Surface Runoff Quality in Grasslands Fertilized with Broiler Litter

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(ABSTRACT)

Surface application of broiler litter to grasslands can increase concentrations of ammonium (NH_4^+-N) and dissolved reactive phosphorus (DRP) in surface runoff. It is not known, however, for how long after broiler litter applications that NH_4^+-N and DRP concentrations remain elevated. Five 0.75-ha, fescue-bermudagrass paddlocks received four broiler litter applications in 1995 and 1996, and only inorganic fertilizer N in 1997 and 1998. Runoff from each paddock was measured, sampled, and analyzed for NH_4^+-N and DRP. Flow-weighted NH_4^+-N and DRP concentrations increased from background values of 0.5 and 0.4 mg L^{-1}, respectively, to values as high as 50.7 mg NH_4^+-N L^{-1} and 18.8 mg DRP L^{-1} in a runoff event that occurred immediately after the third litter application. Concentrations remained high while broiler litter was being applied but decreased steadily after the last application, reaching values near 1 mg L^{-1} (for NH_4^+-N and DRP) by 19 months after the final application. Among the factors that affected the average concentration of NH_4^+-N and DRP in cumulative runoff after a litter application were cumulative runoff, rates of total N and NH_4^+-N applied, and cumulative total litter N, total litter P, and water-soluble litter P applied during the four years of the study. Soil test P also affected DRP concentrations, but its effect depended on when the paddocks last received broiler litter. There is a need for tools to identify situations in which the application of broiler litter may enrich surface runoff with P. One such tool is the simulation model Erosion Productivity Impact Calculator (EPIC). EPIC's ability to simulate runoff volume and losses of dissolved reactive P (DRP) was evaluated.

Data from the five 0.75-ha, tall fescue-bermudagrass plots that were fertilized with broiler litter during two years, and received only inorganic fertilizer N for the two subsequent years, were compared with EPIC estimates. EPIC simulations of runoff volume in individual events did not show bias in three of the plots but underestimated runoff in one plot and overestimated runoff in another. On an annual basis, the runoff volumes simulated by EPIC were similar to the observed values. A modified version of EPIC yielded better estimates of event DRP losses than the original EPIC and generated estimates of annual DRP loss that were similar to observed values. These results suggest that the modified EPIC may be useful for identifying situations where there is a high risk of large annual P losses from grasslands fertilized with broiler litter.

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Chapter 1

INTRODUCTION

In reports to Congress, the USEPA named agricultural nonpoint source pollution as the major source of stream and lake contamination that hinders the attainment of the water quality goals identified in the Clean Water Act (Martin, 1997; Parry, 1998; USEPA, 1988). Specifically, eutrophication has been identified as the critical problem in those surface waters having inferior water quality in the USA, with agriculture the dominant source of nutrients in lakes (50%) and streams (60%) (Parry, 1998; USEPA, 1996). The input of nitrogen (N) and phosphorus (P) in agricultural runoff can stimulate the eutrophication of sensitive surface waters. In an increasing number of areas, the likelihood for N and P loss in runoff has been enhanced by the recurrent application of fertilizer and/or manure from intensive livestock operations (Edwards and Daniel, 1992; McFarland and Hauck, 1995; Sharpley et al., 1996b).

The value of broiler production in the U.S. in 1997 was 14 billion dollars, with Georgia ranking first in production with over 2 billion dollars (NASS, 1999). Central and north Georgia are areas of intensive poultry (*Gallus gallus domesticus*) production. The production of 1.2 billion broilers in Georgia in 1998 (Georgia Agricultural Statistics Service, 1999) generated 1.8 million Mg of broiler litter (manure and bedding), based on an estimate of 1.5 kg litter produced chicken^{-1} yr^{-1} (Perkins et al., 1964). Since broiler litter is an economical nutrient source (Bosch and Napit, 1992), the standard method for its disposal is land application, primarily to permanent grasslands.

Research has shown that surface application of broiler litter to grasslands may cause elevated concentrations of ammonium (NH_4^+-N) and dissolved reactive phosphorus (DRP) in surface runoff (Edwards and Daniel, 1993; Heathman, et al.,1995; Vervoort et al., 1998a; Sauer, et al., 1999; Wood, et al., 1999). Although N, P, and C are essential for the growth of aquatic biota in fresh water, most focus has been on P inputs because P is often the limiting element.Thus, controlling P inputs is of prime importance in reducing the increasing eutrophication of fresh waters.

Though N is often considered secondary in importance, in some regions, especially coastal areas, N acts as the primary nutrient (Allan, 1995). Sometimes, N and P together, influence algal growth. It is commonly acknowledged that when N:P ratios in sensitive waters fall below 16:1, algae will have less N per unit of P and experience N limitation, while ratios above 16:1 indicate P limitation. At N:P ratios between 10:1 and 20:1, mutual limitation by both nutrients is probable. Most estimates of the N:P ratio in freshwaters is above 16:1, implying that N is in abundant supply. This is even truer in freshwater water bodies in watersheds with agricultural land use.

Because of the lack of economically viable alternatives for manure disposal, agriculture production systems are often forced to continually receive manures as fertilizers. The ratio of N/P uptake by crops is usually much wider (8:1) than that provided in broiler litter (3:1) (Edwards and Daniel, 1992; Robinson and Sharpley, 1996). Therefore, repeated applications of broiler litter can lead to accumulations of large amounts of P in the surface soil (Kingerly et al., 1994; Sharpley et al., 1993).

The continued input of P at levels greater than utilization in farm production has created a P imbalance that has elevated soil P to levels that are of environmental concern in an increasing number of geographical areas (Sharpley et al., 1996a). Farmers are currently encouraged to apply animal manures based on crop P requirement, as opposed to N, for soils with high P contents (USDA-SCS, 1994). However, the problems with this suggestion have been: 1) there is a lack of crop response data to manure-P applications and, 2) there is difficulty in the identification of soil test P levels that are high enough to raise concerns about the potential for unacceptable levels of P loss in runoff.

Concerning the first issue, a lack of information on the fate of manure P in soil causes management recommendations for manure to often be based on data for mineral fertilizer P. However, differences between the availability of manure and fertilizer P have been found. Sharpley and Sisak (1997) advise that manure management recommendations should be based on field trials for manure P and its availability in soil rather than on fertilizer P. Another option suggested is the modification of fertilizer recommendations by soil $CaCO_3$, extractable Fe, and clay/organic C to account for the differential availability of manure and inorganic P sources in the soil.

Regarding the second issue, establishing cutoff STP levels is often a highly controversial process for many reasons. Mainly, the data base relating soil test P (STP) to runoff P is limited and, when available, is considered site-specific. Because of the differences in DRP concentration of runoff originating from different soil types with the same Mehlich 3 P content, Sharpley (1995a) concluded that relationships between runoff and soil P will have to be soil specific for use in making nutrient management recommendations or developed with a universal extractant for predicting P in runoff.

Compounding the problem of the identification of unsafe STP levels is the fact that within states and regions, clear areas of P deficiency and excess exist. In spite of the difficulties described above, some states are developing soil and extraction specific critical STP levels ranging from 75 to 200 mg P kg^{-1} (Sharpley et al., 1996a). Reducing system inputs of P and, ultimately, P loss in runoff to freshwaters will be particularly difficult in manure-producing areas with limited acreage and P removal by crops. Sharpley, et al. (1996a) concluded that STP should not be the sole criteria to determine the potential for P enrichment in runoff and subsequent fertilizer and/or manure application rates. Several research groups around the country are currently developing an approach, called the P Index, which integrates STP with potential runoff and erosion losses, local climatic, and agronomic factors to estimate the risk potential for runoff P (Lemunyon and Gilbert, 1993). Another potential approach is the use of simulation models to identify situations with potential for significant P in runoff. Simulation modeling can be a cost-effective approach if the equations and parameters used adequately reflect the relevant processes in the field.

RESEARCH OBJECTIVES

The objectives of this research were 1) to evaluate the changes in NH_4^+-N and DRP concentrations with time in surface runoff from grasslands that received broiler litter during two years and only commercial fertilizer N during the two subsequent years, 2) to identify factors that control the average concentration of NH_4^+-N and DRP in cumulative runoff following a broiler litter application, 3) to determine whether soil test P can be used to assess the potential for broiler litter amended grasslands to release P in runoff, and 4) to evaluate the ability of the EPIC model to simulate runoff volume and runoff P losses from five 0.75-ha, tall fescue-bermudagrass grazed paddlocks fertilized with broiler litter and commercial fertilizer.

LITERATURE REVIEW

GRAZED PASTURES AS SOURCES OF RUNOFF N AND P

Grazed pastures are complex ecosystems that are continuously altered by the activities of man and domestic herbivores. Most of the highly productive pastures of the world came into existence by removing forested vegetation and sowing improved grass, often non-native (Snaydon, 1981). Fertilizer and/or manure applications are necessary to maintain highly productive pasture species. Increased nutrient availability from fertilizer and manure applications and the subsequent increases in pasture production enhance animal production.

Grazing animals influence the amount and distribution of soil nutrients by returning 60-99% of the nutrients that they ingest in feed to the pasture in the form of dung and urine (Barrow, 1987). More than one billion Mg of manure are produced annually by the U.S. livestock industry (Safley et al., 1991). Dung deposited on pastures has been measured to be as much as 25 kg animal^{-1} day^{-1}(wet weight) (MacDiarmid and Watkin, 1972). One third of the total amount of dung deposited can be found on less than 5% of the field (Haynes and Williams, 1993). Although excretal patches may cover only 30-40% of the pasture surface annually, the high nutrient input stimulates herbage growth, which may represent up to 70% of the total annual pasture production (Saunders, 1984). Managed pastures cover about 20% of the earth’s land surface and rangelands cover another 30% (Snaydon, 1981). According to the National Cattlemen’s Association, non-confined cattle operations generally do not pose a significant risk to water quality degradation (Tucker and Smith, 1991). They claim that properly grazed pastures actually improve water quality - acting as a sink to filter sediment and remove excessive nutrient loads. The Cattlemen’s Association admits that the potential does exist for nonpoint source pollution to occur in areas that are improperly grazed or where cattle congregate. They believe that this may be due to vegetative cover loss and that better management can counteract this problem. The National Cattlemen’s Association suggests that rotational grazing, alternative water sources, mineral placement, and proper grazing density could promote efficient use of grazed areas without an environmental threat.

Amounts of nutrients returned to the soil in dung and urine from grazing animals vary widely among farming systems, nutrient content of the diet, individual intake of animals, and physiological differences between animals. Fecal excretion of N is usually 0.8 g N 100 g^{-1} of dry matter consumed, regardless of the N content of the feed (Barrow, 1987). The remainder of N is excreted in the urine and as the content of N ingested increases, so does the N in urine (Haynes and Williams, 1993). The average N content of feces, which is mostly in an organically-bound form, is 2.0-2.8% N (dry matter basis). The N mineralization from feces is slower than that from the plant materials from which they were derived. A large proportion of the C content of feces consists of undigested fibrous material (cellulose, hemicellulose, and lignin), which degrades slowly. Though the concentration of N in urine varies, it has been found to be between 6.8 and 21.6 g N $liter^{-1}$ (Bristow et al., 1992), primarily in the form of urea, which quickly hydrolyzes to NH_4^+-N.

Fecal P represents the predominant pathway for animal returns of P to grazed pasture; only trace amounts of P can be found in urine of ruminants. Total fecal P content is directly correlated with total P intake. Dung contains a higher P content of both organic and inorganic P than does ingested pasture (Rowarth et al., 1988). Dung P decomposes slower than N in urine for physical reasons alone. The dung pat must be broken down by animal trampling, microbial decomposition, or rainfall impact.

Nutrients may leak from the soil/plant/animal system in the dung and urine patch areas through gaseous losses, leaching, and runoff losses. Sauer et al. (1999) suggest that grazing animal wastes are not as significant a source of nutrients in runoff as applied poultry litter. These implied results are relative to the frequency, amount, and type of fertilizer applied to grazed grassland. The conclusions of Sauer et al. (1999) were based on runoff collected 1 and 14d after application of poultry litter, dairy calf feces and urine, and poultry litter and dairy waste combined. Results may not be applicable to long-term situations because the potential losses from poultry litter would diminish with time after application, whereas grazing animals continue to deposit wastes on the surface of the soil throughout the season or year.

NITROGEN AND PHOSPHORUS IN BROILER LITTER

Broiler litter contains between 2 and 5% total N (Edwards et al, 1994a; Yoon et al., 1994; Sauer et al., 1999; Wood et al., 1999). Qafoku (1998) and Gordillo and Cabrera (1997) found that between 6.5 and 9.0%, respectively, of total N in broiler litter is ammonium-N (NH_4^+-N), which results in a typical litter containing approximately 0.4 % NH_4^+-N and 4% organic-N**.** Scott et al. (1995) estimated that 20 to 30% of the organic N is mineralized during the first month after application. The N in broiler waste applied to pastures can subsequently be nitrified and potentially enter ground and surface water supplies as NO_3^- -N and NH_4^+-N.

Broiler litter contains approximately 1.5 to 3.4% P (Edwards et al, 1994a; Yoon et al., 1994; Sauer et al., 1999; Wood et al., 1999), of which 16 to 25% is water soluble (Kuykendall et al., 1999; Sauer et al., 1999). Due to the intensive sorption of P by soil colloids and subsequent formation of insoluble compounds with aluminum, iron, and calcium, P does not normally contaminate groundwater. However, long-term additions of broiler litter may increase soil P levels above the amount required for growth of pastures and may lead to increased P concentrations in surface runoff.

NITROGEN AND PHOSPHORUS IN AGRICULTURAL RUNOFF

Nitrogen in runoff

Ammonium-N is the principal form of N in agricultural runoff, and NO_3^--N is the primary form of N contaminating groundwater. Ammonium is the initial form of N in runoff from broiler litter treated grasslands. In a simulated runoff study with fescue plots receiving 6.7 Mg poultry litter ha^{-1}, Sauer et al. (1999) measured NH_4^+-N concentrations of 33.1 mg N L^{-1} and 0.63 mg N

L^{-1} in runoff occurring 1 and 14 d after application, respectively. Wood et al. (1999) reported flow-weighted concentrations of 2.7 mg NH_4^+-N L^{-1} in a seasonal study determining nutrient losses via surface runoff on 33 by 33 m corn and rye plots fertilized with broiler litter at 18 Mg litter ha^{-1}. In another study, Yoon et al. (1994) reported seasonal losses of 5.8 kg NH_4^+-N ha^{-1} in runoff from plots with conventionally tilled corn and rye (as a winter cover crop) that were fertilized with 18 Mg poultry litter ha^{-1}.

The processes governing the amount of NH_4^+-N available for runoff transport from broiler litter treated grasslands, excluding NH_4^+-N applied initially in the broiler litter, are mineralization, volatilization, immobilization, denitrification, and plant uptake. Mineralization is the conversion of organic N to inorganic N. It occurs quite rapidly following application of poultry litter because a significant proportion of the N in poultry manure is uric acid, which is readily converted to NH_4^+-N by uricase. Ammonium (NH_4) is in equilibrium with ammonia (NH_3), which is available to loss through volatilization. The loss of (NH_3) is favored by high soil pH, high soil temperatures, high winds, and evaporative loss of soil water (Troeh and Thompson, 1993). Ammonium in the soil can also be oxidized to NO_2^--N and NO_3^--N through the process of nitrification. Microbial immobilization can occur under aerobic conditions when poultry litter, having a high C:N ratio, is applied (Gale and Gilmour, 1986). Denitrification, loss of N in gaseous form, may occur if anaerobic conditions exist following application of poultry waste.

Phosphorus in Runoff

Phosphorus in runoff may be found in dissolved and in particulate forms. Dissolved forms can be present as organic P and inorganic P (orthophosphate or PO_4^{-3}). Particulate forms can also be present as organic and inorganic P. Particulate P includes P sorbed by soil particles and organic matter eroded during runoff and constitutes the major portion of P transported from conventionally tilled land (75-95%). Given the lack of mobility of P in soils, the soil surface may be highly enriched in P, relative to the entire topsoil. This is particularly true where long-term P applications coincide with reduced tillage situations. Runoff from grass or forest land carries little sediment and is dominated by dissolved P (Sharpley et al., 1992). Thus, loss of particulate forms of P are not of much concern in grazed grasslands.

Dissolved inorganic P may enter the soil solution, become sorbed onto charged particles, form complexes with metal oxides and hydroxides, or be lost in surface runoff. In most soils, soil solution P ranges between <0.01 and 1 mg L^{-1}. A value of 0.2 mg P L^{-1} is commonly accepted as the solution P concentration needed to meet the nutritional needs of most agronomic crops (Wood, 1998). Sorption of PO_4^{-3} onto charged clays and organic particles occurs at high concentrations of orthophosphate, while desorption is favored by low concentrations. Both orthophosphate and dissolved organic P may complex with metal oxides and hydroxides to form insoluble precipitates, which may be released under anaerobic conditions.

The broiler litter P that can be lost in runoff is initially the water-soluble inorganic P present in the litter that does not react with the soil. In addition to that, dissolved inorganic P in runoff may come from the desorption, dissolution, and extraction of P from soil and crop residues. These processes occur as rainfall interacts with a thin layer (1-2.5 cm) of surface soil before leaving the field as runoff (Sharpley, 1985). Once P is dissolved in runoff water, sorption or desorption with runoff sediment may occur (Sharpley et al., 1981). The magnitude and direction of P transformation is dependent on the concentration of dissolved P, particulate P, and sediment in runoff. In runoff from no till or pasture, the sediment load is generally so low that little sorption of dissolved P occurs, and dissolved P losses can exceed those in runoff from fields with higher erosion (Sharpley et al., 1992).

