RUNOFF LOSSES FROM CORN SILAGE-MANURE CROPPING SYSTEMS

Bill Jokela[1], Mike Casler[2], and Mike Bertram[3]

Introduction

Transport of phosphorus (P), nitrogen (N), sediment, and pathogens via runoff from crop fields, especially where manure has been applied, can contribute to degradation of surface waters, leading to eutrophication and potential health effects. In the dairy cropping system of Wisconsin and most of the northern dairy belt, the silage corn phase of the rotation is the most susceptible to runoff and erosion losses because of the lack of protective crop residue and regular applications of livestock manure. We initiated this study to evaluate cropping systems to minimize adverse water quality impact, while maintaining or increasing nutrient efficiency and productivity.

The objective of this study was to evaluate field runoff losses of nutrients and pathogens from different manure/crop/tillage management systems for silage corn production. We chose to use a paired watershed design, rather than conventional replicated field plots, because the larger field-scale units provide data that more adequately reflects the more complex hydrology of the real-world landscape.

Methods

The 16-acre field site is at the UW/USDA-ARS Research Station near Marshfield in central Wisconsin. The soil is a somewhat poorly drained Withee silt loam soil with 1-3% slope and is representative of soils used for dairy farm production in that area. Surface drainage on this somewhat poorly-drained soil is accomplished using drive-through diversions and berms, which also served to divide the field into four drainage areas or "watersheds" of approximately 4 acres each (Fig. 1). Initial soil tests showed pH values of 5.9-6.3 and soil test P of 25-34 mg/kg Bray P_1.

Runoff monitoring stations set up in each of the fields consisted of a 24-inch H-flume with an approach channel, wing-walls, and earthen berms. Time-based runoff samples were collected by an automated 24-bottle (1 liter) refrigerated ISCO sampler. A datalogger was used to control sampling scheme and data collection, radio telemetry facilitated remote access and program modification, and tipping bucket rain gages provided precipitation data. Runoff samples from individual bottles were combined into flow-weighted composites and analyzed for total P (TP), dissolved P (DP), total N, NO_3-N, NH_4-N, and suspended sediment (SS). For more detail about methods see Jokela and Casler (2011). The focus of this paper will be on SS and P in runoff. Additional samples for pathogen analysis were collected using a flow-through glass wool filter system but pathogen data is not reported in this paper.

[1] Research Soil Scientist, USDA-Agricultural Research Service, Dairy Forage Research Center, Marshfield, WI.
[2] Research Geneticist, USDA-Agricultural Research Service, Dairy Forage Research Center, Madison, WI.
[3] Superintendent, University of Wisconsin Agricultural Research Station, Arlington, WI.

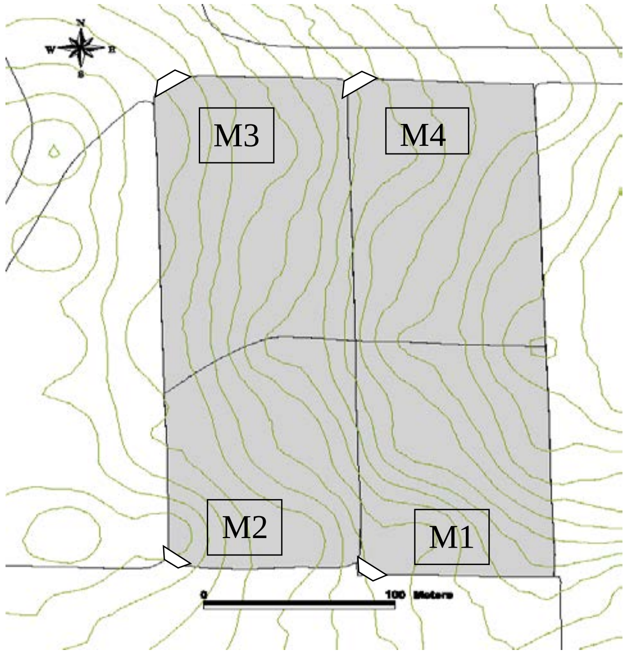

Figure 1. Map of field site showing four drainage areas, or fields, and runoff monitoring stations (trapezoid symbols). Contour lines represent 1 foot elevation differences.

