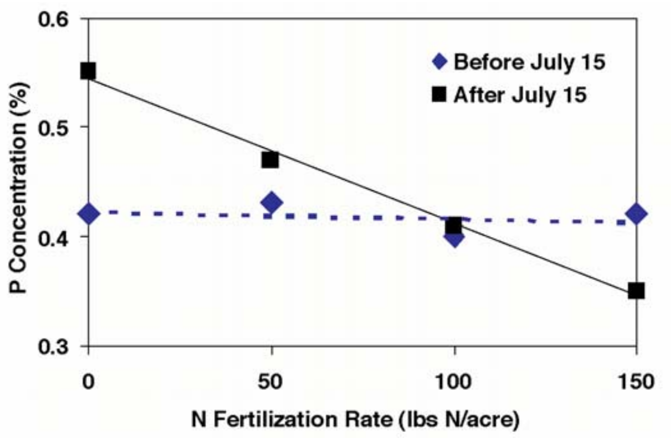


Figure 2. Concentrations of P in Bermudagrass Forage Harvested From Site B Before and After July 15

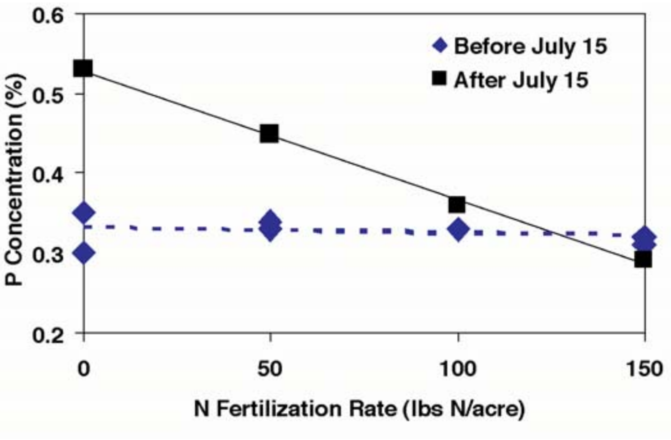
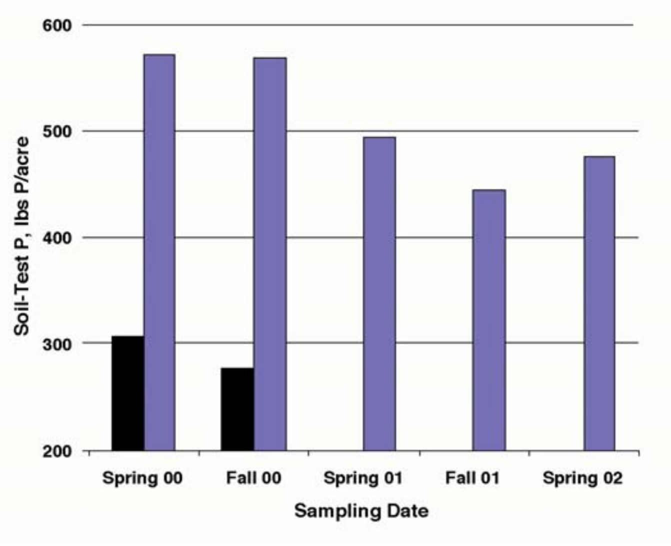


Figure 3. Reduction of Soil-Test P Over Time at Sites A (gray bars) and B (black bars) for the Upper Ballard Creek Watershed Education Project. Data was collected at Site B during 2000 only.



was no obvious relationship between N fertilization rate and levels of STP; however, the average STP of all N fertilization levels fell at both sites over time (Figure 3). Data from Site B were collected for 2000 only, but between April and November of that year, STP fell by about 30 pounds P/acre. At Site A, STP fell by 96 pounds P/acre between April 2000 and March 2002, or an average of just under 50 pounds P/acre/year. It should be pointed out that neither of these sites was irrigated, and weather conditions in both 2000 and 2001 permitted only three harvests per year. With irrigation, or in years with good soil moisture throughout the summer, additional P removal and reduction of STP may be possible.