The amounts of broiler litter P lost in agricultural runoff depend on management factors such as rate, timing, and method of application. A relationship between P loss in runoff and rate and method of P application has been established through field studies. An increase in P loss in runoff with increasing application rate of fertilizer (McLeod and Hegg, 1984), dairy manure (Mueller et al., 1984), poultry litter (Edwards and Daniel, 1993), and swine manure (Edwards and

Daniel, 1994) has been reported. Heathman et al (1995) reported 0.52 mg soluble P L^{-1} concentration in runoff from no-till bermudagrass receiving 11 Mg litter ha^{-1}. Wood et al. (1999) reported flow-weighted concentrations of 1.43 mg DRP L^{-1} in a seasonal study determining nutrient losses via surface runoff on 33 by 33 m corn and rye plots fertilized with broiler litter at 18 Mg litter ha^{-1}. In another study, Yoon et al. (1994) reported seasonal losses of 1.8 kg soluble P ha^{-1} in runoff from plots with conventionally tilled corn and rye (as a winter cover crop) that were fertilized with 18 Mg poultry litter ha^{-1}.

Timing of P application relative to the occurrence of intense runoff events is an overlooked factor in management programs that seek to limit P loss in runoff. The major portion of annual P loss in runoff generally results from one or two intense storms (Sharpley et al., 1994). Edwards and Daniel (1994) found that mean concentrations of nitrate, ammonium, total N, orthophosphate, and total P in runoff from fescue plots treated with broiler litter containing 217.6 and 87.4 kg ha^{-1} N and P, respectively) during a second rainfall (14 d after application) were not significantly different than in runoff from control plots. The authors recommend that environmentally-based management practices should focus on reducing runoff losses during the first post-application runoff event.

Sauer et al. (1999) measured soluble reactive P concentrations of 13.5 mg P L^{-1} and 1.2 mg P L^{-1} in simulated runoff 1 and 14 d after application, respectively, of 6.7 Mg poultry litter ha^{-1} onto fescue plots. Sharpley (1997) found that the decrease in dissolved and bioavailable P in runoff from 10 Oklahoma soils during 10 successive rainfalls after broiler litter addition were related to percent saturation of soil P sorption sites; thus, soil type is nearly as important as runoff event timing in influencing P loss.

In the search for management alternatives that might improve runoff water quality, Edwards et al. (1996) conducted a study with two pairs of fields previously treated with broiler litter. One field in each pair continued to receive broiler litter and the other received ammonium nitrate. Soil and runoff P concentrations decreased with time in the fields receiving ammonium nitrate; thus, it may be possible to improve runoff water quality quickly by replacing animal manures with fertilizer N for fields with adequate soil P.

Edwards et al. (1994b) investigated drying interval effects on runoff quality from fescue plots receiving poultry litter to assess a recommended management practice of not applying poultry litter when rainfall is in the near-term weather forcast. Drying interval did not affect runoff concentrations of total P or orthophosphate indicating that management practices other than simply avoiding a runoff producing storm may be necessary to minimize P losses.

Logically, it seems that runoff quality might be improved if applied poultry litter is incorporated rather than surface applied. Nichols et al. (1994) found that poultry litter incorporated 2 to 3 cm deep by rotary tillage did not improve runoff quality as compared to surface application on grassland. A tillage practice that more thoroughly incorporates the litter might reduce nutrients in runoff more effectively, but this would probably reduce sward productivity and could increase soil erosion**,** thereby increasing sediment-bound nutrient losses. Dissolved P and bioavailable P losses can actually be greater from no till than from conventional practices because of accumulation of crop residues and added P at the soil surface (Sharpley and Smith, 1991; Miller et al., 1993). The tradeoff of high dissolved P loss versus erosion and sediment bound P loss must be weighed against the potential benefits of each tillage practice in assessing their effectiveness.

Composting broiler litter prior to its application has also been proposed as a management scenario to reduce the risk of nutrient loss in runoff water. Surface flow from grassed fields fertilized with poultry litter (10 and 20 Mg ha^{-1}) and a combination of poultry litter and composted poultry litter (10 Mg ha^{-1} litter and 50 Mg ha^{-1} compost) showed highest soluble P concentrations in runoff (8.5 mg L^{-1}) from the fields that received litter and compost (Vervoort et al., 1998a and b). These results suggest that composting does not reduce the amount of phosphorus available for runoff transport. Other measures that could minimize P loss by erosion and runoff include buffer strips, riparian zones, terracing, contour tillage, cover crops, and impoundments (small reservoirs). However, remedial strategies must prioritize P-source management.

In addition to surface runoff, a portion of dissolved P may be transported through subsurface flow. Deal et al. (1986) measured high subsurface P losses in artificially drained soils in the North Carolina Coastal Plains, but others reported little P transport through this mechanism. Vervoort et al. (1998b) reported no P in subsurface runoff samples from bermudagrass-fescue watersheds treated with 10 or 20 Mg ha^{-1} poultry litter, and with 10 Mg ha^{-1} litter combined with 50 Mg ha^{-1} composted poultry litter. Similarly, Heathman et al.(1995) found addition of broiler litter at 11 Mg ha^{-1} had no effect on P loss in interflow on a Typic Paleudult in Oklahoma.

SOIL TEST PHOSPHORUS (STP) AND PHOSPHORUS IN RUNOFF

Concentrations of STP have become elevated through long-term application of manures, especially when applied according to agronomic N rates. Regions with highly concentrated animal production are especially susceptible to eutrophication due to excess P in surface waters. In these areas, manure is often applied to soils as a means of disposal. Thus, the inherent characteristics of animal manures and P uptake by crops promotes P build-up with a corresponding increase in potential P loss. Beef, dairy, poultry, sheep, swine, and turkey manures have an average N/P ratio of 4, while the N/P requirement of the major grain and hay crops is 8 (White and Collins, 1982). Therefore, since most manure application has historically been N-based instead of P-based, STP levels in animal producing areas have been increasing.

Another factor aiding in the elevation in STP levels is that, until recently, most soil test laboratories did not measure the actual value of STP once it exceeded an upper limit that was clearly adequate for crop response. Thus, land owners did not realize exactly how high STP was in many soils. Although soil testing is currently the best management tool available, it alone cannot assess the potential for soil P from an individual site or watershed to play a significant role in non-point source pollution.

Soil testing methods for P have typically been based on the chemical reactions that control P availability in soils. Because these reactions can vary between soils and physiographic regions, several distinctly different soil tests for P are now used in the U.S. (Kamprath and Watson, 1980). Using the current soil test practices, soils are identified that are well above optimum P concentrations needed for crop growth. The length of time that would be required for these soils to be depleted to adequate P range with no fertilization can be predicted. However, it is not known whether the environmental impact on water quality of soils with high P values can be predicted.

A considerable body of research shows that the extractable P content of soils influences the amount of P in runoff water, particularly if STP values exceeded those needed for optimum crop growth (Pote et al., 1996; Sharpley et al., 1985; Sharpley et al., 1996a; Sims et al., 1997). This demonstrates the need for soil testing methods that can accurately quantify the likelihood that environmental problems will be caused by agricultural P.

Traditionally, soil samples have been taken to a depth of 15 to 20 cm since this is the soil depth mixed by most tillage implements and containing the most plant roots. However, the sampling depth may need to be much shallower for an environmental STP. The best sampling depth if erosion or surface runoff of P is of primary concern should be <5 cm (Pote et al., 1996) because this is the zone of greatest interaction between soil and runoff water.

Soil samples for determining environmental P concentrations may need to be handled differently than routine agronomic soil samples. Miller et al. (1993) showed that water soluble P was greater when extracted from dried soils than when extracted from moist soils. The authors attributed the higher water soluble P levels in dried soils to the release of P from biological sources (i.e. microorganisms, plant roots) during the drying process.

Research has shown that traditional soil tests for P (sampling depths and handling) are positively correlated with dissolved P and/or bioavailable P in soils and/or surface runoff (Daniel et al., 1993; Pote et al., 1996; Sharpley, 1995a; Sharpley et al., 1996a and b; Simard et al., 1995). While soil test P is related to P concentrations in runoff, different amounts of P can be lost from sites with similar STP contents depending on site characteristics such as slope, vegetative cover, and soil management and fertilizer application practices (Sharpley, 1995b).

An important first step in relating STP and P losses to water is the establishment of unacceptable P concentrations in agricultural runoff. Theoretically, this concentration would vary depending on the proximity of a P-sensitive water body and its intended use. Once this level is determined for a physiographic region, the critical soil test P value that has the potential to cause this concentration can be determined. This critical level for soil test P is both likely to be site-specific and may change with time. One mg P L^{-1} has been tentatively proposed as the maximum desirable concentration in surface runoff from agricultural fields (USEPA, 1986).

The Phosphorus Index System, a comprehensive approach that integrates STP with many of the other factors that determine the potential for P contamination, has been proposed. The P Index is a field oriented matrix system that assigns an interpretive rating to P availability, fertilizer and organic manure and waste management, and transport phenomena (erosion and runoff). Each of the characteristics is also given a weighting factor, which reflects its relative importance to P loss. Sites are ranked within a given watershed in terms of potential to deliver excessive P to surface waters. It is important to understand that, due to lack of field research, the weighting factors at present are based on the professional judgement of the scientists that developed the P Index System (Lemunyon and Gilbert, 1993; Sims, 1996).

SIMULATION MODELING

It is impossible to use experimental results to evaluate the potential P loss for specific sites. Since the number of variables influential in runoff transport of P is simply too large to rely entirely on experimental techniques for determination of effective management options, indirect methods must be used to at least some degree as a substitute for experimental observations. Mathematical simulation models are increasingly used as an indirect method of calculating the effectiveness of potential management options in reducing off-site pollutant transport. Simulation modeling may be a cost-effective approach if the equations and parameters adequately reflect the physical processes occurring.

Erosion-Productivity Impact Calculator (EPIC):

The EPIC model was originally developed to evaluate the effect of soil erosion on soil productivity. It was used as a part of the 1985 RCA (1977 Soil and Water Resources Conservation Act) analysis. The model has since been broadened and refined to allow the simulation of additional processes important to agricultural management (Sharpley and Williams, 1990; Williams et al., 1990; Williams, 1995).

The EPIC model is a comprehensive, continuous, lumped parameter, field-scale simulation model capable of estimating runoff and runoff transport of nitrate-N, organic-N, soluble-P, total-P, and sediment yield. It runs on a daily time step and considers a drainage area of up to 100 ha. Climatic sequences including temperature, precipitation, wind, solar radiation, and relative humidity can be read as input or generated within the model. Numerous influential processes such as crop growth, soil nutrient dynamics, leaching, and management operations (tillage, harvest, grazing, etc.) are mathematically described within the model.

The plant growth submodel of EPIC operates on a daily time step to simulate water and nutrient uptake and the interception and conversion of energy to above ground biomass, crop yield, and root growth for most common crops. Plant growth is constrained by water, nutrient, and air temperature stresses. Growth for both annual and perennial crops can be simulated.

EPIC describes the soil as a series of layers, up to ten, of varying thickness, each with its own bulk density, hydraulic conductivity, available water capacity, and other soil characteristics. EPIC has an extensive soil data base of 144 soils and consists of soil chemical, physical, and taxonomic data available in the U.S. Soil Conservation (SCS)/State Agricultural Station Soil Survey Investigative Reports (SSIR’s) and SCS pedon descriptions.

The hydrology submodel uses daily rainfall to estimate runoff using the Soil Conservation Service curve number method (USDA-SCS, 1972). A modified rational formula method is used to estimate peak discharge (USDA-SCS, 1986). A stochastic element is included in the Rational Equation to allow realistic simulation of peak runoff rates given only daily rainfall and monthly rainfall intensity.

The model offers four options for estimating potential evapotranspiration: Hargreaves and Samani (1985), Penman (1948) [default], Priestley-Taylor (Priestly and Taylor, 1972), and Penman-Monteith (Monteith, 1965). The Penman and Penman-Monteith methods require solar radiation, air temperature, wind speed, and relative humidity as inputs.

EPIC can estimate erosion with the USLE (Wischmeier and Smith, 1978), Onstad and Foster=s modification of the USLE (Onstad and Foster, 1975), variations of the MUSLE (Williams, 1975), or a variation of the MUSLE that accepts input coefficients. Whereas the USLE relies strictly on rainfall as an indicator of erosive energy, the MUSLE and its variations use only runoff variables to simulate erosion and sediment yield. The Onstad-Foster equation contains a combination of the USLE and MUSLE energy factors.

EPIC’s livestock grazing option is simulated as a daily harvest operation. Daily grazing rates in kg ha^{-1}, minimum grazing height in mm, harvest efficiency, and grazing begin and end dates are required as input. Harvest efficiency estimates the fraction of grazed plant material used by animals and not returned as manure and urine. Grazing pauses when forage height is decreased to the user specified cutoff value and resumes automatically when new growth surpasses the cutoff height and the grazing period has not ended.

Phosphorus in EPIC:

The structure of the soil and plant P model incorporated into EPIC provides for pools of stable, active, and labile inorganic P; fresh organic and stable organic P; and grain, stover, and root P. Fertilizer P is labile at application, but may be quickly transferred into the active inorganic P pool. Flow between labile and active inorganic P pools is governed by the equilibrium equation:

$$MPR_{l} = AP_{l} - MP_{al}\,(PSP_{l}/(1 - PSP_{l}))$$

where: MRP is the mineral P flow rate in $kg^{-1}ha^{-1}d^{-1}$in layer l ;

AP is the amount in labile inorganic P pool in kg ha^{-1};

MP_a is the amount in active inorganic P pool in kg ha^{-1}; and

PSP is the P sorption coefficient, defined as the fraction of fertilizer P remaining in the labile P pool after the initial rapid phase of P sorption is complete.

The amount of P computed with the above formula is daily subtracted from the labile pool and added to the active P pool. When MRP is negative, the flow reverses and is multiplied by 0.1 since the reverse flow is much slower. The P sorption coefficient is a function of chemical and physical soil properties and can be described by one of four different equations (i.e. one for calcareous soils and three for non-calcareous soils including slightly weathered, moderately weathered, and highly weathered). The proportionate sizes of the labile and active inorganic P pools are soil specific and are based on soil classification, texture, and chemical properties.

The flow between active inorganic P pool and stable inorganic P pool is governed by the equation:

$$\mathrm{ASPR}_l = W\,(4\mathrm{MP}_{al} - \mathrm{MP}_{sl})$$

where: ASPR is the flow rate between active and stable inorganic P pools in $\mathrm{kg}^{-1}\mathrm{ha}^{-1}\mathrm{d}^{-1}$ for layer l;

W is the flow coefficient in d^{-1};

MP_a is the amount in active inorganic P pool in kg ha^{-1}; and

MP_s is the amount of stable inorganic P in $\mathrm{kg}^{-1}\mathrm{ha}^{-1}$.

When $\mathrm{MP}_{sl}>4\mathrm{MP}_{al}$, the flow reverses and is multiplied by 0.1 since reverse flow is much slower. This amount of P is added to the stable inorganic P pool and subtracted from the active inorganic P pool daily to simulate slow adsorption of P. The flow coefficient is a function of PSP and is expressed by one of two equations: one for calcareous, and one for nonclacareous soils.

Portions of the P are added to the fresh organic or labile inorganic P pools when organic fertilizer is added. These values can be added to the existing EPIC fertilizer file easily if the user has this data from a specific fertilizer or manure.

Crop P uptake from a soil layer is governed by amounts of labile P, soil water, and roots in the layer. Stover and root P are added to the fresh organic P pool after their death and /or incorporation into the soil. Decomposition of fresh and stable organic matter may result in net immobilization of labile P or net mineralization of organic P (Jones et al., 1984). The daily amount of immobilization is computed by subtracting the amount of P contained in the crop residue from the amount assimilated by the microorganisms. Phosphorus mineralization from the fresh organic P pool is a function of the amount of organic P in crop residue in each soil layer and a decay rate constant. Mineralization of organic P associated with humus is estimated by a separate equation that takes into account the organic P content in each soil layer, soil water and temperature, and the bulk density of the soil. At the end of each day, mineralized residue is subtracted from the fresh organic P pool, humus mineralization is subtracted from the organic P pool, 20% of organic P mineralized (from the fresh organic P pool and humus) is added to the organic P content of the soil, and 80% is added to the labile inorganic P pool.

The EPIC approach to soluble P loss in surface runoff is based on the concept of partitioning pesticides into the solution and sediment phases as described in Leonard and Wauchope (Knisel, 1980). Because EPIC assumes that P is mostly associated with the sediment phase, the soluble P loss in runoff can be expressed in this simple form:

$$YAP = 0.01(c_{LPl})\ (Q)\ /\ k_d$$

where: YAP is soluble P lost in runoff in kg P ha^{-1};

Q is runoff volume in mm;

c_{LP} is the concentration of labile P in soil layer l in g t^{-1}; and

k_d is a constant determined by dividing the P concentration of the sediment by that of the water in $m^3\ t^{-1}$. EPIC assumes k_d to be 175 (Williams, 1995).

A recently developed modification still being evaluated uses a nonlinear function of organic P to adjust the soluble P runoff estimate:

$$YAP = ((AP)(Q)\ x10(Wp/Wt))/0.1(Wt)(k_d)$$

where: YAP is soluble P lost in runoff in kg P ha^{-1};

Q is runoff volume in mm;

AP is labile P content in the top 10 mm soil in g t^{-1};

k_d is the P concentration of the sediment divided by that of the water ($m^3\ t^{-1}$);

Wt is the soil weight of the top 10 mm; and

Wp is the organic P content in the top 10 mm soil.