The paired watershed technique used in this study requires two or more similar watersheds (control and one or more treatment watersheds) and two periods of study -- calibration and treatment. The term "watershed", in this case, refers to individual fields or portions of fields that comprise well-defined surface drainage areas that can be separately monitored for runoff. During the calibration period, all four "watersheds", or fields, were managed the same and event-based runoff and nutrient data were collected. The calibration period for our study began in August 2006 after installation of runoff monitoring and sampling stations for each of the four fields. Management during the calibration period, typical of that on dairy operations in central WI, consisted of fall application of liquid dairy manure, in this case applied at a rate to meet approximately 80% of the crop N need, chisel plowing the same day, and spring field cultivation. The calibration period ended and the treatment period began in early October 2008. Regression equations were developed for each runoff variable between the control field and each of the other three fields.

During the treatment period, management remained the same in the control field, which served as a check on weather and other year-to-year variation, and different management systems were implemented on the others. Treatments were as follows: 1) Control - fall manure, fall chisel plow (M1), 2) Cover crop (fall-seeded rye), spring manure and chisel plow (M2), 3) Fall surface-applied manure with spring chisel plow (over-winter manure, M3), and 4) Fall manure and chisel plow with permanent vegetative buffer strips/grassed waterways (M4). Manure application rates averaged 5100 gal/acre with average nutrient application rates of 145, 75, 53, and 148 lb/acre of total N, NH_4-N, P_2O_5, and K_2O and average solids content of 13.3%.

The treatment period ended in April 2012 and regression equations between each treatment field and the control field were developed for each variable. Treatment and calibration period regressions were compared statistically using a permutation test to determine if there was a significant effect of each treatment. A quantitative measure of the treatment effect, e.g. the increase or decrease of runoff total P concentration, was determined by comparing the percent change during the treatment period compared to the change that would have been expected based on the calibration period relationship. With the paired-watershed design, statistical comparisons can only be made between each treatment and the control, not between all combinations of treatments.

Results and Discussion

Runoff concentrations during the treatment period varied by field and averaged 1.4 mg/liter (or ppm) total P and 0.24 mg/L dissolved P. Concentrations from snowmelt-derived events only were lower in total P (0.6 mg/L) but higher in dissolved P (0.35 mg/L), reflecting the lower concentration of suspended sediment in snowmelt runoff (about 20% of that for all events). Annual export, or load, during the treatment period also varied with treatment but averaged 3.2 lb total P and 0.33 lb dissolved P per acre. Snowmelt-derived runoff averaged almost 40% of the total but contributed only 11% of the export of total P, most of which is associated with eroded sediment. This is in contrast to dissolved P, close to half (45%) of which was snowmelt-derived.

Cumulative runoff, suspended sediment load, and total P load from the four watersheds for the entire study period, both calibration and treatment periods are shown in Figures 2 and 3. Two main observations can be made:

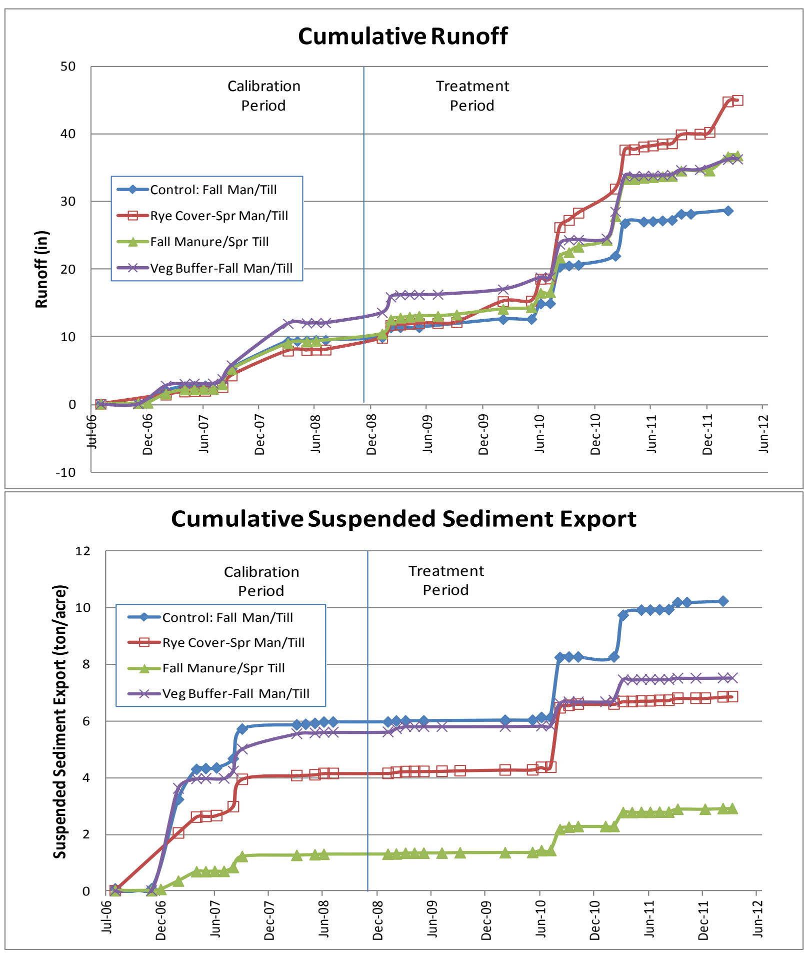

Figure 2. Cumulative runoff and export of suspended sediment for each of four fields during the calibration and treatment periods.

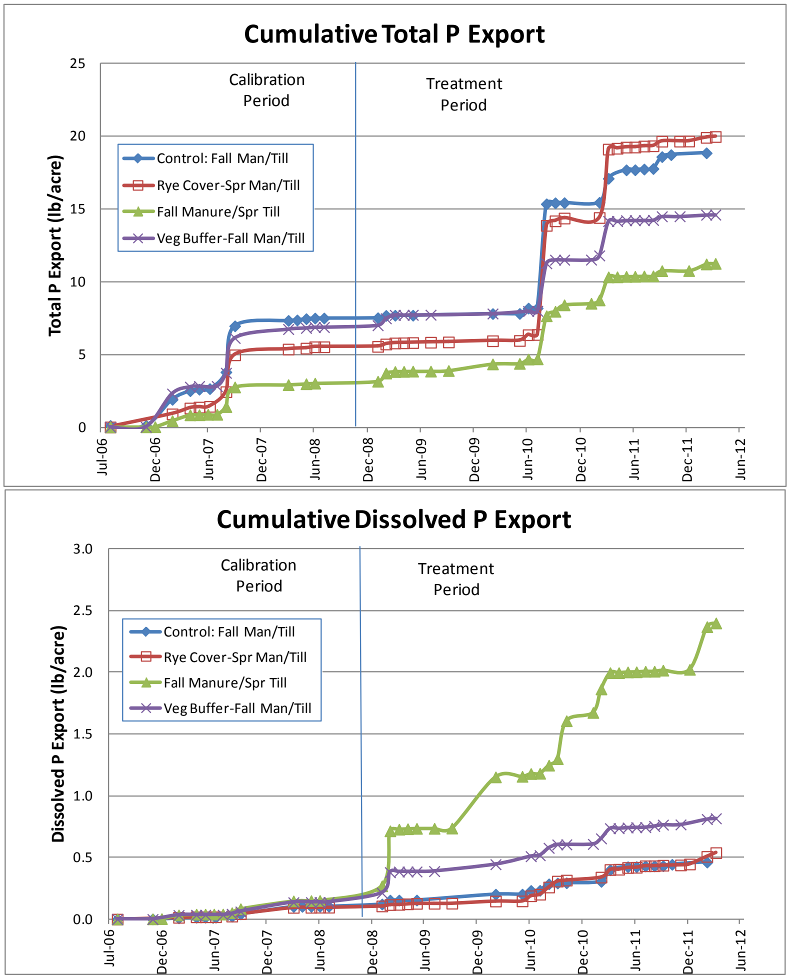

Figure 3. Cumulative export of total P and dissolved P for each of four fields during the calibration and treatment periods.