Cautions

Unlike P, bermudagrass contains high concentrations of potassium (**K**). The statewide average for hay samples submitted to the University of Arkansas Agricultural Diagnostics Laboratory is 1.89 percent, which is between six and seven times greater than the 0.28 percent reported for P (Davis et al., 2002). Because of the high concentrations of K in bermudagrass hay, K is mined from the soil at a much faster rate than P, and levels of soil-test K (**STK**) can be depleted rapidly. This is illustrated by data obtained during one year (Spring 2000 to Spring 2001) from Site A of the Ballard Creek Project (Table 7). Oftentimes, soils that have received repeated applications of broiler litter or other animal wastes will have high levels of STK. This was true for Site A in April 2000. The average initial STK over all N fertilization rates was 496 pounds K/acre, which exceeded the level recommended by the Arkansas Cooperative Extension Service for high production (400 pounds K/acre). However, STK fell to an average value of 361 pounds K/acre by November 2000 and to 307 pounds K/acre by April 2001. After only one year of continuous hay production, levels of STK had fallen well below those recommended for high production, and supplemental fertilization with K would have been required to maximize hay production. An application of 60 pounds potash/acre would be recommended in the spring, followed by additional applications of 80 to 100 pounds of potash/acre after every other hay cutting throughout the summer (Chapman, 1998). Bermudagrass has a critical need for K, which is particularly important with respect to winter hardiness. Bermudagrass stands managed by continual fertilization with commercial N sources but without any attention to STK levels are prime candidates for winterkill and other problems. Any N or K fertilization should be with commercial sources of N and K that contain no P. Commercial blends, such as "triple 13" (13-13-13), contain P and should not be used when P mining is an important producer objective.

Other Considerations

Concentrations of Phosphorus in Other Crops

The process of mining or removing P from the soil with continuous hay or silage production is slow, largely because concentrations of P in forages are very low. An obvious question is whether there is some specific forage crop that has concentrations of P that are inherently higher than those observed in most other forages. Although there is some variability among forages, concentrations of P are very low in all forages. The mean value of 1,006 hays of all types grown in Arkansas between 1985 and 1999 was only 0.29 percent (Table 2; Davis et al., 2002). Therefore, there is no real "super" P accumulator, and progress can be made only by perseverance and patience over a period of years.

Using Winter Annuals

When the base sod of the pasture or hay field is bermudagrass, the potential exists for overseeding with winter annuals in order to increase forage production per unit area and increase P removal.

Table 7. Levels of Soil-Test Potassium (K) on Three Dates in Response to N Fertilization and Continuous Hay Production (Three Harvests) at Site A in 2000

N Fertilization Rate	DM Yield 2000	Soil-test K (Spring 2000)	Soil-test K (Fall 2000)	Soil-test K (Spring 2001)
pounds N/acre	pounds/acre	- - - - - - - - - - - - - - - - - - -	pounds K/acre	- - - - - - - - - - - - - - - - - - -
0	9,692	511	370	325
50	10,310	506	375	306
100	11,198	442	367	293
150	11,684	480	343	318
200	12,467	524	350	316
250	12,564	495	347	301
300	12,532	514	372	291

Experiments were conducted at the Texas A&M Research and Extension Center at Overton, Texas (Evers, 2002), to evaluate DM yield and P removal from a bermudagrass/annual ryegrass forage system. In late October of each year, annual ryegrass was overseeded into a field of 'Coastal' bermudagrass, and broiler litter was applied at a rate of 4 tons/acre. Additional fertilizer N was applied as ammonium nitrate (34-0-0) in 50-pound N/acre units to maximize forage production in the system (Table 8). Averaged over all fertilization schemes, annual ryegrass accounted for about 67 percent of the annual P removal by the forage system. The use of winter annual crops offers considerable potential for increasing P removal. The removal of P was especially improved when N fertilization was timed to benefit production of annual ryegrass. With this management, the maximum P removal for the annual ryegrass component of the system was 35 pounds P/acre. In this study, droughty conditions limited both the production of bermudagrass forage and the associated removal of P during the summer months.

