Phytoremediation of Excessively High Phosphorus Soils and Subsequent Reduced Phosphorus Runoff into the North Bosque River

TSSWCB Project 04-10

Final Report

Prepared by:
Dr. Jim Muir, Professor, Texas AgriLife Research and Extension Center at Stephenville
j-muir@tamu.edu, (254) 968-4144

Funding provided through a Clean Water Act §319(h) Nonpoint Source Grant from the Texas State Soil and Water Conservation Board and the U.S. Environmental Protection Agency

Executive Summary

The goal of this effort was to develop and demonstrate techniques that use plants to sequester or remove the maximum amount of soil phosphorus (P) of dairy manure origin. Forages can contribute to dairy phosphorus cycles in two ways: recycling and sequestration. Our goal was to see which forages and combinations of forages could maximize these actions, thereby reducing soil phosphorus available for runoff into surface waters. These techniques will reduce surface water contamination in the North Bosque and Leon Rivers from soil-applied P of dairy manure origin and should be applicable to other animal feeding operations (AFO) and concentrated animal feeding operations (CAFO) throughout the country. To accomplish this three dairies were recruited in these watersheds and conducted demonstrations with the full cooperation and guidance of these operations, including dairy field days and practical guides. We focused on three general aspects as we sought phytoremediation tools: Soils, Forages and Vegetative Buffer Strips.

There are two stories to tell in the soils arena. First, soil phosphorus (P) concentrations on dairies are not evenly distributed. Dairy waste phosphorus is more evenly distributed on forage fields in north-central Texas feedlot dairies than they would be on pasture-based dairies where cow feces are concentrated in paddies. In feedlot situations, manure is spread mechanically via manure spreaders or effluent pivots, resulting in more even distribution. Concentrations can vary up to 100 ppm from acre to acre in a single field. This has far-reaching implications on how to mitigate P concentrations in surface water runoff, plans for future manure-P application, as well as how and where soil samples should be taken by regulatory agencies when determining soil-P concentrations. The second story is that not all soils within Erath County are equal when it comes to sequestering P and dairies are not always located on the most promising P-holding soils. This finding may come too late for dairies that are already built, but can guide the selection of future dairy sites and manure application fields not only in this region but elsewhere in the nation.

The demonstrations conducted through this effort indicated that cool-season annual forages can extract from 6-38 lbs/acre per growing season, depending on rainfall and soil preparation. At the higher end, this equates roughly to 8,800 lbs dry manure, twice what the average dairy cow produces per year. In addition, cool-season annual forages can sequester from 7-260 lbs P/acre/growing season, depending on rainfall and soil preparation. At the higher end, this equates roughly to 28,600 lb dry manure. There is a trade-off, however, in late winter annual forage P extraction and early spring bermudagrass (Tifton 85 & Coastal) P extraction. Selection of precocious cool-season forages that mature earlier in the spring can circumvent this competition. The two most commonly used warm-season forages are both bermudagrasses: Coastal and Tifton 85. Tifton 85 extracts an average 32 lbs P/acre/year (0.25% P in forage) whereas Coastal extracts 32% less (0.21% P in forage). Because Tifton 85 is also of greater nutritive value to cows and grows later into the cool season, the advantages of cultivating this over Coastal for both milk production and P recycling are obvious. The take-home message from these efforts is that the dairymen must choose their forage carefully based on what year-round system they seek, what nutritive value is important, when peak production matters most

and, last but not least, which species combine yields and P concentrations to maximize soil-P removal and minimize cost.

The use of Vegetative buffer strips to reduce runoff P by slowing runoff and soil transport were demonstrated in this project. Vegetative cover protects soil from raindrop impact and surface runoff from fields above the strips. Cover types used in this project sequestered on average 10 lb P/acre as compared to 7 lb P for the residual cover type, a 41% increase in P sequestration. Again, choice of species within the strip is all-important. This choice is influenced not only by which species sequester or stabilize the most P but also what additional uses the buffer can offer the landowners. The choice of natives versus exotic plant species, diverse versus monocultures, bunch versus turf type grasses, seed production, and many other factors enter into the equation each land manager must consider when he/she sets P sequestration value along side other considerations such as forage production, plant community stability, wildlife use, fire breaks, and the other income sources to be considered from vegetative buffer strips.

The economic analysis indicates that there is a cost to increasing phytoremediation capacity of forage systems on dairies in north-central Texas. The best option for decreasing land area requirement (LAR) per lactating cow is to over-seed dormant winter Tifton 85 bermudagrass fields (the most common forage used today on dairies in north-central Texas) with cool season legumes. Arrowleaf clover, for example, will increase LAR or phytoremediation (P removal) efficiency by 36%. However, the additional forage produced during the winter does not compensate for the cost of cultivation and the loss of spring bermudagrass production; over-seeding with arrowleaf clover ends up costing dairymen 10% more than they would spend cultivating and harvesting only Tifton 85 during the summer months. Increasing P removal by intensifying forage production can be accomplished in north-central Texas but only at a cost to dairymen.

Introduction

The goal of this project was to develop and demonstrate remedial best management practices (BMP) for both abandoned and currently used dairy waste (manure, effluent, and compost) application fields that will reduce soil P levels. These BMPs should provide the tools with which dairy operators or their consultants can harvest soil-P in amounts equal to or greater than that contained in dairy waste applied to fields without risking soil-P buildup. Regardless of whether soil-P on dairy crop fields increases, maintains, or decreases, there is an urgent need to intercept P-rich runoff from these fields by establishing permanent vegetation buffer strips between tilled soils or permanent forages and the streams, rivers, lakes or other surface waters receiving runoff.

Year-round forage systems that extract plant available P from soils can reduce, recycle, and stabilize excess P in Windthorst soils (the predominant sandy loam used for growing forages in north-central Texas). Developing and promulgating these crop systems involves maximizing land-occupation time (compatibility of winter and summer crops) and finding species whose high yields and herbage-P concentrations combine to export the greatest possible amount of soluble soil-P. Dairies have mostly gone to perennial summer bermudagrass pastures and, where the option exists (IE new pastures). Tifton 85 is the cultivar of choice due to its higher nutritive and yield value. When developing year-round forage systems that maximize P recycling, we need to use Tifton 85 as the base and seek out annual cool-season forages that can be over-seeded into these pastures as they become dormant in late autumn.

The goal is to develop and demonstrate year-round forage systems that can reduce P loads on cropping land that soon will or already exceeds safe levels of plant-available P on the North Bosque and Leon River drainages. Until soil-P levels are brought down to acceptable levels, vegetative buffer strips can serve as BMP to intercept most runoff P. These solutions have to be cost-effective and acceptable to ensure implementation. Widespread implementation of these forage systems will promote sustainability of the vibrant dairy industry in north-central Texas and improve environmental quality of surface water.

Tasks

Task 1: Document/demonstrate a measureable rate of P removal via forages from crop fields with histories of excessive dairy waste application.

Subtask 1.1: Locate three crop fields that have an excess of 200 ppm plant-available P due to historical applications of dairy wastes, and measuring all components (both stable and plant-available) of P in the soil.

The project recruited two dairies in the Bosque River watershed and one in the Leon River watershed on which to develop and demonstrate BMPs. As part of the agreement to cooperate with this project, these dairies and their location will remain anonymous.

The spatial variability of soil test P (STP) was examined on the three cooperating dairies using soil sample analyses and historical manure/effluent application information. The dairies were divided into a hypothetical sampling grid of 0.4 ha areas with four sample points equally spaced around the grid. Surface soil samples (0-12 cm) were collected from each sample point and composited into one sample per acre. Soil test P was analyzed using Mehlich-3 extractant. Environmental P, also called runoff P, was measured.

High STP levels were observed with values ranging from 19 mg kg^{-1} to 3446 mg kg^{-1}. Water soluble P ranged from 2 mg kg^{-1} to 317 mg kg^{-1}. Interpolated maps (see Figs. 1 & 2) clearly show higher P levels around the effluent application areas and barns. Lower P levels were observed in vegetated areas and buffer strips. Phosphorus levels also varied with soil types and management practices. Sixty-six percent of the samples from these dairies produced a STP value of more than 200 mg kg^{-1} P. Areas with more than 500 mg kg^{-1} P were identified across the dairy landscape. Further data also is needed to establish environmental threshold levels for water soluble P (WSP) which more accurately reflects the potential for P runoff from dairy lands. Similarly, current sampling intensity used for monitoring and management of P on diaries deserves further attention. Information gathered from this effort will undergo further examination in an attempt address the question of sampling and monitoring intensity. A post-project manuscript related to this, *Application of Statistical Sampling Methods to Soil Phosphorus Data from North Central Texas Dairies,* is being drafted.