a) Most of the runoff and export occurred in relatively large events during snowmelt periods or, in some cases, in the fall. A particularly large fall runoff event occurred in September of 2010 when heavy rains resulted more than twice the monthly average precipitation.
b) Patterns over time were relatively similar for all four fields during the calibration period. However, during the treatment period when management was different for each field, some shifts in position relative to the control occurred, suggesting effects due to the change in management. Most pronounced was the dramatic increase in dissolved P export from the fall manure/spring till (over-winter manure) treatment. Note also that almost all of the export from that treatment occurred during snowmelt (primarily March) events.

Regression analysis showed that all three treatments significantly reduced SS concentrations in runoff, and the rye cover-spring manure and vegetative buffer treatments reduced TP concentrations. However, not unexpectedly, concentrations of TP and DP increased in the over-winter manure treatment (fall manure-spring till), DP more than two-fold.

There were fewer significant treatment effects on sediment and nutrient export, or load, which is the product of concentration and runoff volume. Greater variability affected statistical significance and, in some cases, an increase in runoff counteracted a reduction in runoff concentration. The rye cover treatment resulted in a small (9%) decrease in SS export, and the vegetative buffer reduced both SS (62%) and TP (42%) export. Dissolved P export increased in all management treatments, most markedly by three-fold from over-winter manure, a result to be expected from manure left on the soil surface during winter and early spring snowmelt and rain runoff events. This is consistent with observations noted earlier based on graphs of cumulative dissolved P export (Fig. 3). The lack of beneficial effects on dissolved P from the other treatments is not totally unexpected because cover crops and vegetative buffers are designed primarily for erosion control, so are more effective for sediment-bound nutrients than for dissolved forms. Furthermore, at least at our site, leaving the soil surface untilled through the winter-spring period, combined with minimal growth of the rye cover, resulted in an increase in runoff quantity compared to the fall chisel plowed control, which provided some storage for runoff due to the rough surface.

Summary

- Snowmelt-derived runoff was important, representing 11 to 45% of the P and N export, averaged across treatments. It may be more difficult to control with conventional practices designed for control of erosion from rain-derived runoff.
- Surface-applied over-winter manure (fall manure/spring till treatment) increased total P and, especially dissolved P, runoff concentrations and dissolved P export (3 x Control). Over-winter manure decreased suspended sediment concentrations, presumably due to the mulching effect of the surface manure.
- Rye cover crop with spring manure and tillage decreased runoff suspended sediment, total P, and dissolved P concentrations and suspended sediment export, but not total P or dissolved P export. Reduced concentrations indicate a potential for beneficial effects, but effectiveness was limited by poor rye growth and increased runoff volume.
- The vegetative buffer/waterway system was the most effective management system in this study, resulting in (slightly) decreased runoff and decreased concentration and export of suspended sediment and total P (but not dissolved P).
- None of the manure-crop management systems were effective in controlling dissolved P in runoff. This poses a challenge to develop systems that go beyond those practices designed for control of erosion and sediment-bound nutrients.

References

Jokela, W.E., and M.D. Casler. 2011. Transport of phosphorus and nitrogen in surface runoff in a corn silage system: Paired watershed methodology and calibration period results. Can J Soil Sci 91:479-491.