EPIC has been shown to produce reasonable results under a variety of site and management conditions. For example, it has been validated with a number of crops (Kiniry et al., 1990; Martin et al., 1993) and it has been found to adequately simulate runoff volumes and sediment yields during snowmelt (Puurveen et al., 1997). EPIC was also found to accurately reflect runoff quality trends on an event basis for fescue pastures receiving poultry manure slurry and poultry litter in Arkansas (Edwards et al., 1994). Predictions of both runoff volume, total P, and soluble P (except for dry poultry litter) were statistically ($p = 0.05$) correlated to corresponding observations. The overall performance of EPIC on a calendar year basis was also satisfactory. Because of the limited data available on the performance of EPIC in grasslands fertilized with poultry litter, however, more work is needed to determine if EPIC could be used to estimate runoff P losses under those conditions.

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Chapter 2

DYNAMICS OF PHOSPHORUS AND AMMONIUM CONCENTRATIONS IN SURFACE RUNOFF FROM GRASSLANDS FERTILIZED WITH BROILER LITTER

ABSTRACT

Previous research has shown that surface application of broiler litter to grasslands can increase concentrations of ammonium (NH_4^+-N) and dissolved reactive phosphorus (DRP) in surface runoff. It is not known, however, for how long after broiler litter applications that NH_4^+-N and DRP concentrations remain elevated. This project was conducted to study the dynamics of NH_4^+-N and DRP concentrations in surface runoff from grasslands fertilized with broiler litter, and to identify factors that affect those concentrations. Five 0.75-ha, fescue-bermudagrass paddlocks received four broiler litter applications in 1995 and 1996, and only inorganic fertilizer N in 1997 and 1998. Runoff from each paddock was measured, sampled, and analyzed for NH_4^+-N and DRP. Flow-weighted NH_4^+-N and DRP concentrations increased from background values of 0.5 and 0.4 mg L^{-1}, respectively, to values as high as 50.7 mg NH_4^+-N L^{-1} and 18.8 mg DRP L^{-1} in a runoff event that occurred immediately after the third litter application. Concentrations remained high while broiler litter was being applied but decreased steadily after the last application, reaching values near 1 mg L^{-1} (for NH_4^+-N and DRP) by 19 months after the final application. Among the factors that affected the average concentration of NH_4^+-N and DRP in cumulative runoff after a litter application were cumulative runoff, rates of total N and NH_4^+-N applied, and cumulative total litter N, total litter P, and water-soluble litter P applied during the four years of the study. The effect of STP on DRP concentrations depended on when the paddocks last received broiler litter.

INTRODUCTION

Surface application of broiler litter to grasslands may cause elevated concentrations of ammonium (NH_4^+-N) and dissolved reactive phosphorus (DRP) in surface runoff (Edwards and Daniel, 1993; Heathman, et al.,1995; Vervoort et al., 1998; Sauer, et al., 1999; Wood, et al., 1999). Surface water quality becomes of concern because P is usually the element limiting eutrophication in lakes and streams (Schindler, 1977). Nitrogen is of lesser concern, although in some regions, especially coastal areas, it can act as the primary limiting nutrient. Because of the lack of economically viable alternatives for broiler litter disposal, agricultural production systems are often forced to continually receive these manures as fertilizers. The ratio of N/P uptake by crops is usually much wider (8:1) than that provided in broiler litter (3:1) (Edwards and Daniel, 1992; Robinson and Sharpley, 1996). Therefore, repeated litter applications can lead to accumulations of large amounts of P in the surface soil (Kingerly et al., 1994; Sharpley et al., 1993).

Concentrations of NH_4^+-N from a runoff event simulated 1d after application of 6.7 Mg ha^{-1} poultry litter to tall fescue were found to be 33.1 mg NH_4^+-N L^{-1} (Sauer et al., 1999). In the same study, concentrations of DRP were recorded as 13.5 mg P L^{-1}. Similar, but more moderate, results have been found in other studies when runoff occurred soon after broiler litter application (Edwards and Daniel, 1994; Heathman et al., 1995; Sharpley, 1997). The reason for these high concentrations is that surface applications deposit the litter on top of the soil, where it is likely to interact with surface runoff water. Nutrient concentrations in runoff decrease with time after application (Edwards and Daniel, 1994; Sharpley, 1997; Sauer et al., 1999), probably because manure constituents are incorporated into the soil by the action of rain and/or animals with time. Most studies addressing surface runoff quality associated with the application of broiler litter have evaluated nutrient concentrations in simulated runoff events occurring soon after litter application (7 to 68 d; Edwards and Daniel, 1994;Sauer et al., 1999). Limited data are available on the changes in NH_4^+-N and DRP concentrations during an extended time after application. Wood et al. (1999) reported flow-weighted surface runoff concentrations of 2.69 mg NH_4^+-N L^{-1} and 1.43

mg DRP L^{-1} from corn and rye plots fertilized with broiler litter at 18 Mg litter ha^{-1}. Although Wood et al. (1999) determined longer term effects than studies monitoring runoff only immediately after application, runoff was not from grassland. To date, no study has evaluated long-term NH_4^+-N and DRP losses from permanent grassland with large plots that closely resemble field conditions. Such information is needed to design broiler litter management practices that minimize the potential for contamination of surface waters with N and P.

Farmers are currently encouraged to apply animal manures based on crop P requirement, as opposed to N requirements, for soils with high P contents (Soil Conservation Service, 1994). One of the challenges with this management is the difficulty of identifying soil test P levels that are high enough to raise concerns about the potential for unacceptable levels of P loss in runoff. Establishing these levels is often a highly controversial process because the data base relating soil test P (STP) to runoff P is limited and, when available, is considered site-specific (Sharpley, 1995; Sharpley et al., 1996). In spite of the difficulties described above, some states have established critical STP levels, ranging from 75 to 200 mg P kg^{-1} soil and specified by extraction method (Sharpley et al., 1996). It is clear, however, that more work is needed to study the relationship between STP and runoff DRP, especially for grasslands fertilized with broiler litter. Since applied litter is not incorporated into grasslands, STP may not be useful for determining the risk of runoff transport of P in these situations.

The objectives of this study were 1) to evaluate the changes in NH_4^+-N and DRP concentrations with time in surface runoff from grasslands that received broiler litter during two years and only commercial fertilizer N during the two subsequent years, 2) to identify factors that control the average concentration of NH_4^+-N and DRP in cumulative runoff following a broiler litter application, and 3) to determine whether soil test P can be used to assess the potential for broiler litter amended grasslands to release P in runoff.

MATERIALS AND METHODS

Five 0.75 ha fescue [*Festuca arundinacea* Schreb.]-common bermudagrass [*Cynodon dactylon* (L.) Pers.] paddocks located at the Central Georgia Branch Station, near Eatonton, Georgia (latitude 33°24' N, longitude 83°29' W, and elevation 150 m) were used for this study. Soil series at the site are Altavista (fine-loamy, mixed, thermic Aquic Hapludults), Cecil (fine, kaolinitic, thermic, Typic Kanhapludults), Helena (fine, mixed, thermic Aquic Hapludults), and Sedgefield (fine, mixed, thermic Aquic Hapludults).

During late fall and early winter 1994-95, paddocks were monitored to obtain baseline values for runoff NH_4^+-N and DRP concentrations before broiler litter application. The experimental design was one treatment only with each paddock treated as a replication. From March 1995 until March 1997, a put and take system was used to maintain 1340 to 1680 kg forage ha^{-1} on a dry matter basis. Broiler litter was applied in March and September/October 1995 and 1996 and urea-ammonium nitrogen solution (UAN) was applied in March of 1997 and 1998 (Table 2.1). The stocking method was continued through March of 1997; after that, all the paddocks were used for hay production.

Earthen berms (0.6 m high, 1.5 m wide) were constructed around each paddock to direct surface runoff to a 0.45-m H-flume equipped with a SENIX ultrasonic sensor (SENIX Corporation, Burlington, VA) to measure depth of flow, and with a 0.6-m Coshocton wheel to subsample surface runoff. The Coshocton wheel was modified so that at any point in time its pan would hold a composite sample of the last 1000 L of runoff that flowed through the flume. At pre-determined runoff volumes, samples were automatically collected from the Coshocton wheel pan and stored in an ISCO 3700FR refrigerated sampler (ISCO Corporation, Lincoln, NE). Samples were kept at 4°C until analyzed. Precipitation and runoff volume data were recorded with CR10 dataloggers (Campbell Scientific, Inc., Logan, UT). Yearly rainfall and number of rainfall events per year used in the analysis are in Table 2.2.

Preceding the initiation of the study and prior to each late winter application of broiler litter, 12 soil samples from the 0-5 and 0-15 cm were taken from each paddock (1.8 cm diameter). Soil samples were analyzed for Mehlich P (Mehlich, 1953), and the resulting values were averaged by paddock and sampling period.

Broiler litter samples were analyzed in quadruplicates for TKN and TKP using the micro-Kjeldahl method (Baker and Thompson, 1992). Inorganic N was extracted by shaking 0.2 g of litter with 40 mL 1.0 *M* KCL for 30 min. The supernatant volume was analyzed for ammonium-N with the salicylate-hypochlorite method (Crooke and Simpson, 1971) and for ($NO_3^- + NO_2^-$)-N with the Griess-Ilosvay method (Keeney and Nelson, 1982) after reduction of NO_3^- to NO_2^- with a Cd column. Water soluble P was determined by extracting 0.2 g broiler litter with 40 mL deionized water for 30 min, centrifuging, and measuring the orthophosphate-P in the supernatant volume by the molybdate blue method (Murphy and Riley, 1962).

Filtered samples (0.45 μm) were analyzed for DRP by the molybdate blue method (Murphy and Riley, 1962) and for NH_4^+-N by the salicylate-hypochlorite method (Crooke and Simpson, 1971). Average flow weighted concentrations of DRP and NH_4^{+-}N (mg L^{-1}) were obtained by dividing the mass of nutrient lost during a given interval by the corresponding total amount of runoff recorded for each runoff event. In most runoff events the coefficient of variation (CV) varied between 2.5 and 52%, but 13% of the runoff events had a CV between 52 and 100%.

RESULTS AND DISCUSSION

Dynamics of Ammonium and DRP Concentrations in Runoff

The mean flow-weighted ammonium concentration during the baseline measurement period was 0.5 mg NH_4^+-N L^{-1}. When broiler litter applications were initiated, NH_4^+-N concentrations increased above the baseline value (Fig. 2.1), particularly in the larger runoff events occurring soon after the second and third applications (as high as 50.7 mg NH_4^+-N L^{-1}). The amount of NH_4^+-N in the applied broiler litter available for transport in runoff decreases from the time of application for several reasons. It can be volatilized, used by plants, or oxidized into (NO_3^- + NO_2^-)-N. It is also the preferred form of nitrogen of soil bacteria and fungi (Allan, 1995).

The mean flow-weighted DRP concentration during the baseline measurement period was 0.4 mg P L^{-1}. Most of this DRP was likely derived from the dung deposited by grazing cattle since the soil was relatively low in P (13 mg P kg^{-1} by Mehlich I). This assumption is consistent with Sauer et al. (1999), who reported 0.79 and 0.24 mg soluble reactive P L^{-1} (1 and 14 d, respectively, from application) in runoff from fescue plots receiving 6.7 Mg ha^{-1} dairy feces and urine.

When broiler litter applications were initiated, DRP concentrations increased above the baseline value and remained above the baseline while broiler litter was being applied (Fig. 1). The highest DRP concentration recorded, 18.8 mg P L^{-1}, occurred 2d after the third litter application. Since the concentration of DRP in the runoff before the first broiler litter application was 0.4 mg P L^{-1}, these results confirm previous work showing increases in DRP following surface application of broiler litter (Edwards and Daniel, 1993; Shreve et al., 1995; Sauer, et al., 1999; Wood et al., 1999).

Although the first runoff-producing precipitation occurred 4 months after the fourth litter application, which allowed time for nutrient transformations, average flow-weighted DRP concentrations were high in the spring of 1997. This could have been due to the lower than normal amount of rainfall received during the 1996-97 winter. The rainfall for January, February, and March was 366 and 384 mm for 1995 and 1996, respectively, whereas the amount received in 1997 was 298 mm. A lower amount of rainfall produced a lower amount of runoff (Fig. 2.1), which in turn would lead to higher concentrations of DRP in runoff. The average NH_4^+-N concentrations for the same time period were not elevated, and did not remain high after any application, due to the many pathways of removal already mentioned. If the reason for the high DRP concentrations in Spring 1997 was the lower than normal rainfall the previous winter, then the rainfall received in January, February, and March of 1998 (496 mm) would explain the rapid decrease of DRP concentrations that year.

By 19 months (April 1998) after the last broiler litter application, the average flow-weighted concentration of DRP was 1 mg P L^{-1} and below for large and small runoff events alike. A concentration of 1 mg P L^{-1} has been tentatively proposed as the maximum desirable concentration in surface runoff from agricultural fields (USEPA, 1986).

Our results agree with Edwards et al. (1996), who conducted a study with two pairs of fields previously treated with broiler litter. One field in each pair continued to receive broiler litter and the other received ammonium nitrate. Both soil and runoff P concentrations displayed statistically significant decreasing trends in the fields receiving ammonium nitrate. They concluded that it may be possible to positively affect water quality in a relatively brief period of time by replacing animal manures with ammonium nitrate for fields with adequate soil P.

Factors Affecting NH_4^+-N and DRP Concentrations in Runoff

The average NH_4^+-N and DRP concentrations in the cumulative runoff following each application is shown in Fig. 2. The average concentrations were regressed against several variables suspected to be capable of explaining the concentrations obtained. The regression equations containing the relevant variables are shown in Fig. 2. 2. It should be kept in mind that these relationships apply to the conditions in the present study and should not be used for general prediction under different conditions. According to these regression equations, 99% of NH_4^+-N lost in runoff can be explained by cumulative runoff, total N applied in the latest application, cumulative N applied in the four years of the study, an interaction between cumulative runoff and NH_4^+-N applied in the last application, and an interaction between cumulative runoff and cumulative total N applied in the four years of the study. Ninety-six percent of the DRP lost in runoff can be explained by cumulative runoff, cumulative total P applied, cumulative soluble P applied, an interaction between cumulative runoff and soluble P applied in the last application, and an interaction between cumulative runoff and cumulative soluble P applied.

The average NH_4^+-N and DRP concentrations in cumulative runoff started at lower values for the first and fourth applications than for the second and third applications (Fig. 2). Also, concentrations for the first and fourth applications did not reach values as high as those for the second and third applications. This was probably caused by the long period of time observed between application and the next subsequent runoff for the first and fourth applications (approximately 7 and 4 months, respectively). In contrast, the first runoff event following the second and third applications occurred 11 and 2 d after application, respectively. Average DRP and NH_4^+-N concentrations in cumulative runoff decreased steadily after the fourth and final application, but the decrease was slower for DRP than for NH_4^+-N (Fig. 2.2; Table 2.3).

Soil Test P and DRP Concentrations in Runoff

Soil test P (STP) (Melich I) in the upper 5 cm of soil increased from 20.7 mg P kg^{-1} in the spring of 1995 to 197.4 mg P kg^{-1} in the spring of 1997 (Fig. 3, bottom graph). This period of time included four broiler litter applications that added a total of 468 kg P ha^{-1}. For the same period of time and corresponding soil samplings, the STP increased from 13 to 81.0 mg P kg^{-1} in the upper 15 cm. Because these high levels decreased relatively rapidly after the last litter application, it would appear that the highest STP levels were attained through the sampling of not only soil, but also broiler litter on the soil surface. Once runoff removed most of the soluble litter P from the soil surface, STP values decreased because the soil samples no longer included surface litter P.

The average DRP concentration in the cumulative runoff between two soil samplings increased from 0.35 to 9.48 mg P L^{-1} (Fig. 2.3) after three broiler litter applications and decreased to 1.05 mg P L^{-1} by the last soil sampling (2 yr after the last application). The general relationship between STP and DRP in runoff is not good because a given STP value is associated with a high

DRP while broiler litter was being applied and with a low DRP after broiler litter applications ceased (Fig. 2.3). Sharpley et al. (1996) reported that STP (0-5 cm) accounted for 58 to 98% of the variation in dissolved P concentration of runoff from watersheds of varying management and diverse agricultural land use.

The relationship between STP and DRP in runoff from grasslands that receive broiler litter may depend on time after application. For the purpose of further investigating this relationship, data from the first and last two soil samplings were grouped together because there had not been litter addition before the first sampling, and there had not been litter addition for 18 and 25 months before the last two soil samplings, respectively. Data from the middle three soil samplings were also grouped together since these were samples taken while the pastures were receiving broiler litter. The regression lines for the two data groups are different (Fig. 2.4). This illustrates that STP may not provide an accurate estimate of potential DRP loss in runoff from grasslands fertilized with broiler litter because the relationship is dependent on when the plots last received broiler litter.

An issue of importance not investigated in this study is the long-term effect of repeated bi-annual broiler litter additions. Pastures which have received broiler litter for many years could have STP values that are high enough for substantial desorption of P to occur during runoff events (Kingerly at al., 1994; Sharpley et al., 1993). Under those conditions, the decrease in DRP concentrations in the runoff and the STP levels may not take place as quickly as in this study.

CONCLUSIONS

Our results show that flow-weighted NH_4^+-N and DRP concentrations in individual runoff events remained above the initial background levels while broiler litter was being applied. As soon as broiler litter applications ended, NH_4^+-N and DRP concentrations began to decrease and were near 1 mg NH_4^+-N L^{-1} and 1 mg P L^{-1} by 19 months after the final litter application.