Producers interested in using winter annuals to mine additional P from high STP soils should be advised that annual ryegrass may persist deeper into the summer than other winter annual grasses. Frequently, this reduces the initial late spring growth of bermudagrass via shading. If bermudagrass hay production for cattle feed or for cash sale is a critical producer need, other winter annuals may be better choices. These choices include cereal rye or wheat that can be removed earlier in the spring with little or no subsequent potential for regrowth.

Summary Concepts

1) Surface runoff from pastures fertilized with broiler litter or other animal manures contributes to eutrophication of streams, lakes and reservoirs.
2) Phosphorus accumulates quickly in the soil when repeated applications of broiler litter or other animal manures are made to pastures that are grazed routinely compared to those that are hayed regularly. Similar problems can occur when litter or other manures are applied to meet the N needs of forages for growth.
3) Concentrations of P in all forages are very low (the state average for all hays is 0.29 percent), and mining P from high STP sites via continuous hay production will require patience and diligence.
4) During the mining process, do not apply commercial sources of N and K fertilizers that contain P.
5) Make sure all hay or silage harvested from the high STP site is fed on other (low STP) sites or sold.
6) Results from the Upper Ballard Creek Watershed Education Project suggest that P removal from bermudagrass hay is generally not increased at annual N fertilization rates greater than 150 pounds N/acre. Fertilization at higher rates may improve DM yield, but it is not likely to improve P removal because concentrations of P in the hay tend to decline with N fertilization.

Table 8. Dry Matter Yield and P Removal in a Bermudagrass/Ryegrass Forage System with Broiler Litter Applied at a Rate of 4 Tons/Acre/Year and Additional N Fertilizer Applied in 50-Pound N/Acre Units to Maximize Forage Production During 1999-2000 (Evers, 2002)

Additional Ammonium Nitrate (34-0-0)	Application Dates	DM Yield			P Removal		
		Ryegrass	Bermuda	Total	Ryegrass	Bermuda	Total
pounds N/acre	month	- - - - - - - pounds/acre - - - - - - -			- - - - - - - pounds P/acre - - - - - -		
0	---	4,197	3,778	7,975	25.3	12.7	38.0
50	Dec	5,417	3,858	9,275	30.4	12.7	43.1
50	Mar	5,328	4,277	9,605	29.1	12.9	42.0
50	May	4,134	4,963	9,097	23.4	15.4	38.8
50	July	4,125	4,883	9,008	23.2	14.2	37.4
100	Dec, Mar	6,397	4,179	10,576	35.0	12.1	47.1
100	May, July	4,571	5,159	9,730	25.9	14.9	40.8
100	Mar, May	5,898	4,927	10,825	32.8	13.8	46.6
150	Mar, May, July	5,916	6,023	11,939	32.6	16.6	49.2
200	Dec, Mar, May, July	6,094	5,711	11,805	33.4	15.5	48.9

7) The use of commercial N fertilizers to drive DM yield and P removal is probably more efficient early in the growing season because concentrations of P in the forage tend to be more stable. Late in the summer, forage P concentrations may decline sharply with N fertilization.

8) With good forage management practices, bermudagrass can reduce STP by 40 pounds/acre/year or more. Greater reductions may be possible if the site is not drought prone or if irrigation is available.

9) Levels of STK will fall rapidly with continuous bermudagrass hay production. Monitor levels of STK closely, and apply K as recommended by soil test. Do not use sources of K that contain P.

10) Some studies with bermudagrass/annual ryegrass forage systems indicate that significant additional P removal can occur if annual ryegrass or other winter annuals are overseeded into the base bermudagrass sod in the fall. Winter annual forages can then be harvested as hay or silage in the spring and fed on other low STP sites or sold. **Grazing winter annuals may provide excellent winter and spring forage for livestock with high nutrient demands, but this approach will not help with P removal because the livestock will recycle the P in these forages back onto the same pastures.**

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