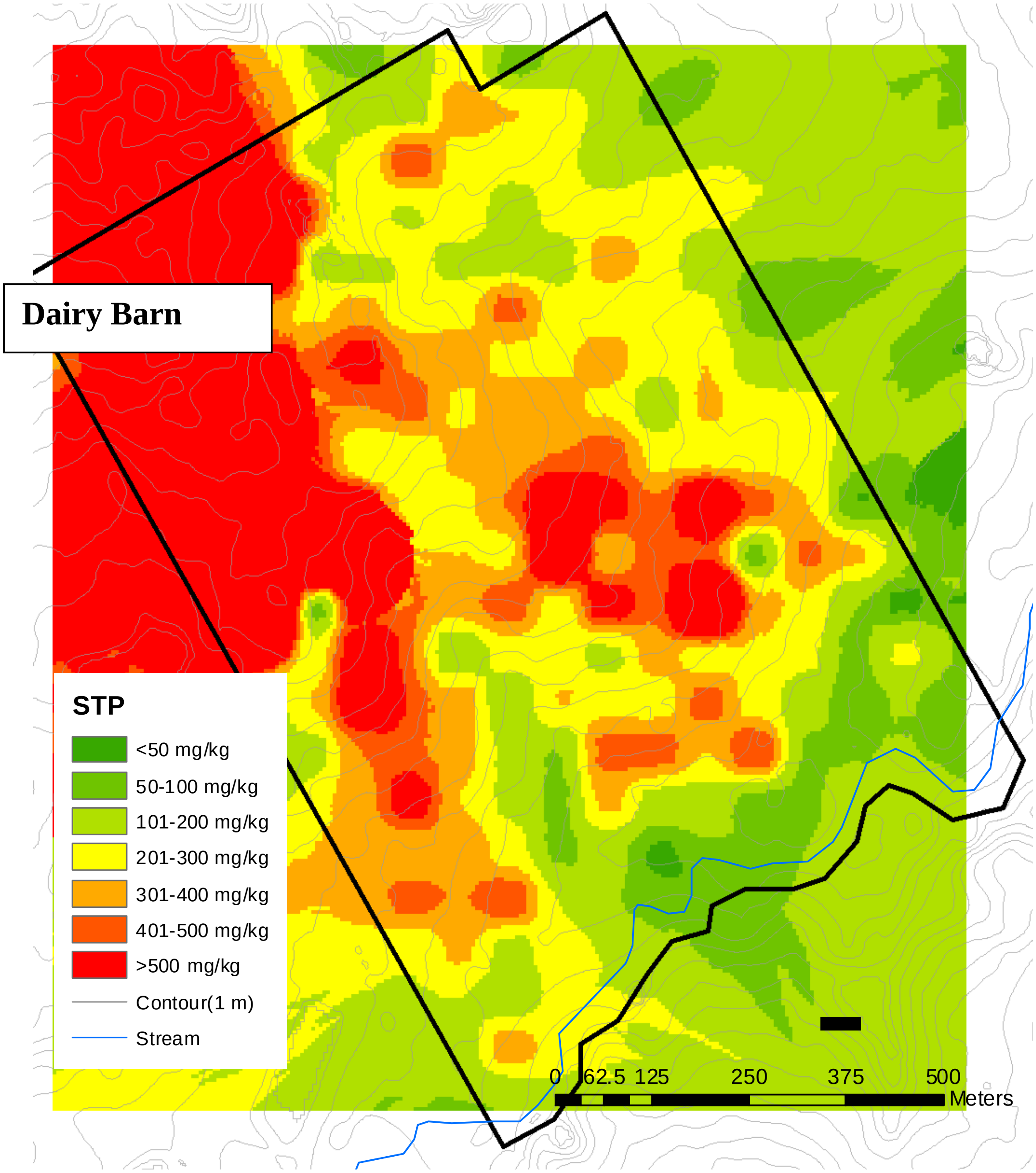

Figure 1. Example of spacial variability of total soil-P (STP) concentrations on a dairy.

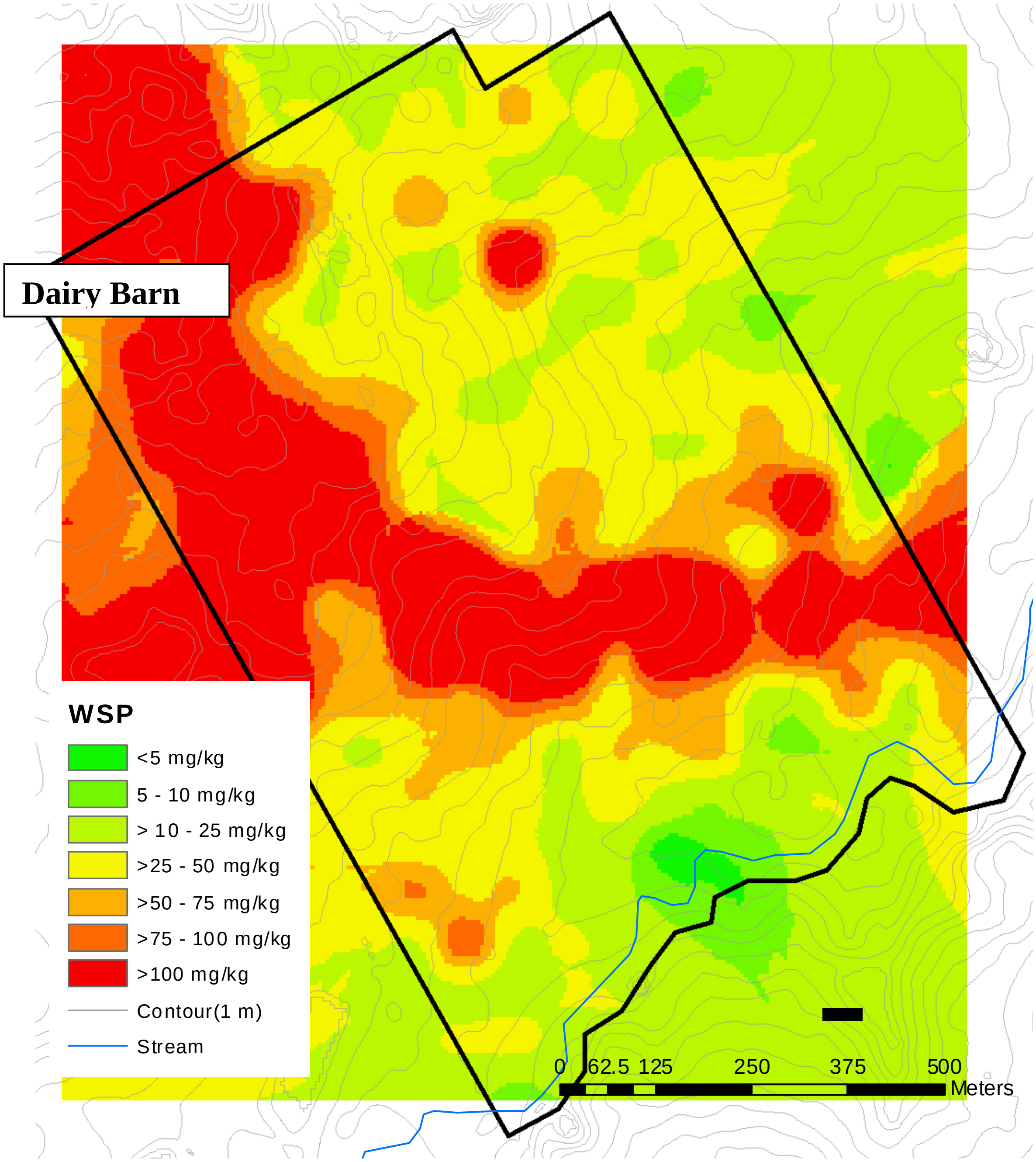

Figure 2. Spacial variability of water-soluble soil-P (WSP) concentrations on the same dairy.

Subtask 1.2: Determine optimal season length and P-extraction potential of cool season winter grasses and legumes on small plots by measuring both forage yields and P concentrations.

Tables 1 and 2 demonstrate a point that was quickly uncovered: most older, well-established bermudagrass fields already had volunteer cool-season grasses, mostly annual ryegrass and brome. Over-seeding them with additional annual forages did not necessarily increase winter forage production, and consequently did not increase P removal, unless they were recently established (relatively weed free) or the dairymen routinely used herbicides to control annual cool-season "weeds". Most dairymen took a more pragmatic approach: harvest the volunteer crop for green chop and allow the annuals to self-reseed.