Factors that affected the average concentration of NH_4^+-N in cumulative runoff after a litter application were cumulative runoff, total N applied, cumulative N applied during the four years of the study, an interaction between cumulative runoff and NH_4^+-N applied, and an interaction between cumulative runoff and cumulative total N applied. Factors that controlled the average concentrations of DRP in cumulative runoff after a litter application were cumulative runoff, cumulative total P applied and cumulative soluble P applied during the four years of the study, and interactions between cumulative runoff and soluble P applied and between cumulative runoff and cumulative soluble P applied.

After four applications of broiler litter, soil test P increased from 20.7 to 197.4 mg P kg^{-1} in the upper 5 cm, and from 13 to 81 mg P kg^{-1} in the upper 15 cm. By the end of the study (2 yr after the last application), STP levels had decreased to 115.7 and 46.7 mg P kg^{-1}, in the upper 5 and 15 cm, respectively. It appears that the highest STP levels measured in this study may have included P from broiler litter found on the soil surface because STP decreased rapidly after litter applications ended. The relationship between STP and DRP concentrations in the runoff from these plots was found to be dependent on when the plots last received broiler litter. These results suggest that STP may be a difficult parameter to use in estimating the potential loss of P in surface runoff from grasslands fertilized with broiler litter.

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Table 2.1. Dates of applications and average amounts of broiler litter, total N, NH4-N, total P, and water-soluble P applied to plots.

Year	Date	Litter	Nitrogen		Phosphorus	
			Total	NH_4^+-N	Total	H_2O-soluble
		--------------------------kg ha^{-1}dry weight--------------------------				
1995	Mar 16	6037	271	57	105	16
1995	Oct 30	6314	264	58	104	20
1996	Mar 4	7929	483	83	159	29
1996	Sep 25	6402	258	41	103	28
1997	Mar 3	UAN	67	17	0	0
1998	Mar 24	UAN	56	14	0	0

Table 2.2. Annual precipitation and number of runoff events investigated.

Years	1995	1996	1997	1998
Precipitation (mm)	1123	1010	1176	1069
# runoff events	16	23	19	20

Table 2.3. Yearly runoff and losses of DRP and ammonium in runoff (s.d. in parentheses.).

Year	Runoff	Phosphorus	Ammonium-N
	Mm	--------------- kg ha^{-1}	---------------
1995	105.3 (15.8)	4.6 (1.9)	1.5 (0.9)
1996	105.9 (51.4)	9.0 (6.0)	13.3 (10.5)
1997	146.7 (66.5)	5.9 (3.7)	0.9 (0.4)
1998	190.6 (77.7)	2.6 (1.2)	0.5 (0.3)

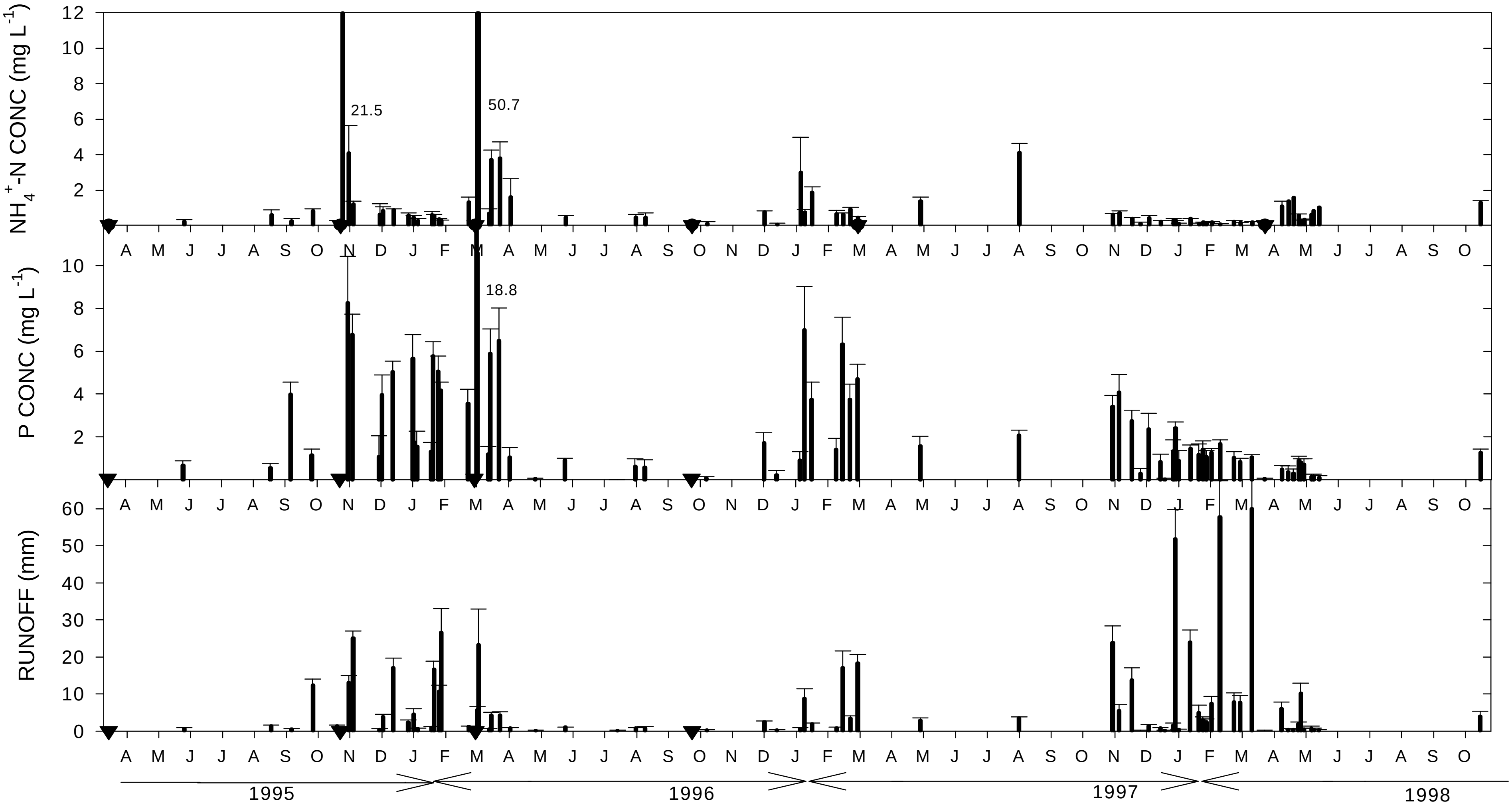


Figure 2.1. Average runoff and flow-weighted NH$_4^+$-N and DRP concentrations from March 1995 through May 1998 (down arrows indicate broiler litter and N fertilizer applications).

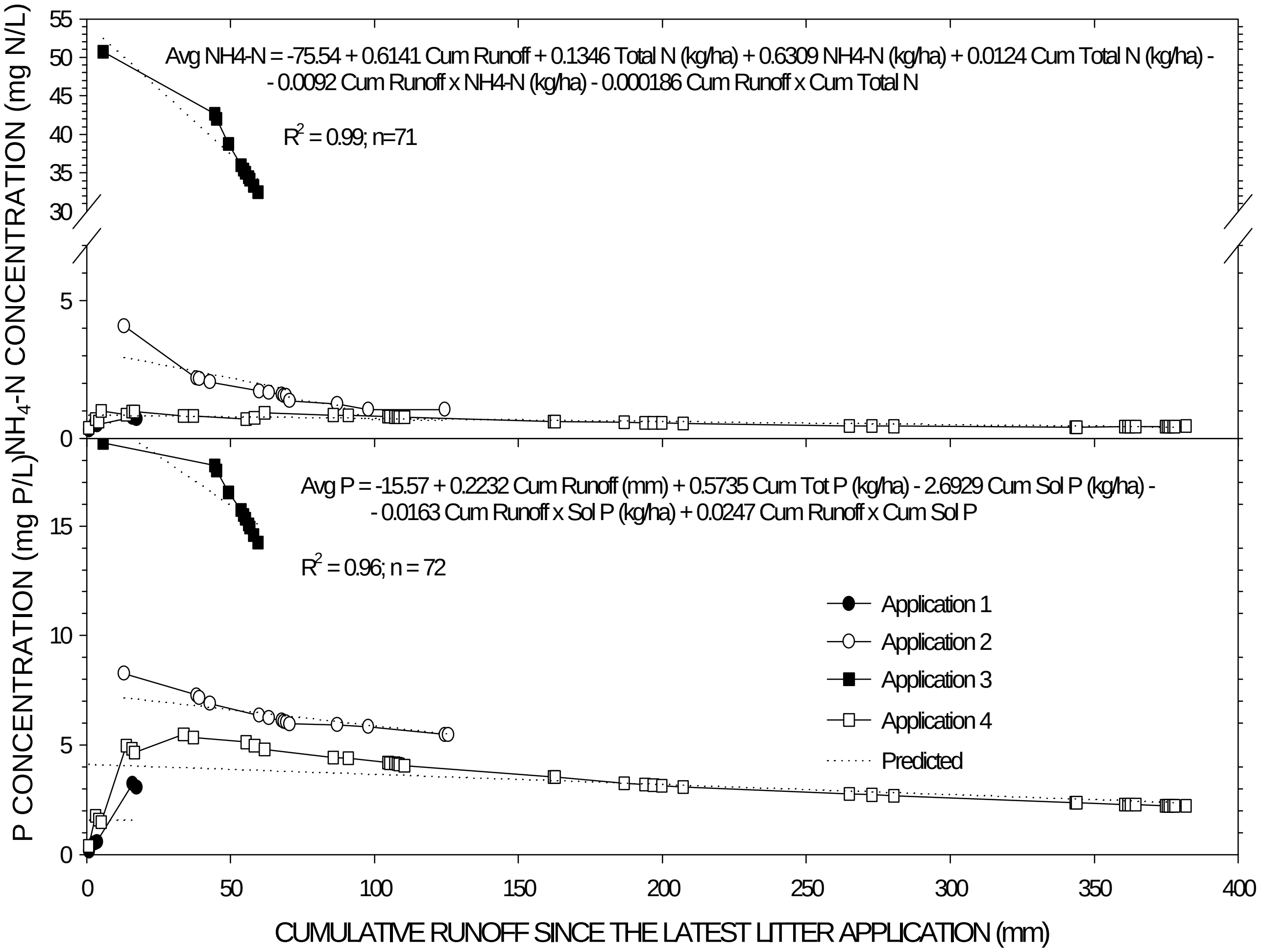


Fig 2.2. Average concentrations of NH_4^+-N and DRP in cumulative runoff after each litter application (dotted line shows concentrations predicted by the equation).

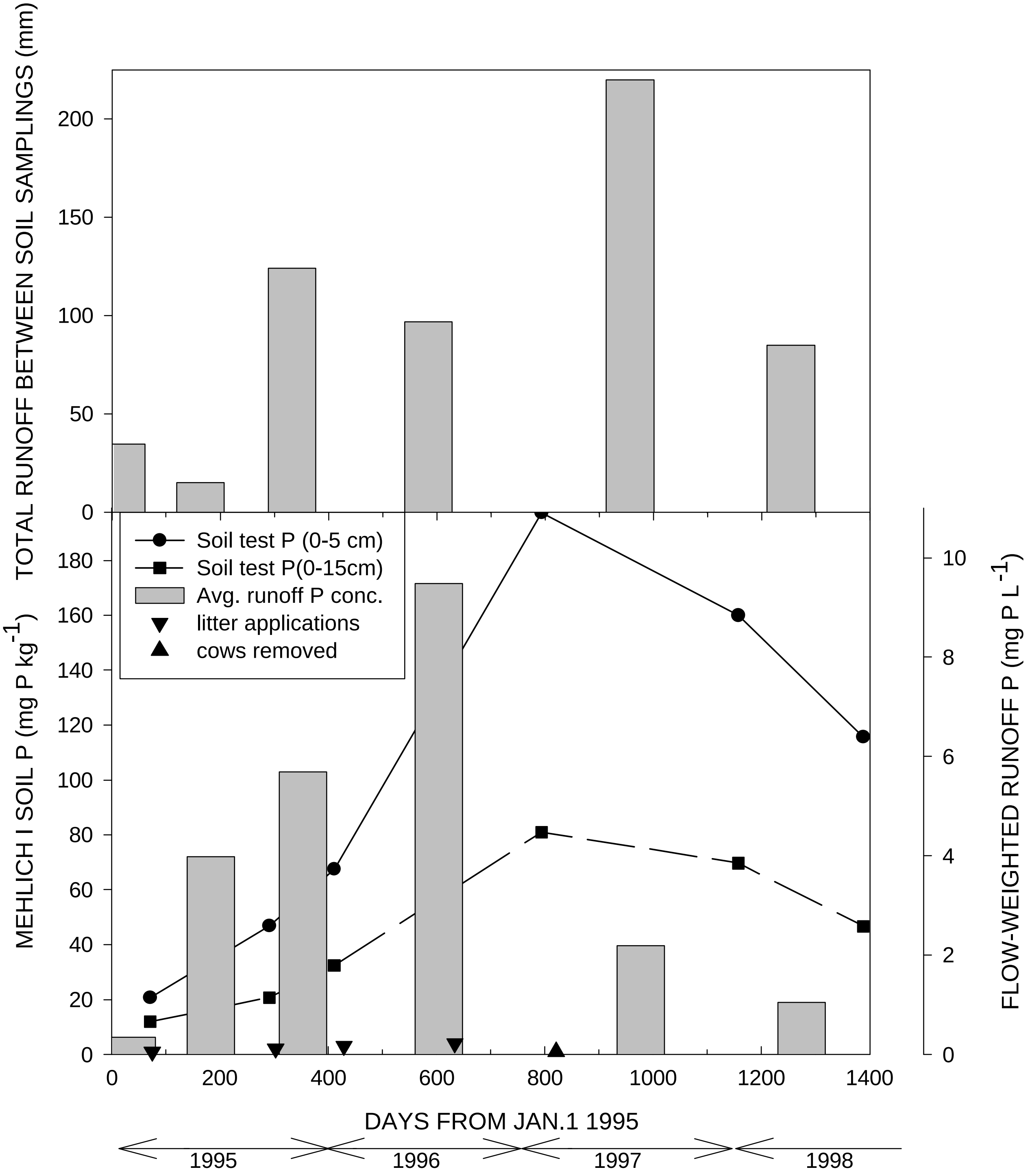
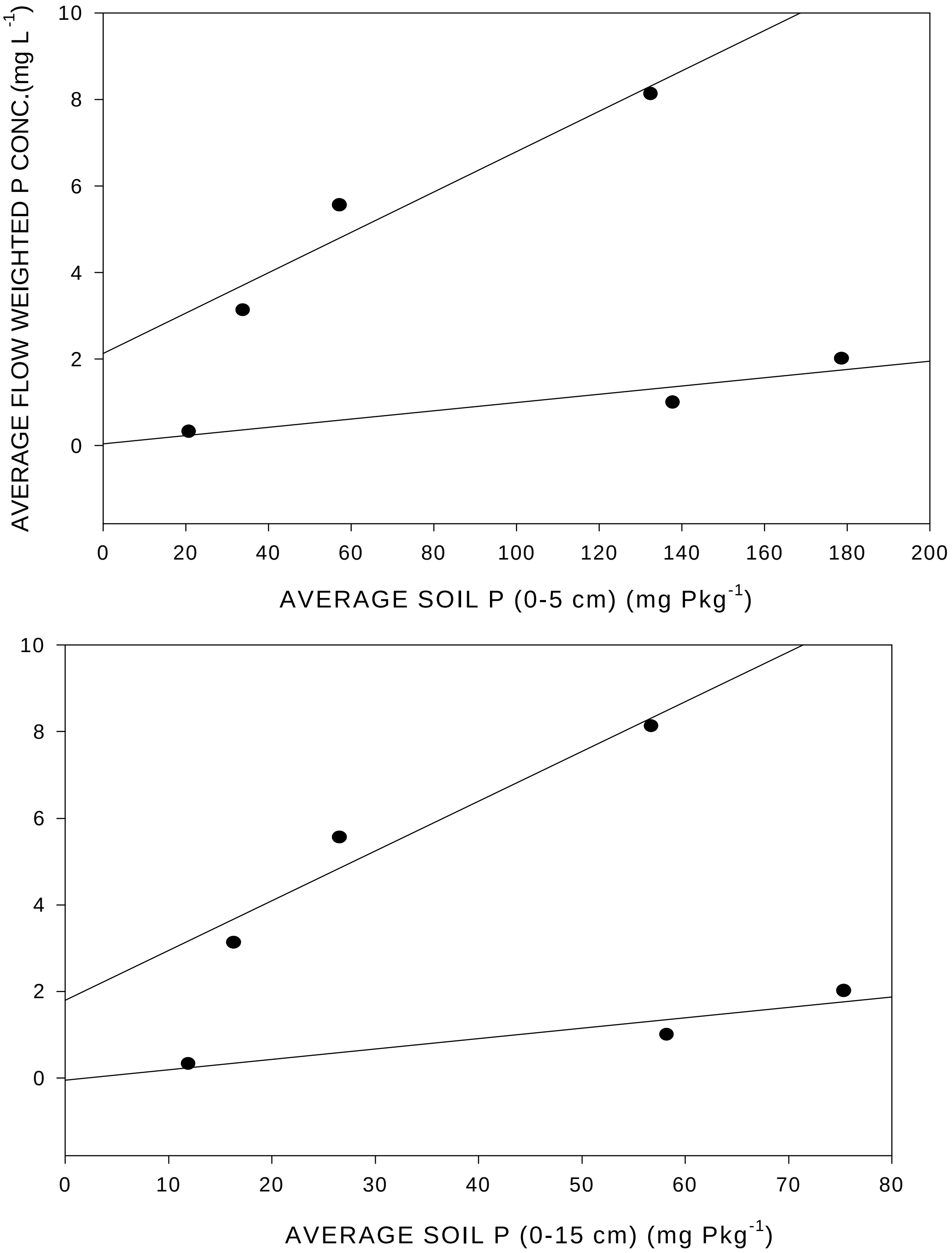


Fig. 2.3. Mehlich I soil P in the upper 5 and 15 cm (line graphs), average DRP concentration in cumulative runoff between two soil samplings (bottom bar graph), and cumulative runoff



between two soil samplings (top bar graph).