MONITORING AND PREDICTING PHOSPHORUS LOSS
FROM WISCONSIN DAIRY GRAZING FARMS

Peter Vadas and Mark Powell [1/]

Non-point source pollution of surface water by nutrients such as phosphorus can degrade water quality for drinking, recreation and industry. When excess nutrients accumulate in lakes and reservoirs, water quality issues such as algal blooms often result. Because agriculture has been identified as a source of non-point phosphorous pollution, there has been a strong push to identify and manage farm sources of phosphorus runoff. On dairy farms, possible sources of this runoff include cropland, grazed pastures and outside cattle holding areas such as feedlots, barnyards and overwintering lots. In the United States, research on phosphorous loss due to runoff from grazed pastures has been limited.

Physically monitoring phosphorous loss from farms is an expensive, lengthy process. Simulation models are potentially a more rapid, cost-effective way to estimate phosphorous loss from farms. Agriculture Research Service soil scientist Peter Vadas, who works at the U.S Dairy Forage Research Center in Madison, worked with a team of USDA scientists to develop the Annual Phosphorous Loss Estimator (APLE) spreadsheet, which predicts the phosphorous lost through runoff for diverse types of farms and field conditions. APLE is free to download at http://ars.usda.gov/Services/docs.htm?docid=21763.

Building on this work, Vadas, along with Mark Powell and Geoff Brink from the Dairy Forage Research Center and Dennis Busch from UW-Platteville, monitored phosphorus loss in runoff from grazed pastures and used APLE to predict phosphorus runoff from grazing farms. This research took place from 2010-2012 at the UW-Platteville Pioneer Farm and four Wisconsin grazing farms, and was funded by the WI DATCP Grazing Lands Conservation Initiative (GLCI). The researchers monitored phosphorous loss due to runoff from beef and dairy grazed pastures at the Pioneer Farm. They used this data to validate that APLE can reliably predict phosphorus loss from grazed pastures. They then used APLE to simulate phosphorous loss from the four farms, all of which use managed grazing. The focus of this brief is on the modeling results from these farms.

The researchers visited each farm three times in January, June and November 2011 to gather seasonal information about farm management. Questionnaires completed by each farm provided snapshot assessments of cattle, feed, fertilizer, manure and cropping management. Using this information, the researchers modeled year-round, whole-farm phosphorus losses under typical management for each farm.

The Four Study Farms

Farm A, located in southwestern Wisconsin, has an annual average of 40 milking cows, 20 heifers and one or two dry cows. This farm has about 100 acres of cropland in a six-year rotation, with one year of corn silage (20 acres), and one year of an oats/grass/alfalfa seeding mix followed by four years of an alfalfa/grass hay mix (80 acres). The farm has 44 acres of pastures rotated for milking cows and 28 acres of non-rotated pastures for dry cows and heifers; the hay ground is also grazed. There are two outdoor lots totaling 1.5 acres used for overwintering cows. Soils are mostly silt loams, with some fairly steep slopes. There is no manure storage on this farm.

Farm B, also in southwestern Wisconsin, has an annual average of 118 milking cows, 92 heifers, 23 dry cows and 20 beef steers. The farm rents 200 acres of cropland under no-till management with a five-year rotation: two years of corn silage (80 acres), and one year of an oats/grass/alfalfa seeding mix, followed by two years of an alfalfa/grass hay mix (120 acres). The home farm has about 120 acres of rotated pasture for lactating cows, and 100 acres of non-rotated pasture are rented locally for dry cows, heifers and steers. There is one quarter-acre barnyard, and 2.5 acres of lots on the home farm are used for overwintering and housing young stock year-round. Soils are mostly silt loams, often on steeper slopes. There is a small pit on the home farm that stores manure from the parlor, barn and half of the barnyard.

[1/] USDA-ARS Dairy Forage Research Center, Madison, Wisconsin.