That said, however, the over-seeding did extract greater amounts of P in some of the fields, namely the cultivated (plowed) fields that were left fallow (not as widespread a practice as 10 years ago) and dormant bermudagrass pastures where annual "weeds" had been suppressed. The rates were greatest on fallow cultivated land (Table 1) where high forage yields translated into P removal rates of up to 42 kg ha^{-1} (38 lbs P $acre^{-1}$), depending on the year. This is the equivalent to the P contained in roughly 8-10 Mg (17,600-22,000 lbs) of aged drylot scrapings. Some entries were nowhere as effective at removing P as others, usually because of low yields due to low rainfall or poor species adaptation. These extraction rates varied from 14-31 kg P removed ha^{-1} $year^{-1}$ on dormant bermudagrass pastures (Table 2, 3, 4) depending again on rainfall and adaptation.

Table 1. Phosphorus yields of annual cool-season forages grown on fallow cultivated cropland on a dairy in Erath County with a soluble soil P level of 250 ppm.

	2005	2006	2007
	----------kg P ha^{-1}----------		
Rye	AB 21.6 ab	B 15.0 a	A 38.9 a
Ryegrass	B 22.3 a	B 14.6 a	A 42.4 a
Barley	AB 22 ab	B 15.7 a	A 25.2 b
Triticale	B 16.9 abc	B 11.5 a	A 39.9 a
Oats	B 13.0 cde	B 11.4 a	A 25.3 b
Wheat	B 7.5 e	B 15.6 a	A 25.3 b
Hairy Vetch	B 16 bcd	C 2.6 b	A 21.9 bcd
Burr Medic	A 7.4 e	A 2.1 b	A 10.0 de
Crimson	A 9.4 e	B 1.7 b	A 7.4 e
Arrowleaf	A 7.4 e	A 1.3 b	A 11.3 cde
Rose	A 9.4 e	A 0.8 b	A 3.1 e
Essex rape	A 17.8 abc	-	A 24.1 bc
Turnips	A 10.6 de	A 3.0 b	A 11.7 cde

Means followed by different lower case letters within columns of the same group and preceded by upper case letters within rows differ (*P* = 0.05) according to a least significant difference multiple mean separation.

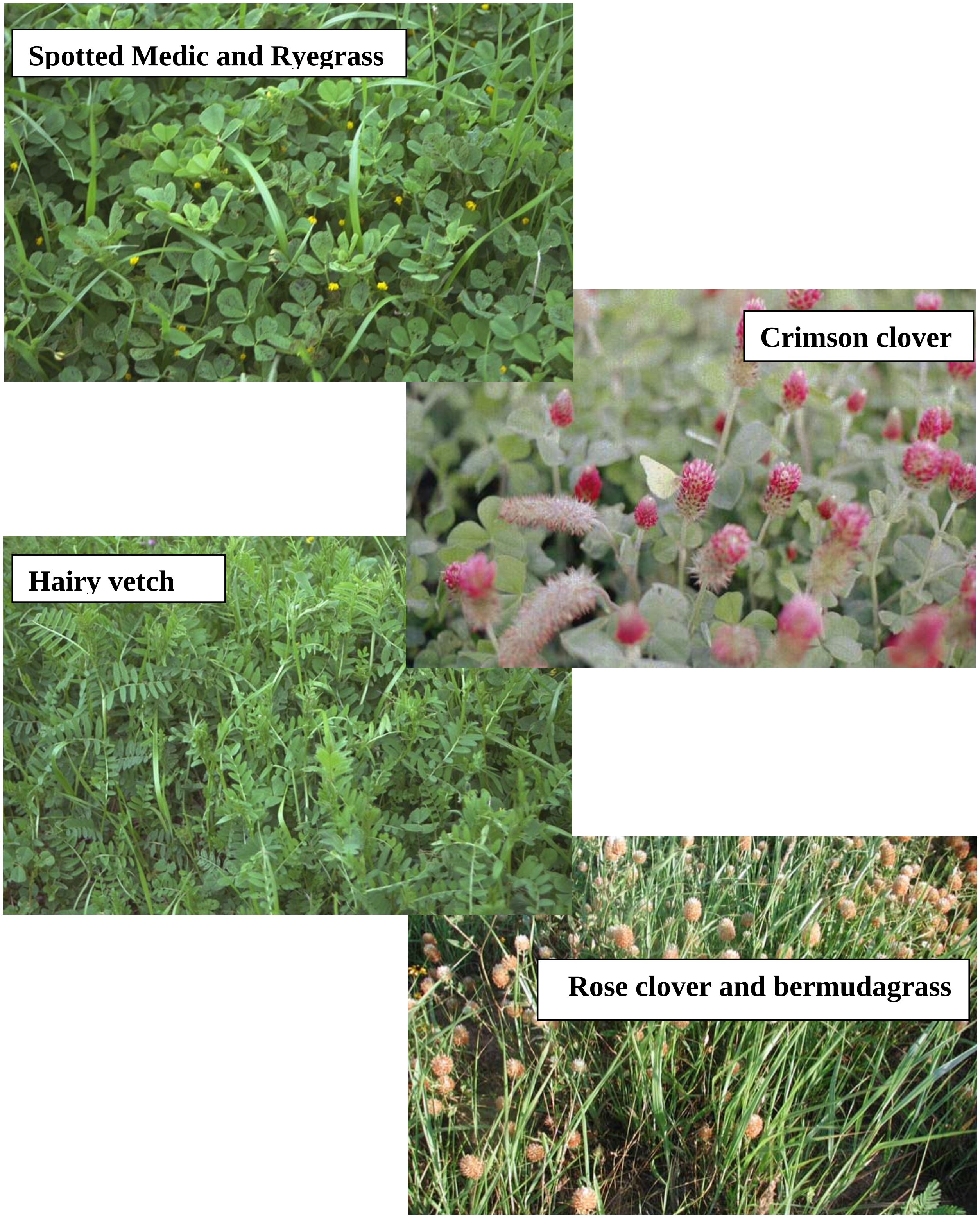

Figure 3. Crimson clover is an early growing cool season legume that interferes less with subsequent bermudagrass spring growth. Hairy vetch, by contrast, grows late into the spring and suppresses spring growth of underlying bermudagrass.

Table 2. Phosphorus yield (P removed in forage tissue), herbage phosphorus (P) concentration and herbage crude protein (CP) of different winter legumes seeded with annual ryegrass with and without N fertilizer for the 2005-06 winter season at Stephenville, TX.†

Totals	*Grass Component*			*Legume Component*			*Grass+Legume*
	P yield	Tissue P	CP	P yield	Tissue P	CP	Totals P yield
Treatment	kg ha^{-1}	%	%	kg ha^{-1}	%	%	
Winter legume:							
Crimson clover (C)	5.6	0.25	5.7	2.0	0.24	16.1	14.4
Arrowleaf clover (A)	8.6	0.21	5.0	2.7	0.27	16.5	21.8
A + C clovers	4.1	0.28	7.0	3.2	0.29	18.8	17.8
Armadillo medic	9.0	0.28	5.0	0.7	0.26	19.6	15.2
Devine medic	8.5	0.24	4.8	0.2	0.32	16.0	16.3
N Fertilizer:							
None	4.0	0.30	7.3	---	---	---	4.0
80 lb/acre	8.3	0.25	4.6	---	---	---	8.3

† Ryegrass and clovers were over-seeded on an established coastal bermudagrass field

Tifton 85 and coastal bermudagrass first cutting growth within winter forage micro-plots were measured to determine effects of over-seeding winter forages as well as to determine P extraction rates during 2005-2006 and 2006-2007. From Tables 3 and 4 it is quickly apparent that the net increase, in terms of P extraction from bermudagrass pastures over-sown with cool-season winter annuals, is negligible. Although cool season annuals do extract P during winter and spring harvests, they suppress bermudagrass regrowth in the spring sufficiently to nearly cancel out the benefit. The lost spring bermudagrass yields diminish the P extracted by the bermudagrass had it been grown with no winter/spring competition. Looking at the results from a positive perspective, however, indicates that the over-seeding of winter annuals onto bermudagrass as a forage strategy (these cool-season annuals are very high in quality and become available during a season when fresh forage availability is severely limited) will not decrease overall P extraction from the pastures.

Table 3. Effect of over-seeding winter annual forages onto dormant Tifton 85 bermudagrass.