Fig. 2.4. Regression equations for Mehlich I soil P in 0-5 (top) and 0-15 cm (bottom) and average DRP concentration in cumulative runoff between soil samplings while plots were not

receiving broiler litter (bottom lines on each graph) and while plots were receiving broiler litter (top lines on each graph).

Chapter 3

ESTIMATING PHOSPHORUS RUNOFF LOSSES FROM GRASSLANDS FERTILIZED WITH BROILER LITTER WITH THE EPIC MODEL

ABSTRACT

Broiler litter, a mixture of poultry excreta and bedding material, is commonly used to fertilize grasslands in the southeastern United States. Previous work has shown that under certain conditions, application of broiler litter to grasslands may lead to elevated levels of P in surface runoff. Thus, there is a need for tools to identify situations in which the application of broiler litter may enrich surface runoff with P. One such tool is the simulation model Erosion Productivity Impact Calculator (EPIC). This work was conducted to evaluate EPIC's ability to simulate runoff volume and losses of dissolved reactive P (DRP) from five 0.75-ha, tall fescue-bermudagrass plots that were fertilized with broiler litter during two years and received only inorganic fertilizer N for the two subsequent years. Runoff volume simluated by EPIC for individual events was underestimated in one plot, overestimated in another, and predicted accurately in three plots. On an annual basis, the runoff volumes simulated by EPIC were similar to the observed ones. Whereas the original EPIC underestimated annual as well as event DRP losses, a modification of EPIC yielded better estimation of event DRP losses and generated estimates of annual DRP loss that were similar to the observed ones. These results suggest that the modified EPIC may be useful for identifying situations where there is a high risk of large annual P losses from grasslands fertilized with broiler litter.

INTRODUCTION

Phosphorus in agricultural runoff can stimulate eutrophication in P-limited surface waters. The likelihood of P loss in runoff is increased by the recurrent application of fertilizer and/or manure from intensive livestock operations (Edwards and Daniel, 1992; McFarland and Hauck, 1995; Shreve et al., 1995; Sharpley et al., 1996b). Surface application of broiler litter to pastures elevate concentrations of dissolved reactive phosphorus (DRP) in surface runoff (Edwards and Daniel, 1993; Heathman, et al.,1995; Vervoort et al., 1998; Sauer, et al., 1999; Wood, et al., 1999). The concentration of DRP in a runoff event simulated 1d after application of 6.7 Mg ha^{-1} poultry litter to tall fescue was 13.5 mg P L^{-1} (Sauer et al., 1999). Similar results have been found in other studies when runoff occurred soon after broiler litter application (Edwards and Daniel, 1994; Heathman et al., 1995; Sharpley, 1997; Kuykendall et al., 1999). The reason for these high concentrations is that surface applications deposit the litter on top of the soil where it is vulnerable to interaction with surface runoff water. Nutrient concentrations in runoff decrease with time after application (Edwards and Daniel, 1994; Sharpley, 1997; Sauer et al., 1999), because manure constituents are moved into the soil by rainfall and incorporated by fauna. Reduced availability of DRP is due to a combination of lessened contact with subsequent runoff and decreased surface P concentrations.

Farmers are encouraged, and in some states, required, to apply animal manures to soils with high P contents based on crop P requirement (USDA-SCS, 1994). One of the challenges with this suggested management is the difficulty of identifying soil test P of sufficiently high concentrations to cause unacceptable levels of P loss in runoff. Establishing these levels is often controversial because the data relating soil test P (STP) to runoff P is limited and, when available, is site-specific. Sharpley, et al. (1996a) concluded that STP is not the sole criteria to determine the potential for P enrichment in runoff and subsequent fertilizer and/or manure application rates. An approach that integrates STP with estimates of potential runoff and erosion losses and local climatic, topographic, and agronomic factors is being developed (Sharpley et al.,1996a; Lemunyon and Gilbert. 1993). Another approach involves the use of simulation models to identify situations with potential for significant P in runoff. Simulation modeling can be a cost-effective approach if the equations and parameters accurately reflect the relevant processes in the field.

The Erosion Productivity Impact Calculator (EPIC) (Williams, 1995) is a comprehensive, continuous, lumped parameter, field-scale simulation model capable of estimating runoff and runoff transport of nitrate-N, organic-N, soluble-P, total-P, and sediment yield. EPIC runs on a daily time step and can consider a drainage area of up to 100 ha. The model was designed to simulate soil erosion and its long-term effects on crop productivity for a wide variety of soils, climates, crops, and soil conservation practices using readily available data inputs.

The P submodel of EPIC simulates soil organic, inorganic, and plant P dynamics on a daily time step. It simulates P uptake and transformations in up to ten soil layers, and is sensitive to soil chemical and physical properties (i.e. sorption characteristics), crop P requirements, fertilizer rate, tillage practice, soil temperature, and soil water content (Williams, 1995).

EPIC has produced reasonable results under a variety of site and management conditions. For example, it has been validated for use with a number of crops (Kiniry et al., 1990; Martin et al., 1993). EPIC adequately simulated runoff volumes and sediment yields during snowmelt (Purveen et al., 1997). The model accurately reflected runoff quality trends on an event basis for fescue pastures receiving poultry manure slurry and litter in Arkansas (Edwards et al., 1994). Predictions of both runoff volume, total P, and soluble P (except for dry poultry litter) were statistically ($p = 0.05$) correlated to corresponding observations. The overall performance of EPIC on a calendar year basis was also satisfactory.

The objective of this study was to evaluate the ability of the EPIC model to simulate runoff volume and runoff P losses from five 0.75-ha, tall fescue-bermudagrass grazed paddlocks fertilized with broiler litter and commercial fertilizer. The EPIC model was chosen because of its comprehensive nature and its wide range of applications.

MATERIALS AND METHODS

Description of Monitored Site

Five 0.75 ha fescue [*Festuca arundinacea* Schreb.]-common bermudagrass [*Cynodon dactylon* (L.) Pers.] paddocks located at the Central Georgia Branch Station, near Eatonton, Georgia (latitude 33°24' N, longitude 83°29' W, and elevation 150 m) were used for this study. The dominant soil series at the site is Cecil (fine, kaolinitic, thermic, Typic Kanhapludults) but other series also present are Altavista (fine-loamy, mixed, thermic Aquic Hapludults), Helena (fine, mixed, thermic Aquic Hapludults), and Sedgefield (fine, mixed, thermic Aquic Hapludults).

Baseline values for runoff DRP concentrations were established before broiler litter application during late fall and early winter 1994-95, when paddocks were managed under continuous stocking. From March 1995 until March 1997, a put and take system that maintained 1340 to 1680 kg forage ha^{-1} on a dry matter basis was used. The stocking method was continued through March of 1997, after which all the paddocks were used for hay production. Broiler litter was applied in March and October, 1995 and March and September, 1996. Urea-ammonium nitrogen solution (UAN) was applied in March of 1997 and 1998. Selected chemical properties and rates of the broiler litter and fertilizer applications are presented in Table 1. Broiler litter samples were analyzed as described in Kuykendall et al., (1999). For statistical purposes, each paddock was treated as a replicate of the single treatment.

The paddocks were bordered by earthen berms (0.6 m high, 1.5 m wide) with a 0.45-m H-flume supplied with a sensor to measure depth of flow as described in Kuykendall et al. (1999). At planned runoff volumes, samples were automatically collected and stored at 4°C until analysis. Samples were analyzed for DRP by the molybdate blue method (Murphy and Riley, 1962). Precipitation and runoff volume data were recorded with dataloggers at the site.

Description of Simulation Model

The EPIC model was originally developed to evaluate the effect of soil erosion on soil productivity. It was used as a part of the 1985 RCA (1977 Soil and Water Resources Conservation Act) analysis. Since then, the model has been broadened and refined to allow for the simulation of additional processes important to agricultural management. Numerous influential processes such as crop growth, soil nutrient dynamics, leaching, and management operations (tillage, harvest, grazing, etc.) are mathematically described within the model.

The plant growth submodel of EPIC operates on a daily time step to simulate water and nutrient uptake and the interception and conversion of energy to above ground biomass, crop yield, and root growth for most common crops. Plant growth is constrained by water, nutrient, and air temperature stresses. Growth for both annual and perennial crops can be simulated.

EPIC describes the soil as a series of layers, up to ten, of varying thickness, each with its own bulk density, hydraulic conductivity, available water capacity, and other soil characteristics. EPIC has an extensive soil data base of 144 soils and consists of soil chemical, physical, and taxonomic data available in U.S. Soil Conservation (SCS)/State Agricultural Station Soil Survey Investigative Reports (SSIR's) and SCS pedon descriptions.

The hydrology submodel uses daily rainfall to estimate runoff using the Soil Conservation Service curve number method (USDA-SCS, 1972). A modified rational formula method is used to estimate peak discharge (USDA-SCS, 1986). A stochastic element is included in the Rational Equation to allow realistic simulation of peak runoff rates given only daily rainfall and monthly rainfall intensity.

The model offers four options for estimating potential evapotranspiration: Hargreaves and Samani (1985), Penman (1948) (default), Priestley-Taylor (Priestley and Taylor, 1972), and

Penman-Monteith (Monteith, 1965). The Penman and Penman-Monteith methods require solar radiation, air temperature, wind speed, and relative humidity as inputs.

EPIC can estimate erosion with the USLE (Wischmeier and Smith, 1978), with Onstad and Foster's modification of the USLE (Onstad and Foster, 1975), with variations of the MUSLE (Williams, 1975), or with a variation of the MUSLE that accepts input coefficients. Whereas the USLE relies strictly on rainfall as an indicator of erosive energy, the MUSLE and its variations use only runoff variables to simulate erosion and sediment yield. The Onstad-Foster equation contains a combination of the USLE and MUSLE energy factors.

EPIC's livestock grazing option is simulated as a daily harvest operation. Daily grazing rates in kg ha^{-1}, minimum grazing height in mm, harvest efficiency, and grazing begin and end dates were input. Harvest efficiency estimates the fraction of grazed plant material used by animals and not returned as manure and urine.

Phosphorus in EPIC

The structure of the soil and plant P submodel incorporated into EPIC provides for pools of stable, active, and labile inorganic P; fresh organic and stable organic P; and grain, stover, and root P. Fertilizer P is labile at application, but may be quickly transferred into the active inorganic P pool. Flow between labile and active inorganic P pools is governed by the equilibrium equation:

$$MPR_l = AP_l - Mp_{al} \, (PSP_l /(1- PSP_l))$$

where: MRP is the mineral P flow rate in $kg^{-1}ha^{-1}d^{-1}$in layer l ;

AP is the amount in labile inorganic P pool in kg ha^{-1};

MP is the amount in active inorganic P pool in kg ha^{-1}; and

PSP is the P sorption coefficient defined as the fraction of fertilizer P remaining in the labile P pool after the initial rapid phase of P sorption is complete.

The amount of P computed with the above formula is daily subtracted from the labile pool and added to the active P pool. When MRP is negative, the flow reverses and is multiplied by 0.1 since the reverse flow is much slower. The P sorption coefficient is a function of chemical and physical soil properties and can be described by one of four different equations (i.e. one for calcareous soils and three for non-calcareous soils including slightly weathered, moderately weathered, and highly weathered). The proportionate sizes of the labile and active inorganic P pools are soil specific and are based on soil classification, texture, and chemical properties.

The flow between active inorganic P pool and stable inorganic P pool is governed by the equation:

$$\mathrm{ASPR}_l = W\,(4\mathrm{MP}_{al} - \mathrm{MP}_{sl})$$

where: ASPR is the flow rate between active and stable inorganic P pools in $kg^{-1}ha^{-1}$;

d^{-1} for layer l ;

W is the flow coefficient in d^{-1};

MP_s is the amount of stable inorganic P in $kg^{-1}ha^{-1}$; and

MP_a is the amount in active inorganic P pool in kg ha^{-1}.

When $MP_{sl}>4MP_{al}$, the flow reverses and is multiplied by 0.1 since reverse flow is much slower. This amount of P is added to the stable inorganic P pool and subtracted from the active inorganic P pool daily to simulate slow adsorption of P. The flow coefficient is a function of PSP and is expressed by one of two equations: one for calcareous and one for noncalcareous soils.

Portions of the P are added to the fresh organic or labile inorganic P pools when organic fertilizer is added. These values can be added to the existing EPIC fertilizer file easily if the user has this data from a specific fertilizer or manure.

Crop P uptake from a soil layer is governed by amounts of labile P, soil water, and roots in the layer. Stover and root P are added to the fresh organic P pool after their death and/or incorporation into the soil. Decomposition of fresh and stable organic matter may result in net immobilization of labile P or net mineralization of organic P (Jones et al., 1984). The daily amount of immobilization is computed by subtracting the amount of P contained in the crop residue from the amount assimilated by the microorganisms. Phosphorus mineralization from the fresh organic P pool is a function of the amount of organic P in crop residue in each soil layer and a decay rate constant. Mineralization of organic P associated with humus is estimated by a separate equation that takes into account the organic P content in each soil layer, soil water and temperature, and the bulk density of the soil. At the end of each day, mineralized residue is subtracted from the fresh organic P pool, humus mineralization is subtracted from the organic P pool; 20% of organic P mineralized (from the fresh organic P pool and humus) is added to the organic P content of the soil, and 80% is added to the labile inorganic P pool.

The traditional EPIC approach to soluble P loss in surface runoff is based on the concept of partitioning pesticides into the solution and sediment phases as described in Leonard and Wauchope (Knisel, 1980). Because EPIC assumes that P is mostly associated with the sediment phase, the soluble P loss in runoff can be expressed as:

$$YAP = 0.01(c_{LPl}) (Q) / k_d$$

where: YAP is soluble P lost in runoff in kg P ha^{-1};

Q is runoff volume in mm;

c_{LP} is the concentration of labile P in soil layer l in g t^{-1}; and

k_d is a constant obtained by dividing the P concentration of the sediment by that of the water in m^3 t^{-1}.

EPIC assumes that k_d equals 175 (Williams, 1995). This approach is referred to as the “original” EPIC in our results.

A recently developed modification, which is still being evaluated, was used in obtaining a second set of simulated results for P loss (Williams, personal communication, 1999). This approach, which we have labeled as the “modified” EPIC, uses a nonlinear function of organic P to give it more weight in the determination of the soluble P runoff estimate:

$$YAP = ((AP)(Q) \times 10(Wp/Wt) /0.1(Wt)(k_d)$$

where: YAP is soluble P lost in runoff in kg P ha^{-1};

Q is runoff volume in mm;

AP is labile P content in the top 10 mm soil in g t^{-1};

k_d is determined by dividing the P concentration of the sediment by that of the water ($m^3\ t^{-1}$);

Wt is the soil weight of the top 10 mm; and

Wp is the organic P content in the top 10 mm soil.

The mathematical model descriptions and model input data requirements have been fully documented (Sharpley and Williams, 1990; Williams et al., 1990; Williams, 1995), and the model has produced reasonable results under a variety of site and management conditions (Edwards et al., 1994).

Model Inputs

An EPIC input file was constructed for each monitored paddock. Values of selected parameters (Table 2) were determined from readily available, published sources. EPIC’s default options were selected when given a choice. The Green & Ampt estimate of runoff volume was initially used because rainfall intensity, which was available, was input along with other weather inputs. However, results more closely matched observed data when the curve number estimate of runoff volume was used; thus, rainfall intensity data were discarded. Although EPIC has broiler litter as an option for fertilizer addition, values for mineral and organic N and P and the NH_4^+-N fraction were entered for the particular broiler litters used in this study instead of the ones provided in EPIC (Table 3). The average rates of broiler litter, N, and P applied to the paddocks were entered as input (Table 1).

Our simulations used the EPIC Cecil soil file, although small areas of the experimental plots were mapped as other soil series. Rainfall data were obtained from tipping bucket rain gauges located next to the plots. Maximum and minimum daily temperatures, solar radiation, relative humidity, and wind speed were obtained from a nearby (3 km) weather station. Other than the fertilizer and weather inputs already mentioned, base EPIC parameters were used for the simulations.

Daily estimates of runoff (Q, mm) and runoff losses of soluble P (YAP, kg ha^{-1}) were generated by EPIC based on the constructed data sets for the period of 1 January 1995 to 31 December 1998. Observed values were regressed against these daily estimates to assess the performance of EPIC on both an event-by-event basis and on a calendar year basis. The root mean square error of the simulated values were calculated. This study challenged EPIC's capabilities because (a) no parameters were calibrated, (b) the system involved pastures with mixed species, rather than single species, (c) the plots were grazed, and (d) broiler litter was used as an organic fertilizer.