Farm C in north-central Wisconsin has an annual average of 164 lactating cows, 130 heifers and 17 dry cows. There are 226 acres of pasture at the home farm, and the farm locally rents 70 acres of grass hay ground. A two-acre dry lot next to the barn is used for freshening cows and, infrequently, for milking cows in the winter. Milking cows are in the barn, barnyard and dry lot from December 1 to February 1. As they dry off, they are moved to overwintering areas until April 1. These overwintering areas are several-acre portions of pasture, with a different area used each winter. From April 1 to December 1, milk cows graze pastures with some time spent in the barn on hot days. Soils are silt loams with mild slopes. There is a pit on the home farm that stores manure from the parlor, barn and barnyard.

Farm D, also in north-central Wisconsin, annually averages 60 milking cows, 46 heifers, 21 calves and nine dry cows. It has 110 acres of cropland in a six-year rotation, with three years of corn (30 acres in corn silage and 30 acres in grain), and one year of an alfalfa/grass seeding mix followed by two years of an alfalfa/grass hay mix (50 acres). The farm has 70 acres of rotated pasture for lactating cows and 30 acres of non-rotated pasture for dry cows, heifers and calves. The heifers also graze about 70 acres of woods near the crop ground. There is one 0.2-acre barnyard and one half-acre dry lot for cows and heifers. Soils are silt loams with mild slopes. Manure from the parlor and barn is stored in a pit.

Details of APLE-simulated total P lost from four Wisconsin grazing dairy farms

Land use	Acres	Total P loss (lbs/acre)	% of farm area	% of Total Farm P Loss
		Farm A		
Corn silage	16.7	4.9	9.6	22.0
Hay, all*	83.5	2.0	48.1	44.8
Pastures	72	0.7	41.4	13.1
Cattle lots	1.5	50.2	0.9	20.1
Whole farm		2.4		
		Farm B		
Corn silage	80	1.8	18.8	21.2
Hay, all	120	1.3	28.2	23.4
Pasture, all	221.5	0.6	52.1	18.6
Cattle lots and barnyard	3.5	79.2	0.9	36.7
Whole farm		1.6		
		Farm C		
Hay, all	70	0.2	21.5	5.6
Pasture	226	0.5	69.3	37.3
Overwintering pasture	28	2.2	8.6	20.7
Cattle lot	2.0	54.1	0.6	36.4
Whole farm		1.2		
		Farm D		
Corn, all	60	5.4	21.4	60.9
Hay, all	50	1.7	17.9	15.7
Pastures	169	0.5	60.4	15.6
Cattle lots and barnyard	0.7	59.1	0.3	7.7
Whole farm		1.9		

*Runoff, erosion, and total P loss was always higher in the seed year of hay than in established hay fields

Findings from the Simulations

Whole-farm phosphorus loss per unit of land on the grazing farms was relatively low, ranging from 1.2 to 2.4 lbs./acre. This compares well to the WI 590 Nutrient Management Standard 590 where the risk of runoff phosphorus as determined by the Phosphorus Index must be at or below 6 lb/acre in order to apply manure to a field. Phosphorus loss from pastures was consistently very low. This demonstrates that these types of grazing farms as a whole may not represent significant sources of phosphorus loss to the environment.

However, some land uses on these grazing farms have the potential for significant phosphorous loss. While barnyards, dry lots and overwintering areas tend to be a small portion of each farm, phosphorus loss per unit of land area can be high. This is expected, since these areas can have high manure and animal densities. These areas represented seven to 57 percent of total farm phosphorus loss, depending on lot management and phosphorus loss from other farmland uses. Farm management options to decrease phosphorus loss in these areas include frequent cleaning of barnyards and containing runoff in a storage area. Corn fields and and hay fields in a seeding year also have the potential for high phosphorus loss due to the increased risk of soil erosion and sediment loss. In general, the simulation results showed that the greatest variability in phosphorous loss was due to erosion. When erosion was low, total phosphorous loss was also low. No till practices are a management option to reduce phosphorus loss due to erosion in cropland.

Overall, the project demonstrates how simulation models can be reliably used to identify areas on dairy farms with the high potential for phosphorus loss, which in turn helps to target cost and environmentally effective management alternatives.