	YEAR 1 Cool-season forages			Tifton 85			Tifton 85 1st cut
	DM Kg/ha $^{-1}$		P Kg/ha $^{-1}$	DM Kg/ha $^{-1}$		P Kg/ha $^{-1}$	% loss
Ryegrass	*2584	CDE	**10	3203	B	6	48
Barley	3857	ABC	13	2048	BC	6	67
Rye	3725	ABC	13	1637	BC	4	73
Triticale	3288	BCD	11	2000	BC	5	67
Oats	4112	AB	12	2133	BC	7	65
Wheat	3065	BCDE	8	1891	BC	6	69
Hairy Vetch	4850	A	13	1235	C	2	80
Arrowleaf clover	895	FGH	3	2194	BC	9	64
Crimson clover	2276	EDF	7	3243	B	10	47
Rose Clover	1777	EFG	5	1776	BC	6	71
Burr Medic	0	H	0	6366	A	13	-4
Turnips	394	GH	2	5103	A	10	17
Essex Rape	839	GH	4	5700	A	14	7
Control (volunteer)	2793	BCDE	6	6137	A	13	0

	YEAR 2 Cool-season forages			Tifton 85			Tifton 85 1st cut
	DM Kg/ha $^{-1}$		P Kg/ha $^{-1}$	DM Kg/ha $^{-1}$		P Kg/ha $^{-1}$	% loss
Ryegrass	3242	AB	13	1594	CD	3	54
Barley	3843	A	13	1193	D	3	65
Rye	2943	ABC	11	1372	CD	3	60
Triticale	2049	CDE	7	1639	CD	4	53
Oats	3204	AB	9	1785	CD	6	48
Wheat	2538	BC	7	1824	CD	5	47
Hairy Vetch	499	E	1	3794	ABCD	8	-10
Arrowleaf clover	210	E	1	6531	A	27	-89
Crimson clover	393	E	1	3790	ABCD	11	-10
Rose Clover	0	E	0	6511	A	21	-88
Burr Medic	627	E	3	4967	AB	10	-44
Turnips	1004	DE	4	3970	ABCD	8	-15
Essex Rape	170	E	1	4316	ABC	10	-25
Control (volunteer)	0	E	0	3456	BCD	8	0

Table 4. Effect of over-seeding winter annual forages onto dormant Coastal bermudagrass. Year 1 had greater rainfall.

YEAR 1	Cool-season forages			Coastal			Coastal 1st cut
	DM Kg/ha $^{-1}$		P Kg/ha $^{-1}$	DM Kg/ha $^{-1}$		P Kg/ha $^{-1}$	% loss
Ryegrass	10655	A	41	942	DE	2	70
Barley	9219	B	36	1960	BC	6	37
Rye	7455	C	29	2645	AB	7	15
Triticale	8368	B	33	1711	BCD	4	45
Oats	7807	C	31	1932	BC	6	38
Wheat	7748	C	31	1810	BCD	5	42
Hairy Vetch	1021	F	4	720	E	1	77
Arrowleaf clover	31	F	0	1028	CDE	4	67
Crimson clover	273	F	1	1689	BCD	5	46
Rose Clover	59	F	0	657	E	2	79
Burr Medic	89	F	0	2251	AB	5	28
Turnips	844	F	4	2110	B	4	32
Essex Rape	2283	E	10	2121	B	5	32
Control (volunteer)	5234	D	20	3112	A	7	0

YEAR 2	Cool-season forages			Coastal			Coastal 1st cut
	DM Kg/ha $^{-1}$		P Kg/ha $^{-1}$	DM Kg/ha $^{-1}$		P Kg/ha $^{-1}$	% loss
Ryegrass	314	NS	1	999	NS	2	12.6
Barley	1335	NS	5	1071	NS	3	6.3
Rye	356	NS	1	1091	NS	3	4.6
Triticale	146	NS	1	1249	NS	3	-9.3
Oats	280	NS	1	1083	NS	4	5.2
Wheat	1343	NS	5	1082	NS	3	5.3
Hairy Vetch	0	NS	0	1258	NS	3	-10.1
Arrowleaf clover	43	NS	0	1140	NS	4	0.3
Crimson clover	381	NS	2	794	NS	2	30.5
Rose Clover	0	NS	0	1048	NS	3	8.3
Burr Medic	222	NS	1	968	NS	2	15.3
Turnips	1150	NS	6	1013	NS	2	11.4
Essex Rape	1371	NS	6	893	NS	2	21.9
Control (volunteer)	415	NS	2	1143	NS	3	0.0

Despite the decrease in Tifton 85 bermudagrass yields in spring as a result of over-seeding with cool-season annual forages, P removal efficiency increased from 19 to 38% with cool-season forage cultivation (Table 5). This resulted in land area requirements per cow (the amount of land needed to safely absorb manure nutrients from each cow) that decreased by 40% in the best cool season legumes, in this case hairy vetch and arrowleaf clover. These legumes have the additional benefit of providing high levels of crude protein and are very digestible to dairy cows, characteristics that make them very attractive to dairymen. In addition, they are available during the late winter and spring months as greenchop when no other forages are available locally. When winter forages are not available, dairies are forced to import alfalfa hay from great distances (New Mexico and Colorado), increasing the price of milk as well as burning large quantities of fossil fuel.

Table 5. Land area requirement (LAR) and increase in land use efficiency when Tifton 85 bermudagrass is over-seeded with cool season annual forages.

species #	species	LAR per cow (ha) based on P removal	SD	Increase in Land use efficiency (%)
1	rye maton	0.39	0.04	23.36
2	triticalie T-23	0.41	0.12	18.90
3	wheat Russian	0.39	0.14	23.60
4	Oats Ozark	0.38	0.10	25.14
5	Barley Tambar 501	0.41	0.09	20.15
6	Ryegrass Gulf annual	0.37	0.15	26.72
7	Turnips Purple Top White	0.40	0.18	21.85
8	Essex Rape Dwarf	0.37	0.14	27.03
9	Crimson clover	0.36	0.11	28.20
10	Overton Rose R-18 clover	0.34	0.20	34.04
11	Yuchi Arrowleaf clover	0.31	0.23	38.78
12	Hairy Vetch	0.33	0.09	35.88
13	Armadillo Burr medic	0.40	0.19	20.57
Tifton 85 transect lines (2006 and 2007)		0.51	0.45	0.00

Subtask 1.3: Determine optimal season length and P-extraction of warm season grasses and legumes on small plots by measuring both forage yields and P concentrations.

After discussion with cooperating dairymen, it was decided that only Tifton 85 and Coastal bermudagrass cultivars would be measured for warm-season potential phosphorus uptake. Unlike a few years back when annual warm-season grasses such as sorghum-Sudangrass were widely cultivated under dairy effluent pivots, only these two warm-season perennial grasses are currently cultivated on most dairies in the region, including our three cooperating dairies. Coastal is slowly being phased out in favor of Tifton 85, but the cost of switching is keeping some manure/effluent application fields in Coastal for the time being while all new fields are going to Tifton 85 which has 5-7% greater digestibility and results, consequently, in greater milk production. These were therefore the target species for developing year-round P-extraction systems based on forages: bermudagrass in the warm season over-seeded with cool-season annuals.

During the warm-season growing seasons of 2006 and 2007, Tifton 85 and Coastal fields on Dairies A, B & C were sampled whenever the dairies themselves harvested forage for hay or haylage. This was done in an effort to measure production and P removal in production situations. Samples were analyzed for P concentration to estimate P removal (recycling) rates. Results and conclusions will be distributed to dairymen to assist them in adapting BMPs that maximize manure-P recycling from bermudagrass fields. Based on field and laboratory results, a year-round forage production system that have compatible growing seasons (do not overlap) that can extract the maximum amount of plant-available P from these crop fields was designed and demonstrated to dairymen. The goal was to determine which systems extract the greatest amount of soil-P and determine if the plant-available P extraction affects stable P in the soils.

This was accomplished on all three cooperating dairies and demonstrated to neighboring dairies. Intensive use of warm-season pastures (bermudagrass) over-seeded with cool-season legumes during the autumn and harvested for haylage or greenchop during winter and early spring maximized recycled P on pastures. Dairymen are particularly interested in utilizing greenchop in their production systems since milk production almost always responds positively to the addition of fresh forages to the diet. In addition, over-seeding bermudagrass with cool-season legumes also contributes significant N to subsequent bermudagrass regrowth during the warmer months.
Results in Table 6 make it obvious that Tifton 85 has almost 40% greater potential for P recycling compared to Coastal, but these data were collected from different dairies so results could vary considerably depending on soil and management.

Table 6. Bermudagrass cultivar forage and phosphorus (P) yields averaged over three years on two dairies in north Texas.

Bermudagrass Cultivar	Forage Dry Yield lbs/acre/year	Phosphorus %	Phosphorus Yield lbs/acre/year
Coastal	9,100	0.21	19
Tifton 85	12,400	0.25	31

Subtask 1.4: Design and demonstrate year-round forage production systems that have compatible growing seasons and extract a maximum amount of plant-available P from these crop fields.