RESULTS AND DISCUSSION

Runoff volume – event performance

There was a strong linear relationship (p=0.05) between observed and estimated values of runoff for single events (Fig. 1). These results are consistent with those found by Edwards et al. (1994), who used the EPIC model to estimate runoff volume and quality from fescue fields treated with poultry manure slurry, dry poultry litter, and ammonium nitrate. They found that the performance of EPIC for event predictions of runoff volume were significantly correlated (r^2=0.86;n=35;p = 0.05) to corresponding observations in all cases. In our study, the regression of observed against estimated runoff values for individual plots yielded intercepts that were not significantly different from zero and slopes that, with the exception of Plots 1 and 3, were not significantly different from one. These results indicate that the model did not have any bias in the estimation of event runoff volumes for Plots 2, 4, and 5. In contrast, Plot 1 had a slope significantly smaller than one (indicating overestimation) and Plot 3 had a slope significantly larger than one (indicating underestimation). These biases may have been due to the presence of soil series with different permeability in certain areas of these plots. For most runoff events the coefficient of variation of observed values varied between 2.5 and 52%, but 13% of the runoff events had a CV between 52 and 100%.

The regression of observed against estimated runoff volumes for all plots yielded parameters (Table 4) that were not very different from those obtained by Edwards et al. (1994). The slope was 0.97 (versus 1.14) and the intercept was 1.24 (versus 1.40). These results are encouraging because EPIC was developed to estimate runoff volume on a long-term basis, not in single runoff events. An improvement in single event runoff estimation could probably be obtained with a smaller time step, but that would require more detailed input values.

Runoff volume – annual performance

The regression of observed against estimated annual runoff volumes also showed a strong and significant (p=0.05) linear relationship (Fig. 2). The graph only employed 11 data points out of 20 possible points (5 plots X 4 years = 20) because only those data sets that were complete for each year were used in the regression. The intercept was not significantly different from zero, but the slope was smaller than one, which indicated a slight overestimation of annual runoff (Table 5). It is interesting to note, that the average annual runoff was 140 mm (standard deviation = 53 mm), and the EPIC estimated annual runoff was 135 mm (standard deviation of 53 mm). Thus, EPIC was able to simulate the trends in annual runoff observed in the data.

Loss of P in runoff – event performance

With the exception of Plot 2, there were strong (r^2 = 0.56 to 0.81) and significant (p=0.05) relationships between observed DRP losses in single events and values estimated by the original EPIC (Fig. 3, Table 4). The slopes of the regression of observed against simulated values were much larger than one, which indicates that the original EPIC had underestimated actual observed values. This was particularly true for large DRP losses (> 0.1 kg P ha^{-1}). In contrast to the original EPIC, the modified EPIC simulated DRP losses that were closer to the observed ones (Fig. 4, Table 4). There was still considerable scatter in the plots of observed versus simulated values, however, which may have been due at least in part to errors in the simulation of runoff volumes.

Loss of P in runoff – annual performance

As was the case for single events, the original EPIC significantly underestimated annual DRP losses (Fig. 5, Table 5). In contrast, the modified EPIC simulated annual DRP losses that were much closer to the observed ones (Fig. 6, Table 5). The mean observed annual DRP loss was 7.37 kg P ha^{-1} (std dev = 4.09) whereas the mean simulated values were 0.79 kg P ha^{-1} (std dev = 0.50) for the original EPIC and 5.93 (std dev = 5.07) for the modified EPIC. Thus, the modified EPIC was able to simulate the trends in annual DRP loss observed, and as such it may be a useful tool for identifying situations with a high potential for P loss.

Original EPIC's underestimation of DRP

The original EPIC less successfully predicted DRP in runoff than runoff volume for the following likely reasons. Firstly, accurately predicting a specific model output can be complicated with the number of intermediate results necessary for computing the output. The P model in EPIC considers several P transformations that can affect the estimation of DRP in runoff. Inaccurate modeling of any of those transformations may compound the errors in predicting DRP in runoff. Secondly, the lack of soil incorporation of surface-applied broiler litter reduces the P adsorption upon which the EPIC P submodel is very dependent. In the original EPIC, DRP in runoff is a function of runoff volume, concentration of labile P in the top soil layer, and ratio of the P concentration in sediment to that in the water. The labile P concentration is, in turn, dependent on the flow between labile and active mineral P pools, which is governed in part by a sorption coeffficient that is somewhat soil specific. There is likely little interaction between the labile P applied with the litter and the active P pool in the soil when broiler litter is surface-applied to grassland. In effect, equations in the original EPIC may be estimating P sorption that is not actually happening, or at least not to a large extent, due to limited contact between soil and litter. Although the estimation of DRP in runoff in the modified EPIC simulates more DRP in runoff because of an adjustment of P in runoff by increasing the influence of organic P in the top 10 mm of soil, the flow between labile and active mineral P pools is still the same as in the original EPIC. The surface application of broiler litter to grasslands not only complicates the issue of modeling P sorption by soil, but also increases the chances that litter P will be lost directly in runoff before ever entering the labile soil P pool. It is interesting to note that Edwards et al. (1994) found significant ($p = 0.05$) relationships between predicted and observed soluble P in runoff for a field that received poultry manure slurry, but not for a field that received dry poultry litter.

CONCLUSIONS

These results should be interpreted in light of the fact that EPIC was designed to reflect trends in runoff quality on a long-term basis, not on an event basis. EPIC simulations of runoff volume for individual events did not show bias for three of the plots, but showed underestimation for one plot and overestimation for another. These biases were likely due to the presence of soil areas with characteristics different from those used in the simulation. On an annual basis, the runoff volumes simulated by EPIC were similar to the observed ones. On an event by event basis, when the observed DRP losses were small, the original EPIC simulated those losses fairly well. When the DRP losses were large, the original EPIC underestimated the observed values. The modified EPIC simulated larger DRP losses than the original EPIC, but the relationships between observed and simulated values were not very strong. The annual estimates of DRP loss by the original EPIC grossly underestimated the observed annual values, but the annual estimates of DRP loss by the modified EPIC were similar to the observed ones. These results suggest that the modified EPIC may be useful for identifying situations where there is a risk of large annual P losses from grasslands fertilized with broiler litter.

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Table 3.1. Dates of applications and average amounts of broiler litter, total N, NH_4^+-N, total P, and water-soluble P applied to plots.

			Nitrogen		Phosphorus	
Year	Date	Litter	Total	NH_4^+-N	Total	H_2O-soluble
		---------------------------kg ha^{-1}dry weight---------------------------				
1995	Mar 16	6037	271	57	105	16
1995	Oct 30	6314	264	58	104	20
1996	Mar 4	7929	483	83	159	29
1996	Sep 25	6402	258	41	103	28
1997	Mar 3	UAN	67	17	0	0
1998	Mar 24	UAN	56	14	0	0

Table 3.2.

Selected EPIC Inputs

Latitude	33.24°
Elevation	150m
# years of simulation	4
Weather variables	all input
PET	Penman-Monteith equation
Peak Runoff Estimate	Modified Rational equation
Estimate of runoff volume	SCS CN
Soil Hydrologic Group	B
Channel roughness factor	Manning’s “n” = 0.1
Surface roughness factor	Manning’s “n” = 0.2
Channel depth	0.5m
Slope length	100m
Slope steepness	0.06
Equation for water erosion	USLE
Erosion control practice factor	0.5

Table 3.3. Broiler litter properties substituted into EPIC's fertilizer file.

		Mineral		Organic		
Year	Date	N	P	N	P	NH_4^+-N Fraction
		----------------------------------g g^{-1} litter----------------------------------				
1995	Mar 16	0.009	0.003	0.036	0.015	0.998
1995	Oct 30	0.009	0.003	0.031	0.013	0.963
1996	Mar 4	0.011	0.004	0.049	0.017	0.836
1996	Sep 25	0.011	0.004	0.026	0.012	0.605

Table 3.4. Root mean square error of the simulations and intercept, slope, r^2, and significance of regression of observed versus EPIC simulated values of runoff (mm) and loss of P (kg P ha^{-1} for original and modified model) in individual runoff events from 1995 through 1998.

		Output					
	Plot #	RMSE	Intercept	Slope	r^2	Prob>F	n
Runoff (mm)	1	6.9	0.508	0.530*	0.80	0.0001	71
	2	6.6	1.391	1.001	0.78	0.0001	66
	3	10.1	2.166	1.343*	0.81	0.0001	70
	4	6.0	1.263	1.003	0.82	0.0001	65
	5	5.4	0.987	0.949	0.83	0.0001	62
	1-5	7.3	1.246*	0.973	0.73	0.0001	334
P(original) kg P ha^{-1}	1	0.18	0.065*	0.828	0.62	0.0037	71
	2	0.45	0.157*	3.422*	0.26	0.0001	66
	3	0.98	0.147*	10.310*	0.81	0.0001	70
	4	0.99	0.168	7.183*	0.57	0.0001	65
	5	0.96	0.012	7.515*	0.65	0.0001	62
	1-5	0.78	0.087*	7.079*	0.56	0.0001	334
P(modified) kg P ha^{-1}	1	0.50	0.78*	0.038*	0.01	0.3785	71
	2	0.64	0.229*	0.144*	0.04	0.1063	66
	3	0.53	0.254*	0.926	0.76	0.0001	70
	4	0.83	0.280*	0.599*	0.50	0.0001	65

5	0.72	0.097	0.633*	0.65	0.0001	62
1-5	0.65	0.167*	0.623*	0.51	0.0001	334

* indicates intercept significantly different from 0 and slope significantly different from 1 at p=0.05.

Table 3.5. Root mean square error of the simulations and intercept, slope, r^2, and significance of regression of observed versus EPIC simulated values of annual runoff (mm) and annual loss of P (kg P ha^{-1} for original and modified model) from 1995 through 1998.

	RMSE	Intercept	Slope	r^2	Prob>F	n
Runoff (mm)	28.8	28.1	0.83*	0.71	0.0011	11
P (original – kg P ha^{-1})	7.47	2.52	6.10*	0.56	0.0081	11
P (modified – kg P ha^{-1})	3.00	3.35*	0.67	0.70	0.0012	11

* indicates intercept significantly different from 0 and slope significantly different from 1 at p=0.05.

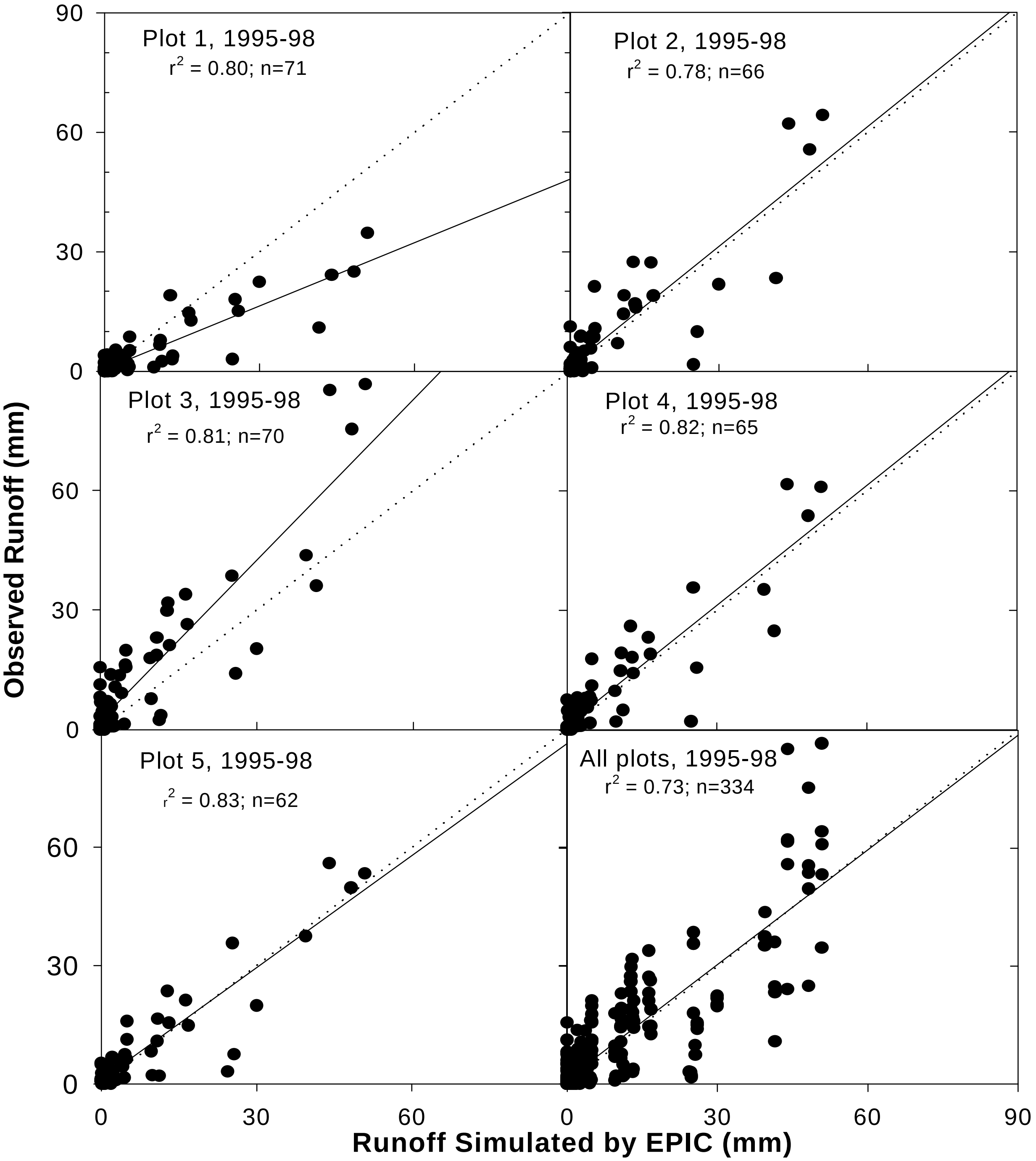


Figure 3.1. Observed versus simulated runoff in each event for individual plots and for all plots combined from 1995 through 1998 (dotted line is 1:1 line).

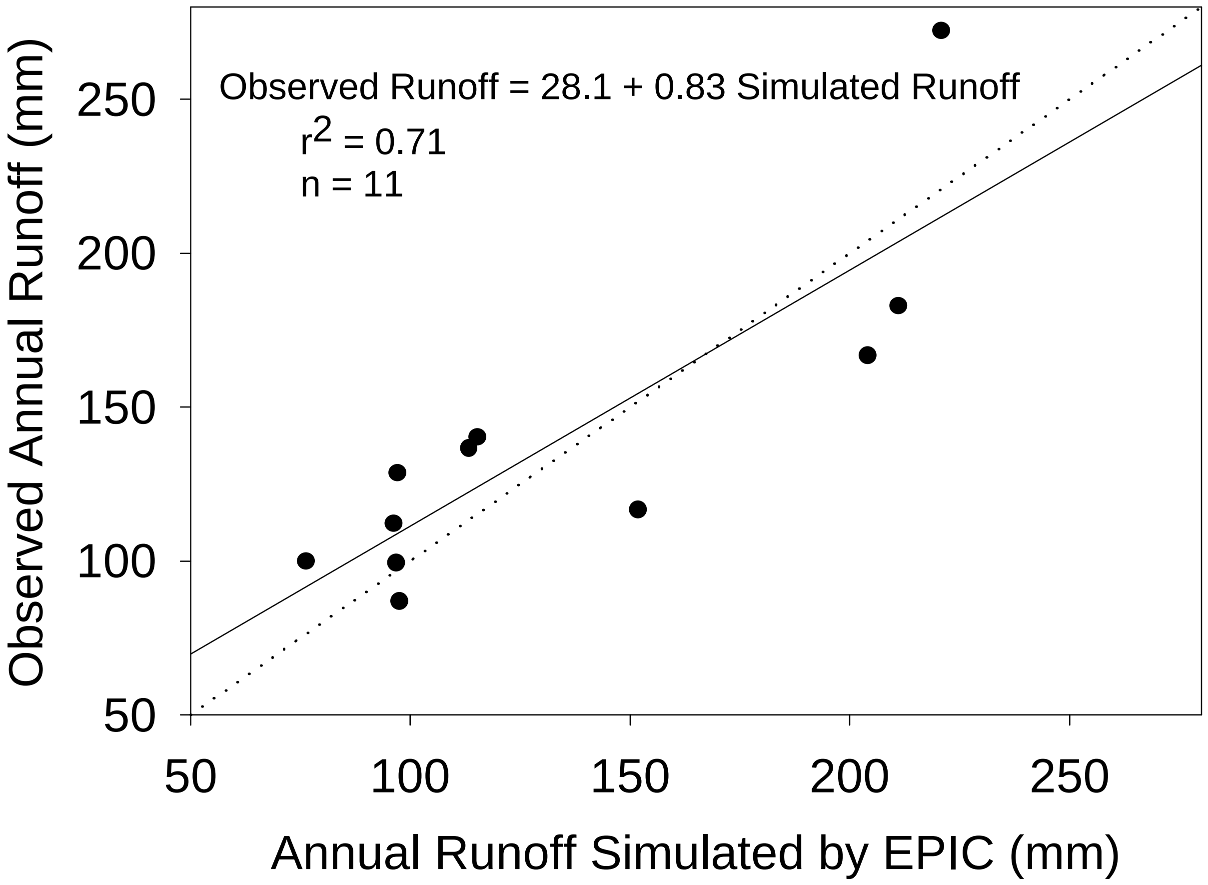


Figure 3.2. Observed versus simulated annual runoff from 1995 through 1998 (dotted line is 1:1 line).