Based on the results of this project, the most efficient year-round system for recycling or phytoremediating high-P soils on dairies is based on the perennial warm-season bermudagrass cultivar Tifton 85 removed as hay or greenchop. The removal of P can be increased up to 39% by over-seeding with a cool-season forage. However, the less efficient cool-season P removing forages, namely those that mature earlier in the spring, are more sustainable because they suppress subsequent Tifton 85 spring regrowth. Crimson clover, which can increase P removal by 28%, is the recommendation because it has done most of its growth by the time Tifton 85 starts to grow. These intensifications should be recommended for fields on dairies with high levels of P, which should be identified by soil P mapping on dairies that have had manure or effluent applied in the past.

This system was demonstrated on the three coopering dairies over three years of the project. A demonstration was also conducted in conjunction with Texas AgriLife Extension on the Hidden Valley Dairy which was viewed by over 100 dairy managers at the annual dairy field tour in 2006.

Task 2: Develop and test easily-established vegetative buffer strips that harvest or stabilize soil-P in surface water runoff moving from dairy waste application fields to streams, rivers or other drainages.

The goal was to design and demonstrate first tier buffer strips composed of harvestable (hay) material with high soil-P extraction (yield X P concentration) potential that will catch and recycle surface runoff from croplands high in water-soluble P of dairy waste origin. In addition, a second tier buffer strip for specific soils, drainages and climate that will foster year-round buffering utilizing mostly (but not exclusively) native vegetation was designed and demonstrated.

Buffer strips

Native species (both grasses and forbs) were identified, seed, and vegetative material acquired, plants established in greenhouses, and then transplanted into micro-plots on dairies A, B & C. These were located in coastal pastures along streams that currently serve as buffer strips on these dairies. The idea was to compare current buffer strip species (bermudagrasses) to more wildlife-friendly, deeper-rooted, diverse mixtures of natives. After several attempts to establish these natives in killed-out bermudagrass (very herbicide resistant), only one plot on one of the dairies remained due to lack of establishment moisture in 2006 and overwhelming bermudagrass re-invasion. Dairy A plots survived due to extensive watering and weeding.

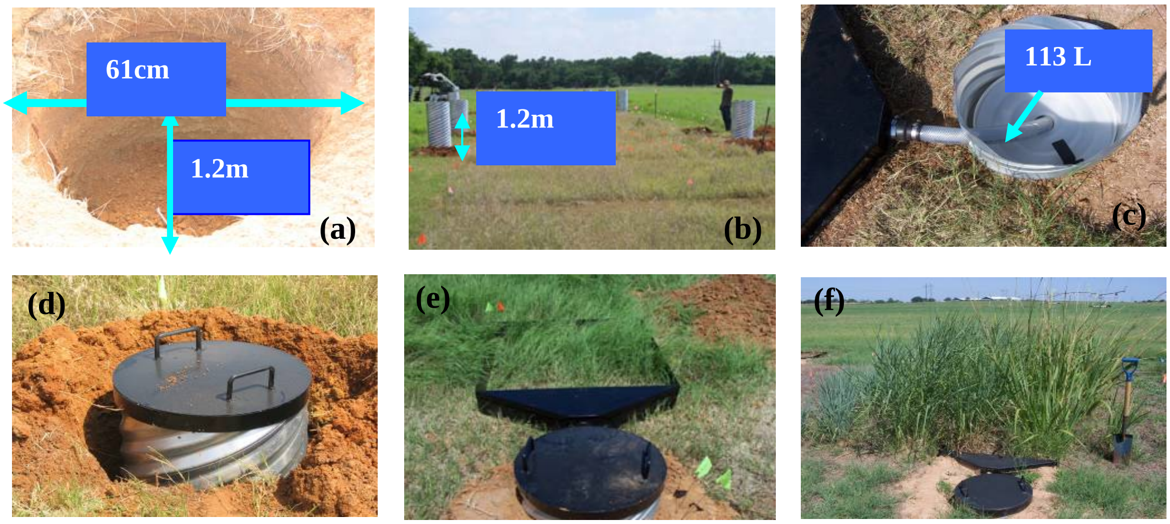

Figure 4. Experimental field plot runoff collection systems in the demonstration area.

A runoff conveyance and collection system was fabricated and installed at a dairy waste application field site that demonstrated the effect of various vegetative covers for sediment control and P sequestration. The system was successfully installed and runoff samples from 22 rainfall events were collected and analyzed for total suspended solids (TSS), total P (TP) and soluble ortho-phosphorus (SOP). Results showed that plots with vegetative covers reduced total runoff, TSS, TP and SOP as compared to the control (bare) plots. Denser vegetative covers of warm season forb and warm season grass covers reduced runoff, TSS and P more than all other covers and could potentially provide a better solution to nonpoint source pollution of P from animal waste application fields. Future long-term studies of these cover types as vegetative filters are needed to demonstrate their efficacy in reducing runoff and P from edge-of dairy waste application fields. A runoff conveyance and collection system (Fig. 4) was constructed and installed at the Dairy A site on the up and down-stream ends of ten 5 m × 5 m replicated plots. For each system, a corrugated metal culvert was installed in the ground by auguring a 61 cm diameter hole (Fig. 4a) to a depth of 122 cm (Fig. 4b). The bottom of the hole was compacted and a 113 L barrel to collect runoff was placed inside the culvert.

The capacity of the barrel was sufficient to hold up to 7.5 cm of runoff from a 25-yr, 24-hr rainfall from a 1 m x 1m metal border sub-plot built within each replicated plot (Fig. 5). The barrel was covered by a plastic lid (Fig. 4c) and a hole was drilled in the center of the lid to accept 5 cm dia. reinforced flexible tubing. The other end of the tubing was connected to a custom-built v-shaped metal gutter installed on the downstream side of the 1 m x 1 m sub-plot (Fig. 4e). The gutter and the culvert were covered with metal lids to prevent the entry of rainfall and/or external water into the barrel (Figs. 4d and 4e). All runoff conveyance and collection systems were positioned and installed perpendicular to runoff from their respective sub-plots. Additionally, a weather station was installed next to the field plots (Fig. 5) to record rainfall amounts received at the experimental site.

The replicated plots (5 m × 5 m) were established on a Windthorst fine sandy loam soil (fine, mixed, thermic, Udic Paleustalf). The entire plot area, plus an additional 5 m margin above and below the plots, was treated with post-emergent herbicides to control existing and competing vegetation. The two replications (R1 and R2) were separated by a 5 m buffer zone and plots within each replicate were separated by a 1 m margin to avoid treatment edge effects. A 1 m × 1 m sub-plot with a runoff conveyance and collection system (Fig. 4) was installed on the upstream and downstream side of each cover treatment. All upstream sub-plots were installed in existing Coastal except two, which were cleared (bare ground) to serve as a negative control. All the downstream sub-plots were installed inside each treatment. Sub-plots were isolated from the overland flow by 10 cm high metal borders. After a natural rainfall event, any runoff produced by a sub-plot was conveyed to its respective collector through plastic tubing.

As shown in Fig. 5, original plantings included cool-season grass (CSG), warm-season grass (WSG), warm-season forb (WSF), warm-season legume (WSL), and the control treatments which were randomly assigned to plot locations. Due to seasonal drought that occurred during the establishment and second year of the project, stands for the CSG and WSL plots were thinned to a point where they were less competitive, thus residual bermudagrass and annual weedy species re-occupied the plots over time. By the end of year two, little to no WSL material remained in the plots. Although information from the WSL plots was collected, it was not used for any comparison. To determine differences between the pre-existing cover, bermudagrass (CB), and the treatment covers, information from the upslope and downslope collectors was compared.

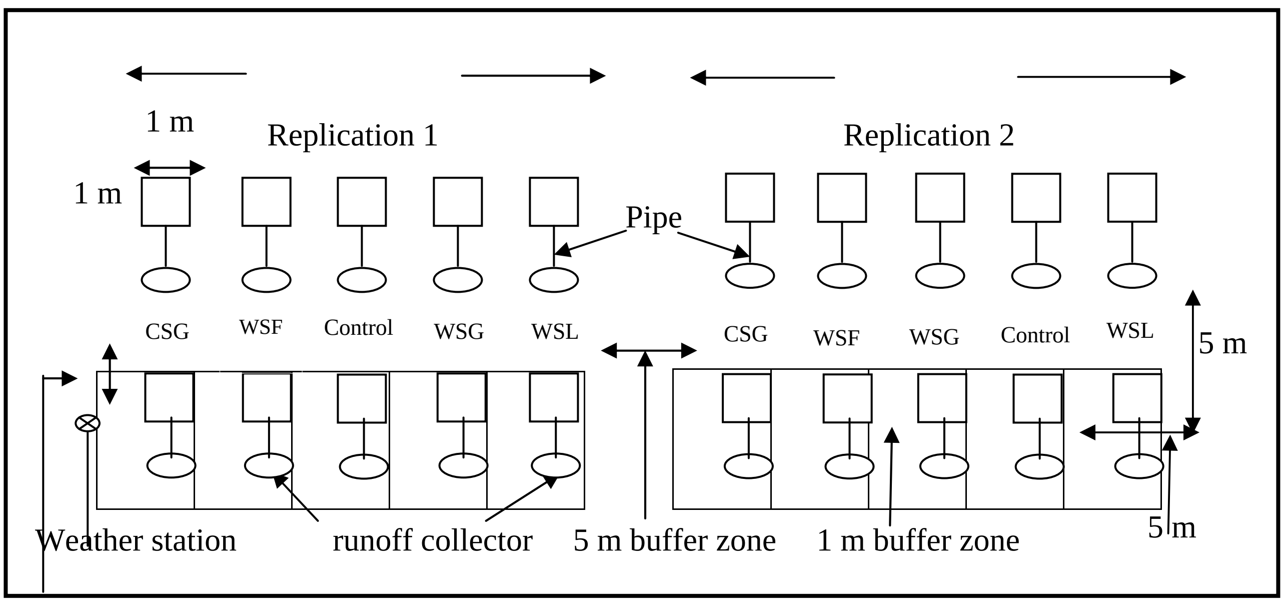

Figure 5. Schematic of field plots in the demonstration area, 2005- 2008.

After a runoff producing event, the barrel from each runoff collector was removed and the entire mass of water and sediment in each weighed. After collecting a thoroughly mixed, 1 L sample of the barrel contents, barrels were emptied, cleaned, and then replaced. Runoff samples were kept on ice and transported to the Texas Institute for Applied Environmental Research (TIAER) laboratory for TSS, TP, and SOP analyses. If the collected runoff samples from the treatment plots were less than 1 L, those samples were sent for analysis of TP to the Soil, Water, and Forage Testing Laboratory (SWFTL) in the Soil and Crop Department at Texas A&M University, College Station.

A total of 22 runoff producing events occurred during the period (2005-2008) of this demonstration. Runoff samples were collected to assess treatment effectiveness for total runoff volume, TSS, TP and SOP.

As expected, runoff produced from a natural rainfall event was less from the vegetated than the control treatment plots. Warm-season forb was the most effective among all treatments in reducing runoff mass followed by WSG, CB (pre-existing), and CSG treatments (Fig. 6). In fact, out of 22 events, WSF and WSG treatments produced no measurable runoff for 12 and 11 events, respectively. This was due to denser vegetative canopies of these two treatments as compared to CB and CSG treatments (Fig. 7) intercepted rainfall, stronger root system, and protected soil surface from compaction due to lesser rain drop impact which increased infiltration.

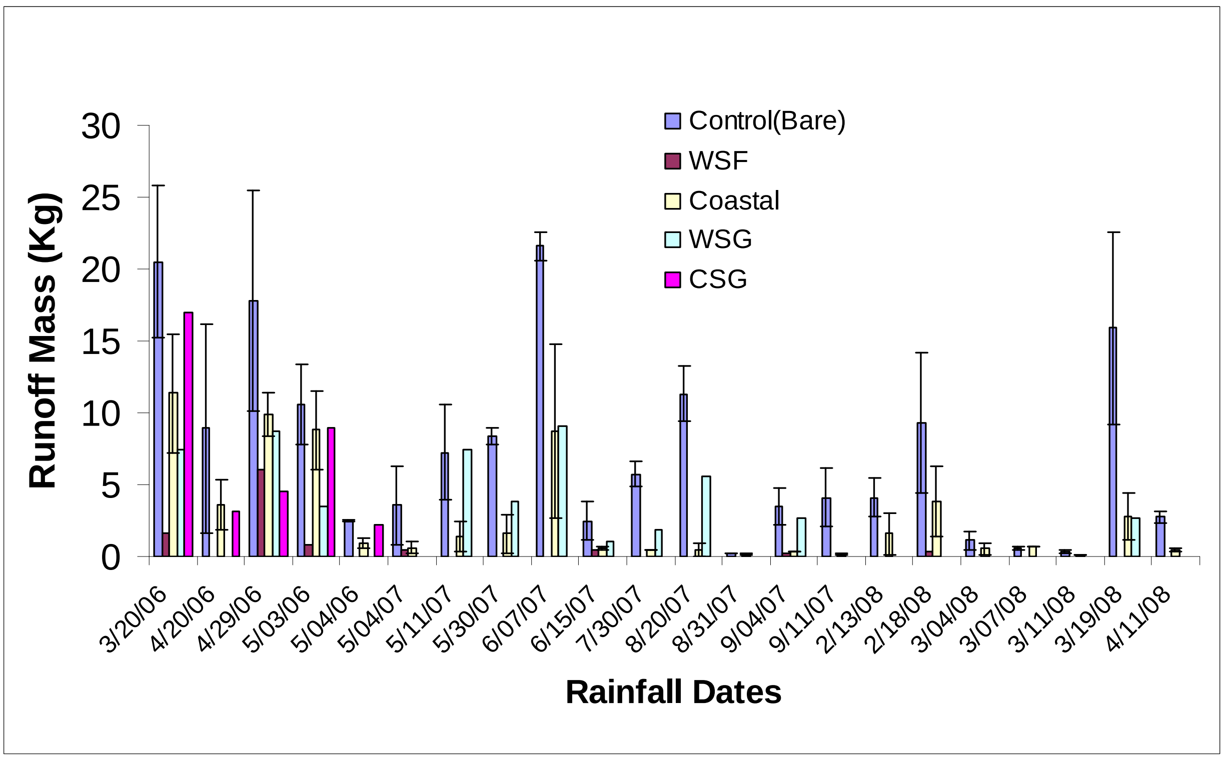

Figure 6. Comparison of mass of runoff among the treatments (Data without error bar is from one plot of the treatment).

A lesser number of analyses were done for TSS compared to TP among the treatments due to less than needed (1 L) runoff mass collected from the sub-plots following some rainfall events. All treatments were deemed effective in reducing runoff TSS when compared to control treatment (Fig. 8). The reduction of sediment mass in runoff was greatest in the WSF followed by WSG, control (mostly coastal bermudagrass), and CSG treatments.

For a given rainfall event, the control treatment produced greater mass of TP as compared to other treatments. Runoff samples from each rainfall event showed that WSF treatment followed by the WSG treatment had lower TP than all other treatments (Fig. 9) due to the least amount of sediment in the runoff (Fig. 8). The control with Coastal Bermudagrass (pre-existing) was the third most effective treatment to reduce TP in the runoff.

Figure 10 illustrates soil and runoff SOP from each treatment. A lesser number of SOP analyses were done among the treatments compared to TP, due to less than needed (1 L) runoff mass collected from sub-plots of each treatment plot. The runoff from WSG treatment plots had the greatest SOP, followed by control, WSF, control, and CSG treatments.

Figure 7. Comparison of vegetative covers among the treatments.

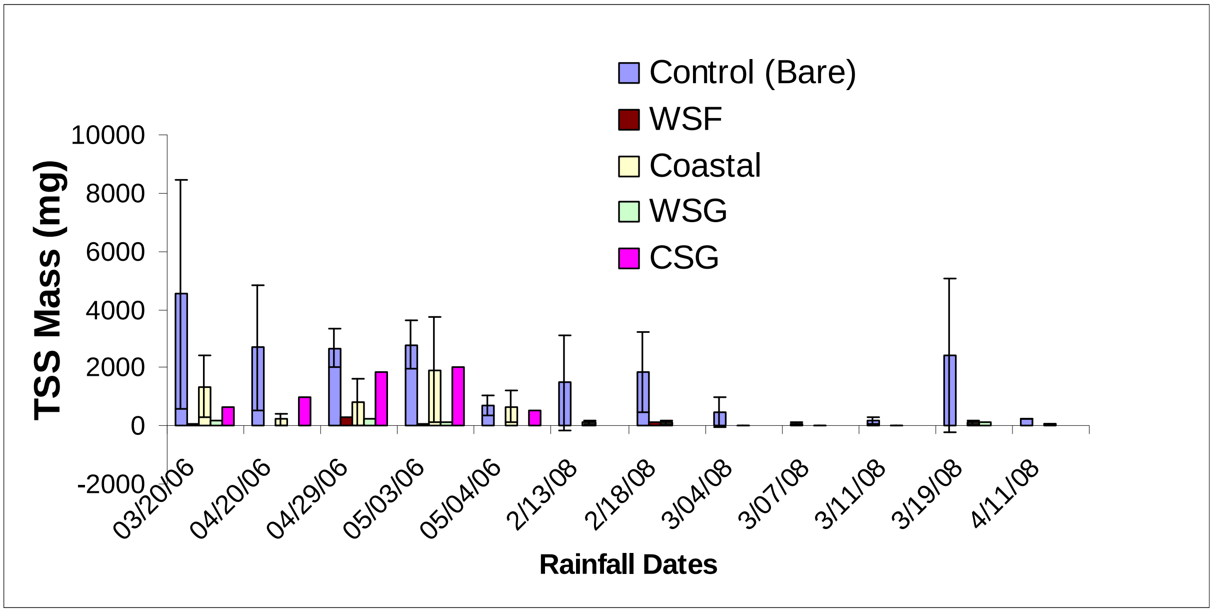

Figure 8. Comparison of mass of runoff TSS among the treatments.
(Data without error bar is from one plot of the treatment)