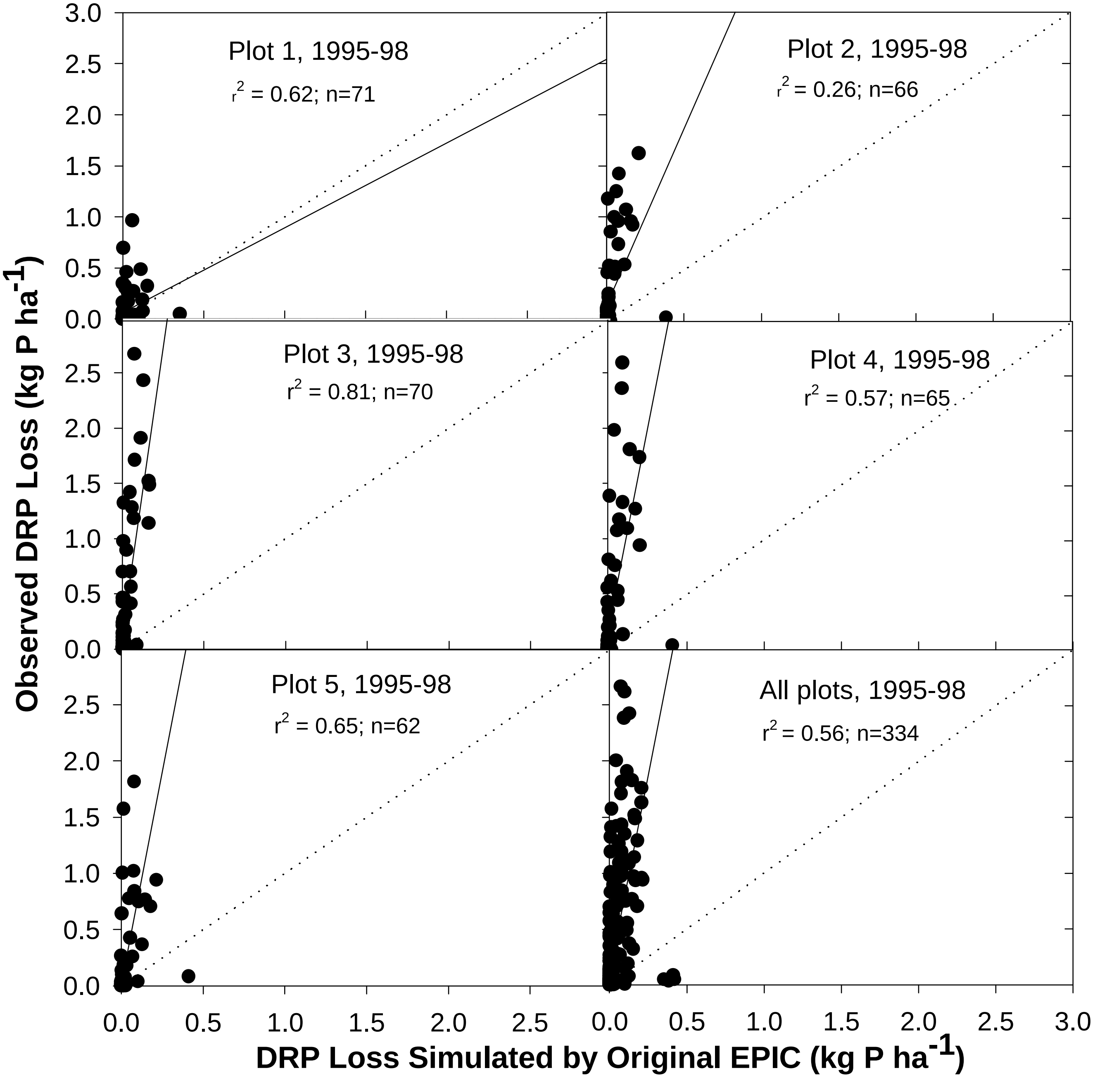
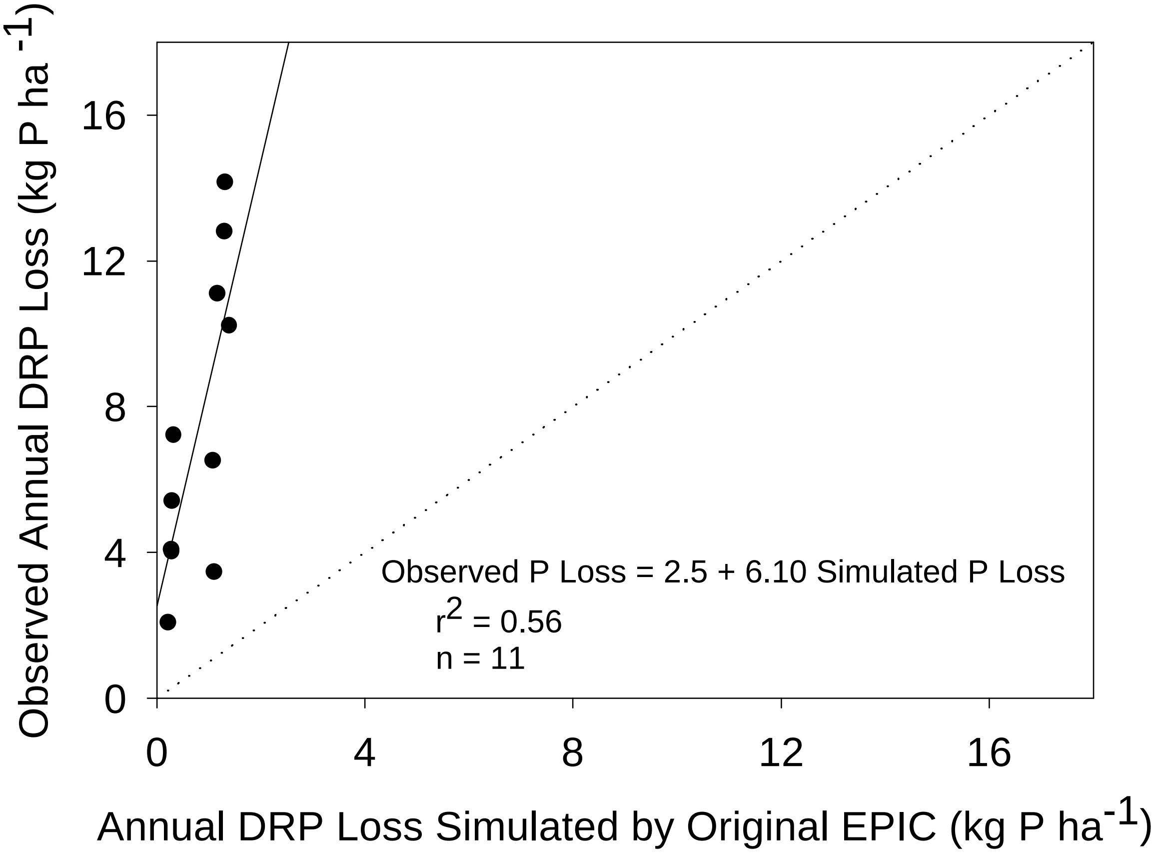


Figure 3.3. Observed versus (original EPIC) simulated loss of P in each runoff event for individual plots and for all plots combined from 1995 through 1998 (dotted is 1:1 line).


Observed Annual DRP Loss (kg P ha $^{-1}$)
0
4
8
12
16
Annual DRP Loss Simulated by Original EPIC (kg P ha^{-1})
Observed P Loss = 2.5 + 6.10 Simulated P Loss
r^2 = 0.56
n = 11

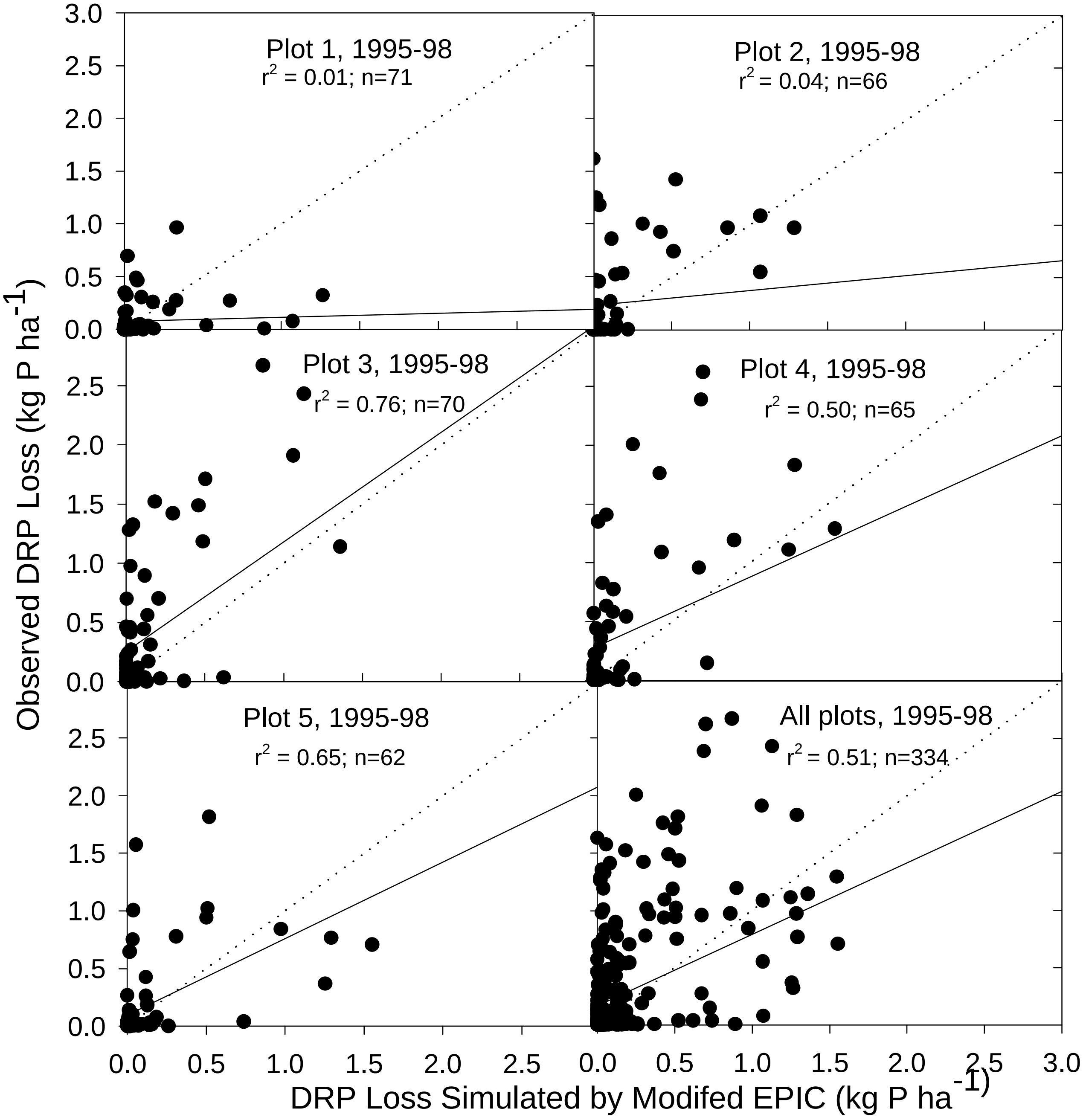


Figure 3.4. Observed versus (modified EPIC) simulated loss of P in each runoff event for individual plots and for all plots combined from 1995 through 1998 (dotted is 1:1 line).

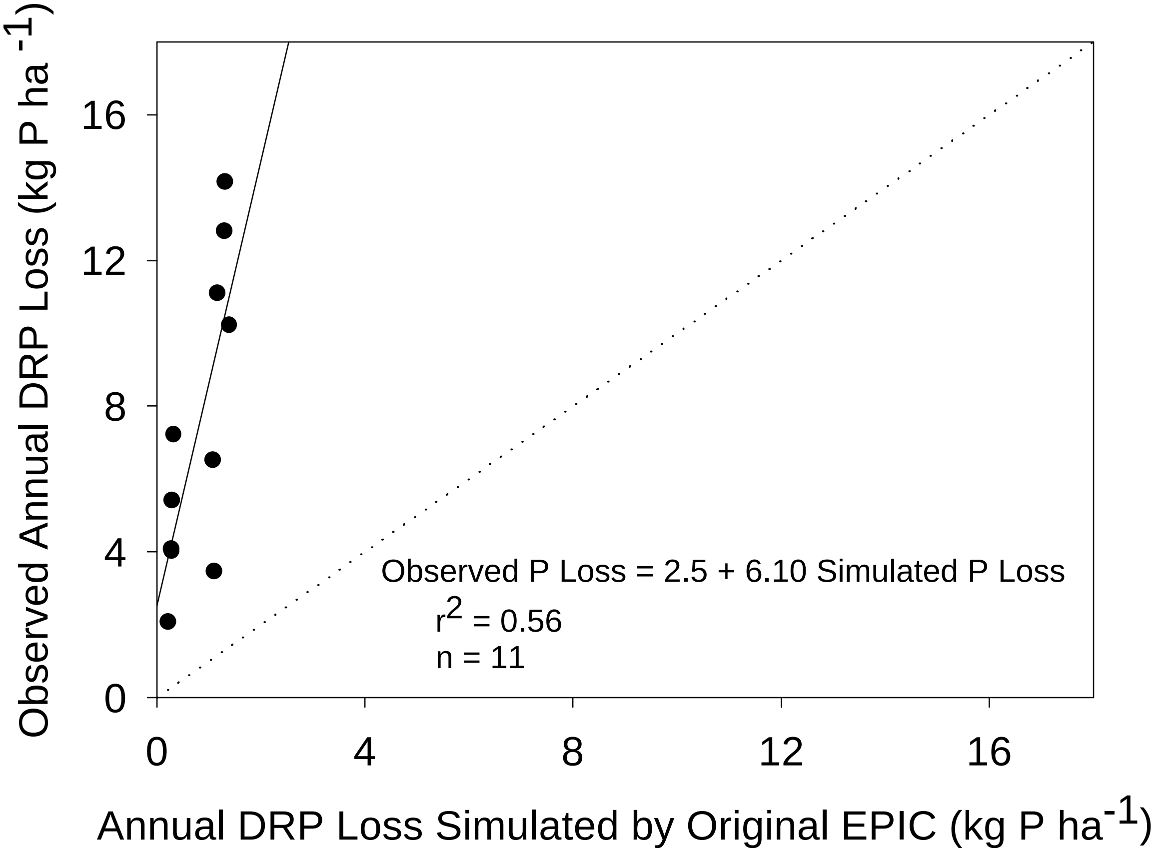


Figure 3.5. Observed versus (original EPIC) simulated annual P loss in runoff from 1995 through 1998 (dotted line is 1:1 line).

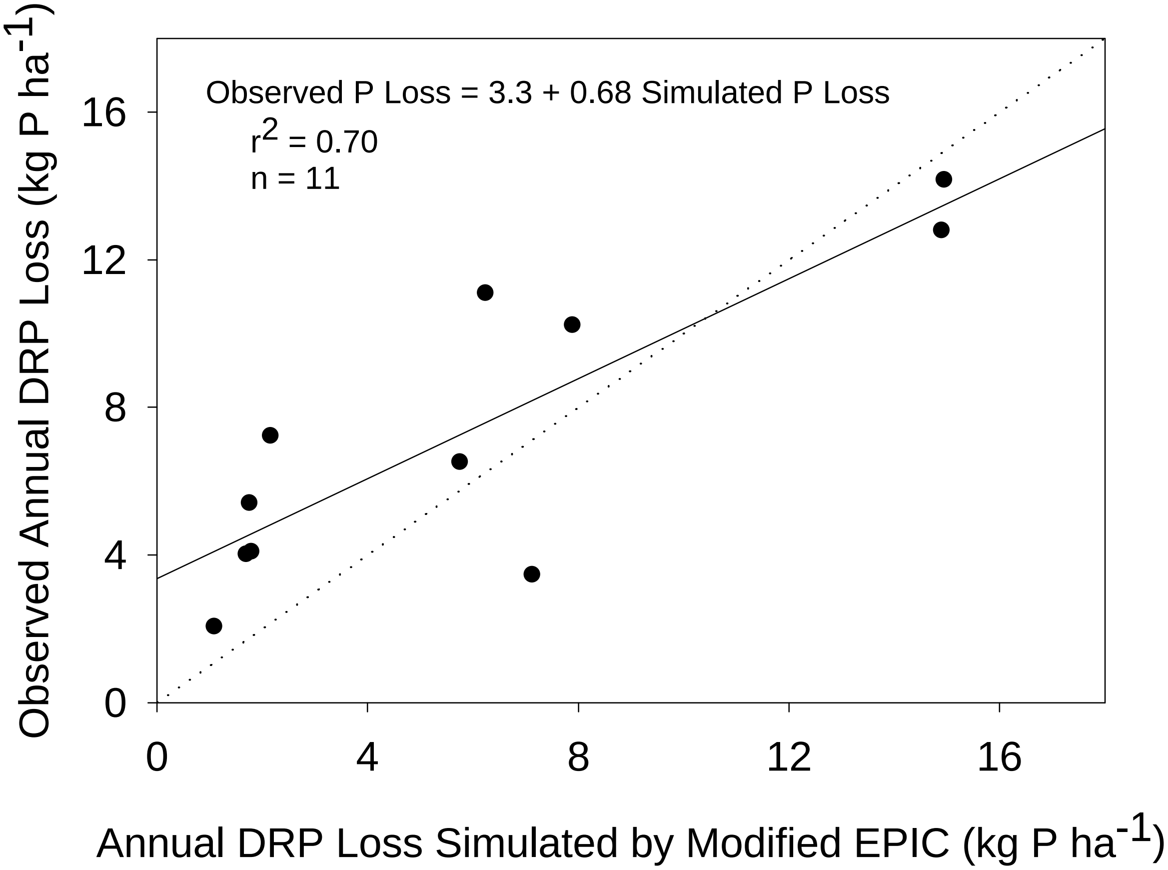


Figure 3.6. Observed versus (modified EPIC) simulated annual P loss in runoff from 1995 through 1998 (dotted line is 1:1 line).