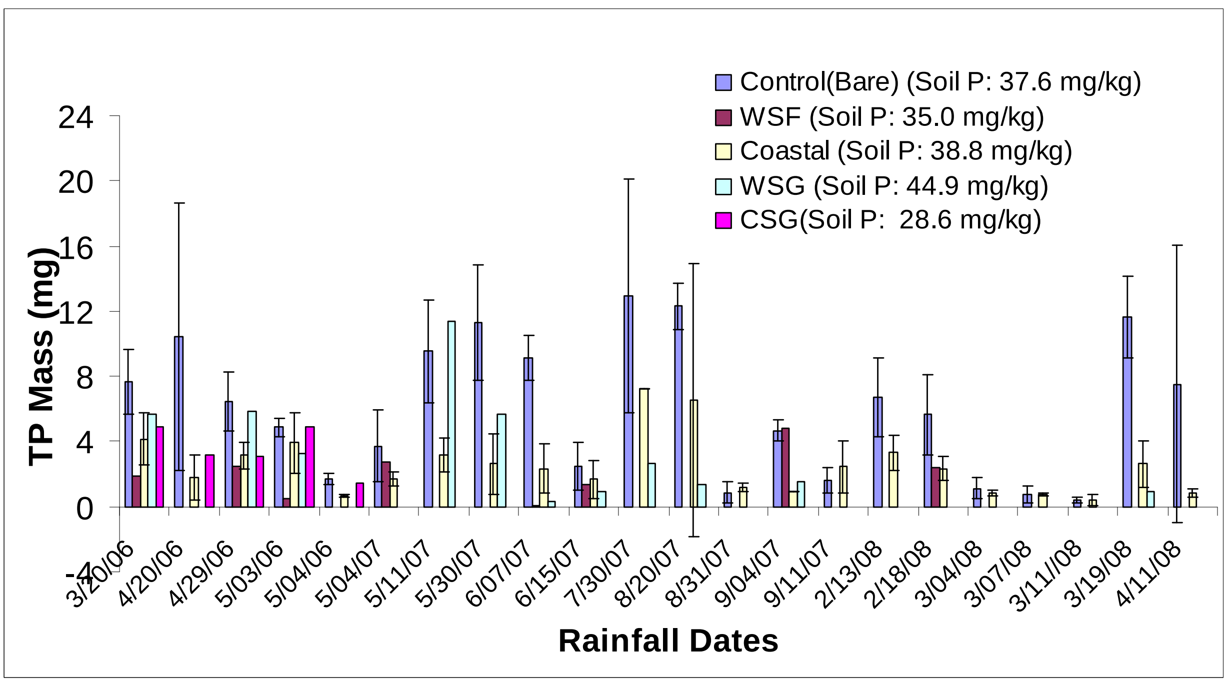

Figure 9. Comparison of mass of runoff TP among treatments.
(Data without error bar is from one plot of the treatment)

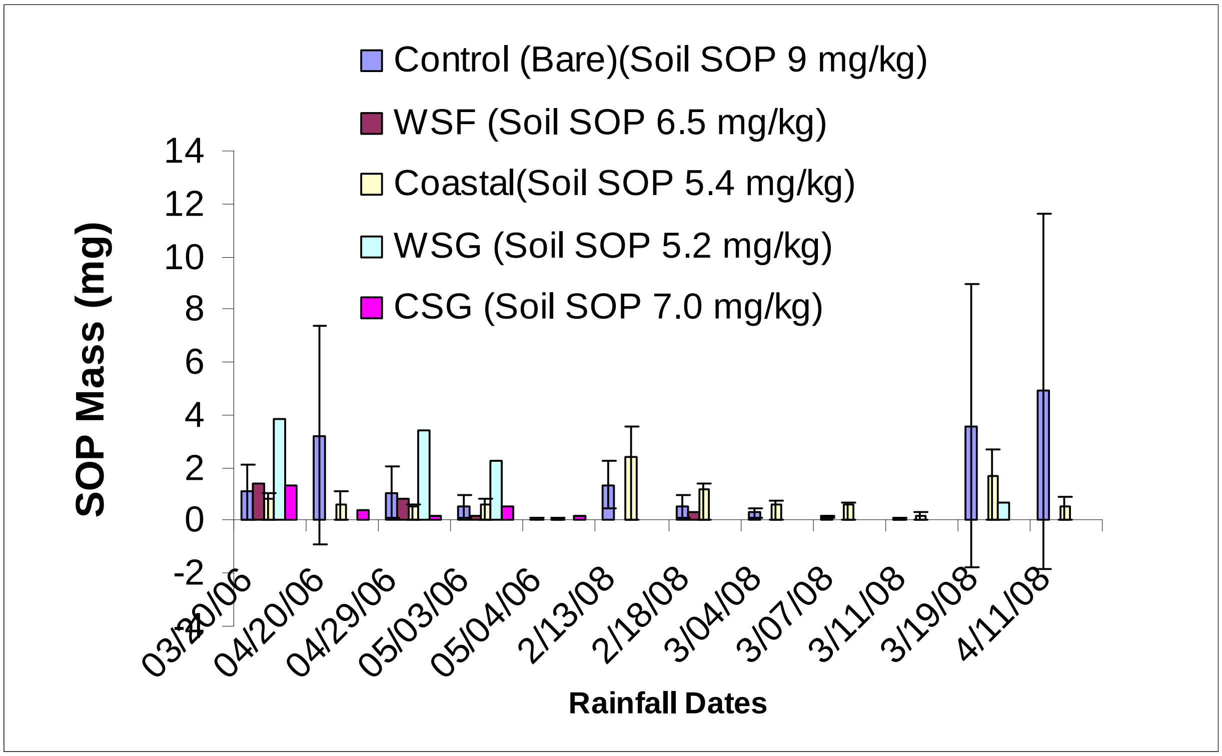

Figure 10. Runoff mass SOP comparison among treatments.
(Data without error bar is from one plot of the treatment)

Table 7 represents effectiveness of P reduction among the treatments**.** Although the soil TP in case of WSG and WSF was greater than other treatments, the runoff TP for these two treatments was lesser than others due to a combination of lesser runoff, lesser TSS, and greater P up-take capacity (Table 7) of these two treatments compared to other treatments. The CB was effective in controlling TP in runoff compared to CSG and control treatments, but lesser effective compared to WSF and WSG.

Table 7. Comparison of different parameters among treatments.

Treatment	Soil TP (mg/kg)	Runoff TP (mg)	Runoff (kg)	TSS (mg)	P up-take (kg/ha)
Control	37.6	6.0	7.4	1675	0.0
CSG	28.6	3.5	7.2	1211	3.3
CB	38.8	2.2	2.7	454	9.3
WSG	44.9	1.8	2.5	55	10.7
WSF	35.0	0.5	0.5	45	11.5

The work described above provided a location and content that was included in a Dairy Waste Management Field Day sponsored by Texas AgriLife Research and Tarleton State University during the summer of 2007. Information gathered also was used as a content module for a course in CAFO management offered through the College of Agriculture and Human Sciences at Tarleton. Furthermore, this information was presented at annual National Integrated Water Quality Program conferences during the course of the project and a manuscript was prepared and submitted to American Society Agricultural Biomechanical Engineers during the summer of 2008.

In addition to these completed activities, information collected during the course of the project was used for two associated MS theses. The first of these, *Vegetative Covers for Sediment Control and Phosphorus Sequestration from Dairy Waste Application Fields*, was completed in August 2008. The second, *Sediment and Phosphorus Transport Predictions on Windthorst Soils Receiving Dairy Effluent in Erath County, Texas,* is in progress. Both will provide information for manuscript preparation and submission.

Field demonstrations

The forage plots and demonstration filter strips were visited and discussed with numerous dairymen, dairy managers, and state agencies/educators. Two demonstration areas (one on dryland and another under a pivot) with overlapping winter annual grass and forb species were established on the Hidden Valley Dairy in Erath County in October 2006, in Erath County TX. These were used for demonstration sites for the spring 2007 Dairy Outreach Program planned by Robert Scott, Erath County AgriLife Extension agent. Participants included over 100 dairy owners and operators as well as regulatory agencies, educators, extension personnel, dairy consultants and students/trainees. Handouts included amounts of phosphorus that different forages are able to extract/recycle as well as nutritive value that make them useful in more ways than simply phytoremediation.

Economics

Objective: Model the economics associated with implementation of the integrated approaches outlined above.

The cost analysis of over-seeding with annual cool season forages based on 2006-2008 average prices was estimated. Crop value of winter annuals is derived by multiplying Tables 3-4 yield values by the value of delivered alfalfa hay they would replace. The "P removal benefit" was defined as the additional land (ha) that would be required if a farmer had chosen to manage P through Tifton 85 alone without over-seeding with a cool season annual forage. Thus, the savings in the rental value of the extra land has been considered to be the benefit of extra P harvest due to over-seeding. Net benefit values in Table 8 indicate that there is a net cost of removing additional P by over-seeding Tifton 85 bermudagrass during winter with cool season annual forages, although the additional value in milk production due to the availability of high quality green chop during the winter months was not included in the equation. These additional costs varied from $288/acre for triticale to $40/acre for rape and were roughly the inverse of how much the winter annual forage suppressed Tifton spring regrowth.

Table 8. Cost analysis of over-seeding with annual cool season forages based on 2006-2008 average prices.
"Phosphorus removal benefit" has been defined as the additional land (ha) that would have required if a farmer had chosen to manage P through Tifton 85 alone. Thus the savings in the rental value of the extra land has been considered to be the benefit of extra P harvest due to over-seeding.

	Benefits			Operation Cost ($/acre)				
Species with Tifton 85	Crop value	P removal	Total	Seed	2006-2008 Fertilizer	Fixed costs	Total	Net Benefits
Rye maton	$1712.14	$11.29	$1723.44	$30.00	$56.62	$372.31	$458.93	$1264.51
Triticale T-23	$1665.04	$ 8.64	$1673.68	$27.00	$56.62	$372.31	$455.93	$1217.75
Wheat Russian	$1687.99	$11.45	$1699.44	$27.00	$56.62	$372.31	$455.93	$1243.51
Oats Ozark	$1816.55	$12.45	$1829.00	$27.00	$56.62	$372.31	$455.93	$1373.07
Barley Tambar 501	$1796.91	$ 9.36	$1806.27	$27.00	$56.62	$372.31	$455.93	$1350.34
Ryegrass Gulf annual	$1802.49	$13.51	$1816.00	$15.00	$56.62	$372.31	$443.93	$1372.08
Turnips Purple Top	$1771.68	$10.36	$1782.04	$10.60	$ 0.00	$372.31	$382.91	$1399.13
Essex Rape Dwarf	$1807.12	$13.73	$1820.85	$10.60	$ 0.00	$372.31	$382.91	$1437.94
Crimson clover	$1726.14	$14.56	$1740.70	$35.00	$ 0.00	$372.31	$407.31	$1333.39
R-18 Rose clover	$1746.20	$19.13	$1765.32	$60.00	$ 0.00	$372.31	$432.31	$1333.02
Yuchi Arrowleaf clover	$1727.46	$23.48	$1750.94	$24.00	$ 0.00	$372.31	$396.31	$1354.63
Hairy Vetch	$1783.75	$20.74	$1804.49	$95.00	$ 0.00	$372.31	$467.31	$1337.18
Armadillo Burr medic	$1868.02	$ 9.60	$1877.63	$40.00	$ 0.00	$372.31	$412.31	$1465.32
Tifton 85 alone	$1865.23	$ 0.00	$1865.23			$372.31	$372.31	$1505.32

Conclusions

The results of this project provide some recommendations for improving or adding BMPs related to managing fields receiving dairy manure/effluent phosphorus or correcting imbalances in fields that have received excessive amounts of dairy waste P.

1) Before taking any action, landowners planning phytoremediation or continued manure/effluent application to agricultural fields should map soil-P concentrations. These soil surveys will guide P removal from forage fields or indicate how much additional manure/effluent can be safely applied.

Mapping soil-P concentrations will be most beneficial if the entire dairy or land area where application is to occur/occurred is sampled. The question is how many samples per unit are needed and how costly this will become. Multiple samples can be batched but the more sample compositing that occurs, the lower the usefulness of the resulting map. Future dairy-P application or intensified phytoremediation management should be based on a soil-P map that is far more detailed than the traditional field scale. Additional testing needs to determine how often this mapping should be repeated over time, IE how much soil-P changes on different soils, climates and management.

2) Over-seeding dormant bermudagrass with cool-season forages can increase the rate of soil-P removal.

This project demonstrated that the selection of cool-season forage species over-seeded into dormant bermudagrass can affect phosphorus removal or recycling on dairies or surrounding land receiving dairy waste. Species yields and P concentrations vary considerably and the interaction of these two factors determines phytoremediation effectiveness. The picture becomes complicated, however, because of autumn and spring interaction of cool-season forages and the bermudagrass stands into which they are seeded. The results indicate that intensive use of over-seeded winter annual forages can reduce the effectiveness of P recycling by the dominant cultivated summer perennial species, bermudagrass. In some cases there will be a tradeoff between cool season and warm season species whose growth patterns overlap in late spring and early summer. The solution is to use precocious cool season annuals that are both productive and early maturing, namely those that are harvested and set seed before bermudagrass begins to grow.

These demonstrations indicate that cool-season annual forages can extract from 7-42 kg P/ha (6-38 lbs/acre) per growing season, depending on rainfall and soil preparation. At the higher end, this equates roughly to 8,000 kg (8,800 lbs) dry matter (DM) manure, twice what the average dairy cow produces per year. In addition, cool-season annual forages can sequester from 8-290 kg N ha-1 (7-260 lbs acre-1) per growing season, depending on rainfall and soil preparation. At the higher end, this equates roughly to 26,000 kg (28,600 lb) DM manure. There is a trade-off, however, in late winter annual forage P extraction and early spring bermudagrass (Tifton 85 & Coastal) P extraction. Again, the selection of precocious cool-season forages that mature earlier in the spring can circumvent this competition.

3) The choice of Coastal or Tifton 85 bermudagrass will affect the soil-P removal rate during the warm season.

Tifton 85 bermudagrass is the warm-season forage of choice for dairies in north-central Texas because of its management ease and milk-production capacity vis-à-vis other options. This is fortuitous because Tifton 85 has greater P-removal capacity than Coastal, its closest competitor. All these factors point to Tifton 85 bermudagrass as the warm-season perennial grass of choice in phytoremediating high-P soils or absorbing greater amounts of manure-P by recycling more P back to the cows.

4) Intensifying soil-P removal using phytoremediation by year-round forage system is based on compatibility of the cool-season and warm-season forage species.

Cool-season forages will compete with warm-season forages that follow them in the spring mostly because of competition for limited moisture but also sunlight. Where irrigation is available, we assume this competition will diminish. Where dryland conditions prevail, the choice of over-seeded cool-season species will favor those that have early spring production and seed set, the latter important for self-reseeding stands.   Through these demonstrations, Tifton 85 over-seeded with crimson clover appears to maximize both year-round P-removal as well as year-round forage production of the highest quality to dairy cattle.

5) The choice of species used in establishing buffer strips is important.

Buffer strips reduced runoff P by slowing runoff and soil transport due to vegetative cover that protects from the raindrop impact and runoff from above the strips. Cover types used in this project sequestered on average 10.87 kg P/ha (9.7 lb/acre) as compared to 7. 71 kg P/ha (6.9 lb/acre) for the residual cover type, a 41% increase in P sequestration. By far, the denser covers of the WSF and WSG plots, possibly combined with greater root biomass, reduced sediment and P transport when compared to the pre-existing cover type. For the 22 events recorded on the site, it is interesting to note that total runoff was reduced by as much as 70% under the WSG cover for events between 1.0 and 1.5" in magnitude (average event magnitude across two years was 1.17") and, as noted, as high as 100% for events of 1" or less. Field days, individual dairyman interaction, and practical guides provided by the project disseminated this information and demonstrated the practices to local dairymen.

Many questions remain, however, to be answered when it comes to phosphorus dynamics in buffer strips. The results from these demonstration efforts show that phosphorus is sequestered in buffer strips but it did not contemplate how wide these need to be to slow down the surface runoff of dairy manure P on differing slopes and how heavy rainfall events can be in different soils before vegetative filter strips are no longer effective as a BMP. In addition, the question of buffer strip management (haying or not, for example) effects on P sequestration or impeded bacterial movement off application fields must be addressed as well.