Chapter 4

SUMMARY AND CONCLUSIONS

A four-year study was conducted to study the dynamics of NH_4^+-N and dissolved reactive P (DRP) in runoff from grasslands that were fertilized with broiler litter for the first two years and with only inorganic fertilizer N for the last two years. Repeated and heavy applications of broadcast broiler litter as a fertilizer increased NH_4^+-N and DRP concentrations in runoff. These elevated concentrations were likely due to the positional availability of broiler litter on the soil surface where it can interact with surface runoff water. When broiler litter applications were stopped, NH_4^+-N and DRP concentrations in runoff started decreasing, but it took 19 months for concentrations to decrease to 1 mg L^{-1}. The main factors influencing the average concentrations in cumulative runoff after an application were cumulative runoff volume, amount of N or P applied in the most recent application, and cumulative amounts of N or P applied to that field. The relationship between soil test P and DRP in runoff varied depending on when broiler litter was last applied. A given soil test P value was related to a much higher DRP concentration in runoff when broiler litter was periodically being applied than when broiler litter had not been applied for at least one year. These results suggest that the risk of contaminating surface waters with DRP could be decreased by fertilizing grasslands with broiler litter only every two or three years instead of every year. These results also suggest that to use soil test P as an indicator of DRP concentration in runoff it is necessary to know how recent was the last broiler litter application.

A potential approach that can aid in the determination of potential P loss from surface application of broiler litter is simulation modeling. A study was conducted to evaluate the simulation model EPIC as a tool to estimate the volume and DRP concentration of surface runoff from grasslands fertilized with broiler litter. EPIC adequately estimated event runoff volume in three out of five cases, and it adequately estimated annual runoff volume in all cases. However, EPIC underestimated event and annual DRP losses in runoff. A modification of EPIC adequately simulated annual DRP losses in runoff, but event loses were still inaccurately estimated. These results suggest that the equations representing P transformations from surface applied broiler litter P may not adequately reflect the processes relevant to the transport of this P in runoff water. In spite of this deficiency, it would appear that the modified EPIC could be used to assess the potential for large annual DRP losses in runoff from grasslands fertilized with broiler litter.

Appendix A

Runoff volume and DRP losses collected and simultaed by EPIC for each runoff event in 1995-1998 for plots 1-5.

	EPIC estimations			Observed values		EPIC estimations			Observed values		EPIC estimations			Observed values	
Date 1995	1 Runoff (mm)	1 YAP(o) (kg P/ha)	1 YAP(m) (kg P/ha)	1 Runoff (mm)	1 DRP (kg P/ha)	2 Runoff (mm)	2 YAP(o) (kg P/ha)	2 YAP(m) (kg P/ha)	2 Runoff (mm)	2 DRP (kg P/ha)	3 Runoff (mm)	3 YAP(o) (kg P/ha)	3 YAP(m) (kg P/ha)	3 Runoff (mm)	3 DRP (kg P/ha)
1/6	2.242	0.001	0.000	3.5026582	0.0113924	2.242	0.001	0.000	2.8362025	0.0189873	2.242	0.001	0.001	3.1445833	0.0083333
1/15	2.207	0.000	0.000	5.235	0.013	2.207	0.000	0.000	8.813	0.047	2.207	0.000	0.000	5.812	0.018
1/28	1.889	0.001	0.001	2.2222785	0.0041772	1.889	0.001	0.001	2.7313924	0.0148101	1.889	0.001	0.001	5.1794444	0.0152778
2/10	29.994	0.012	0.007	22.360	0.058	29.994	0.012	0.007	21.756	0.120	29.994	0.012	0.007	20.250	0.069
6/5	2.560	0.010	0.033	1.1411392	0.0025316	2.560	0.013	0.049	0	0	2.560	0.014	0.056	0.6843056	0.0004861
8/26	4.619	0.007	0.025	1.727	0.009	4.349	0.010	0.039	0.844	0.005	4.705	0.012	0.048	1.327	0.010
9/14	0.614	0.001	0.003	0.7274684	0.0050633	0.415	0.001	0.004	Malfct	Malfct	0.66	0.002	0.007	malfct	malfct
10/4	25.962	0.023	0.083	15.028608	0.4594937	25.579	0.016	0.186	9.8637975	0.5367089	26.032	0.049	0.207	14.011667	0.7013889
10/27	2.158	0.000	0.001	0.5436709	0.0012658	2.16	0.001	0.006	0.9211392	0.0126582	2.023	0.001	0.006	1.1059722	0.0125
10/31	0.209	0.002	0.010	0	0	0.21	0.002	0.015	0	0	0.191	0.002	0.013	0	0
11/2	0.117	0.001	0.001	0	0	0.117	0.001	0.007	0	0	0.124	0.001	0.007	0	0
11/7	10.758	0.057	0.330	6.549	0.272	10.763	0.076	0.514	14.353	0.747	10.809	0.071	0.488	18.598	1.182
11/11	12.770	0.060	0.335	18.987089	0.9632911	12.777	0.08	0.528	27.400633	1.4316456	12.853	0.075	0.503	29.803611	1.7111111
12/6	0.851	0.003	0.018	0	0	0.853	0.004	0.029	0	0	0.876	0.004	0.029	0	0
12/9	1.005	0.004	0.021	1.1292405	0.0139241	1.005	0.005	0.035	3.6087342	0.1405063	1.009	0.005	0.033	5.5970833	0.2666667
12/19	12.800	0.039	0.215	7.662	0.257	12.802	0.058	0.374	19.004	1.011	12.818	0.054	0.351	23.018	1.419

* o= original EPIC ; m= modified EPIC

	EPIC estimations			Observed values		EPIC estimations			Observed values	
Date 1995	4 Runoff (mm)	4 YAP(o) (kg P/ha)	4 YAP(m) (kg P/ha)	4 Runoff (mm)	4 DRP (kgP/ha)	5 Runoff (mm)	5 YAP(o) (kg P/ha)	5 YAP(m) (kg P/ha)	5 Runoff (mm)	5 DRP (kgP/ha)
1/6	2.242	0.001	0.001	3.0257895	0.0065789	2.242	0.001	0.001	3.0017333	0.0106667
1/15	2.207	0.000	0.000	6.496	0.012	2.207	0.000	0.000	6.203	0.013
1/28	1.889	0.001	0.001	3.3535526	0.0069737	1.889	0.001	0.001	3.2812	0.0073333
2/10	29.994	0.012	0.007			29.994	0.012	0.007	19.788	0.075
6/5	2.560	0.014	0.033	0.9778947	0.0013158	2.56	0.011	0.04	0.7354667	0.0008933
8/26	4.625	0.007	0.034	1.688	0.024	4.438	0.008	0.031	1.510	0.002
9/14	0.618	0.001	0.003	0.8343421	0.0078947	0.45	0.001	0.003	0	0
10/4	25.97	0.023	0.081	15.5725	0.6315789	25.636	0.034	0.128	7.4057333	0.18
10/27	2.158	0	0.001	1.9760526	0.0407895	2.165	0.001	0.002	2.1764	0.02
10/31	0.209	0.003	0.021	0	0	0.21	0.002	0.015	0	0
11/2	0.116	0.001	0.01	0	0	0.116	0.001	0.007	0	0
11/7	10.759	0.094	0.689	14.779	2.388	10.757	0.076	0.509	10.775	1.020
11/11	12.77	0.098	0.7	26.004868	2.6223684	12.765	0.079	0.52	23.512	1.8146667
12/6	0.851	0.006	0.039	0.5263158	0.0263158	0.85	0.004	0.029	1.3465333	0.0053333
12/9	1.005	0.007	0.046	5.3663158	0.3631579	1.005	0.005	0.034	3.1174667	0.1
12/19	12.801	0.074	0.512	19.241	1.093	12.800	0.056	0.366	16.503	0.776

* o= original EPIC ; m= modified EPIC

		EPIC ESTIMATIONS			OBSERVED VALUES		EPIC ESTIMATIONS			OBSERVED VALUES	
DAY OF YEAR	DATE 1996	1 RUNOFF (MM)	1 YAP(O) (KG P/HA)	1 YAP(M) (KG P/HA)	1 RUNOFF (MM)	1 DRP (KG P/HA)	2 RUNOFF (MM)	2 YAP(O) (KG P/HA)	2 YAP(M) (KG P/HA)	2 RUNOFF (KGP/HA)	2 DRP (KG P/HA)
2	2-Jan	0.459	0.001	0.007	1.166	0.028	0.459	0.002	0.013	0.000	0.000
7	7-Jan				0.8436709	0.0139241				0.5144304	0.0112658
9	9-Jan	0.609	0.005	0.039			0.732	0.003	0.019		
11	11-Jan	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.5064557	0.0164557
24	24-Jan	0.606	0.000	0.001	0	0	0.611	0.001	0.006	0.963038	0.0088608
27	27-Jan	4.951	0.001	0.004	8.555	0.348	4.952	0.007	0.040	21.211	1.189
31	31-Jan	4.982	0.000	0.002	5.0805063	0.1607595	4.985	0.004	0.017	10.656709	0.4708861
33	2-Feb	25.293	0.004	0.020	17.984051	0.6949367	25.294	0.014	0.062	5.1087342	0.178481
59	28-Feb	0.180	0.000	0.000	1.27	0.029	0.183	0.000	0.001	0.87	0.034
66	6-Mar	4.120	0.066	0.674	4.01	0.271	4.132	0.074	0.859	5.7	0.97
67	7-Mar	39.463	0.572	5.749	0	0	39.476	0.644	7.294	0	0
77	17-Mar	0.316	0.003	0.023	0	0	0.322	0.003	0.029	Malfct	malfct
79	19-Mar	0.114	0.001	0.008	2.38	0.075	0.117	0.001	0.011	Malfct	malfct
87	27-Mar	1.345	0.011	0.086	1.31	0.039	1.383	0.013	0.112	4.59	0.267
97	6-Apr				0	0				0.7691139	0.0063291
121	30-Apr				0	0				0	0
149	28-May	0.703	0.014	0.093	1.41	0.015	2.787	0.017	0.125	0.8063291	0.0088608
198	16-Jul				0	0				0.5125316	0.0002532
215	2-Aug	1.601	0.010	0.071	0.507	0.003	1.275	0.009	0.072	0.586	0.001
224	11-Aug	1.438	0.010	0.075	0	0	1.317	0.011	0.088	0	0
282	8-Oct	1.775	0.026	0.275	0.000	0.000	1.995	0.031	0.348	0.000	0.000
336	1-Dec	24.761	0.353	3.698	2.97	0.048	24.88	0.383	4.296	1.6311392	0.035443
348	13-Dec	0.890	0.012	0.120	0.000	0.000	0.894	0.014	0.138	0.000	0.000

* o= original EPIC ; m= modified EPIC

		EPIC ESTIMATIONS		OBSERVED VALUES		
DAY OF YEAR	DATE 1996	3 RUNOFF (MM)	3 YAP(O) (KG P/HA)	3 YAP(M) (KG P/HA)	3 RUNOFF (MM)	3 DRP (KG P/HA)
2	2-Jan	0.460	0.002	0.012	4.527	0.236
7	7-Jan				8.1376389	0.4597222
9	9-Jan	0.727	0.003	0.017	0.7977778	0.0138889
11	11-Jan					
24	24-Jan	0.644	0.001	0.005	1.1627778	0.0194444
27	27-Jan	4.963	0.005	0.029	19.871	0.976
31	31-Jan	4.997	0.002	0.005	15.586389	0.6986111
33	2-Feb	25.304	0.007	0.044	38.554722	1.3236111
59	28-Feb	0.195	0.000	0.001	1.53	0.05
66	6-Mar	4.181	0.074	0.87	9.07	2.67
67	7-Mar	39.504	0.636	7.296	43.686944	6.5166667
77	17-Mar	0.336	0.003	0.03	0.6940278	0.0097222
79	19-Mar	0.121	0.001	0.011	6.89	0.428
87	27-Mar	1.449	0.013	0.114	7.01	0.443
97	6-Apr				0.9745833	0.0055556
121	30-Apr				0	0
149	28-May	2.773	0.017	0.122	0.9545833	0.0097222
198	16-Jul					
215	2-Aug	1.447	0.010	0.081	0.000	0.000
224	11-Aug	1.369	0.011	0.09		
282	8-Oct	2.164	0.033	0.369	0.720	0.003
336	1-Dec	24.55	0.37	4.146		
348	13-Dec	0.867	0.013	0.131	0.000	0.000

* o= original EPIC ; m= modified EPIC

		EPIC estimations			Observed values		EPIC estimations			Observed values	
Day of Year	Date 1996	4 Runoff (mm)	4 YAP(o) (kg P/ha)	4 YAP(m) (kg P/ha)	4 Runoff (mm)	4 DRP (kg P/ha)	5 Runoff (mm)	5 YAP(o) (kg P/ha)	5 YAP(m) (kg P/ha)	5 Runoff (mm)	5 DRP (kg P/ha)
2	2-Jan	0.459	0.003	0.017	3.163	0.209	0.459	0.002	0.012	2.389	0.049
7	7-Jan				7.5026316	0.5697368				5.308	0.2653333
9	9-Jan	0.733	0.004	0.026			0.733	0.003	0.019		
11	11-Jan				0.8207895	0.025				0.9545333	0.0146667
24	24-Jan	0.606	0.002	0.012	0.8801316	0.0223684	0.606	0.001	0.006	1.4684	0.0213333
27	27-Jan	4.951	0.013	0.081	17.734	1.408	4.951	0.007	0.039	15.857	1.005
31	31-Jan	4.982	0.009	0.056	11.087237	0.8276316	4.982	0.003	0.016	11.2292	0.6426667
33	2-Feb	25.293	0.044	0.251	35.674211	2.0065789	25.293	0.014	0.057	35.680667	1.5733333
59	28-Feb	0.181	0.000	0.002	0.91	0.054	0.181	0.000	0.001	1.47	0.035
66	6-Mar	4.126	0.076	0.9	5.5859211	1.1907895	4.126	0.081	0.975	4.3	0.84
67	7-Mar	39.473	0.633	7.677	35.214868	6.2710526	39.471	0.704	8.271	37.431333	7.54
77	17-Mar	0.321	0.004	0.031	0.5711842	0.0078947	0.32	0.004	0.033	0.8093333	0.016
79	19-Mar	0.116	0.001	0.016	4.79	0.44	0.116	0.001	0.012	2.7	0.136
87	27-Mar	1.382	0.014	0.123	4.78	0.58	1.372	0.014	0.126	3.5681333	0.1853333
97	6-Apr				0.8072368	0.0105263				1.23	0.032
121	30-Apr				0	0				0.5990667	0.0013333
149	28-May	2.809	0.02	0.145	1.0382895	0.0065789	2.831	0.019	0.14	0.8688	0.0066667
198	16-Jul				0	0				0	0
215	2-Aug	0.936	0.008	0.060	1.110	0.022	1.154	0.009	0.072	0.801	0.004
224	11-Aug	1.149	0.01	0.087	1.6748684	0.0276316	1.276	0.011	0.093	1.41	0.017
282	8-Oct	2.082	0.035	0.415	0.000	0.000	1.667	0.028	0.334	0.000	0.000
336	1-Dec	24.844	0.419	4.886	2.12	0.046	24.456	0.413	4.841	3.07	0.083
348	13-Dec	0.901	0.015	0.158	0.000	0.000	0.878	0.015	0.155	1.088	0.012

* o= original EPIC ; m= modified EPIC

		EPIC estimations			Observed values		EPIC estimations			Observed values		EPIC estimations			Observed values	
Day of Year	Date 1997	1 Runoff (mm)	1 YAP(o) (kg P/ha)	1YAP(m) (kg P/ha)	1 Runoff (mm)	1 DRP (kg P/ha)	2 Runoff (mm)	2 YAP(o) (kg P/ha)	2 YAP(m) (kg P/ha)	2 Runoff (mm)	2 DRP (kg P/ha)	3 Runoff (mm)	3 YAP(s) (kg P/ha)	3 YAP(m) (kg P/ha)	3 Runoff (mm)	3 DRP (kg P/ha)
5	5-Jan	1.9	0.021	0.188	0.838	0.006	1.889	0.023	0.224	0.57	0.003	1.844	0.022	0.217	1.11	0.026
9	9-Jan	9.636	0.1	0.892	0.926	0.005	9.634	0.114	1.07	6.94	0.55	9.623	0.113	1.062	17.9	1.91
16	16-Jan	1.429	0.014	0.122	1.15	0.021	1.420	0.016	0.146	1.52	0.057	1.379	0.015	0.141	3.13	0.17
39	8-Feb	1.44	0.014	0.12	0	0	1.426	0.014	0.117	0.56	0.003	1.356	0.014	0.119	1.19	0.035
45	14-Feb	13.133	0.125	1.073	2.99	0.076	13.11	0.126	1.069	16.91	1.084	13.012	0.129	1.129	31.76	2.43
52	21-Feb	2.065	0.019	0.154	2	0.03	2.042	0.019	0.153	3.22	0.15	1.952	0.019	0.156	6.38	0.31
59	28-Feb	16.813	0.153	1.264	12.7	0.32	16.789	0.157	1.286	18.95	0.97	16.693	0.162	1.36	26.35	1.14
118	28-Apr	11.147	0.076	0.524	2.41	0.037	11.202	0.056	0.589	0	0	11.399	0.088	0.62	2.29	0.035
145	25-May	1.585	0	0.041			1.59	0.009	0.049			1.589	0.009	0.05		
165	14-Jun	3.369	0.02	0.119			3.375	0.023	0.137			3.377	0.023	0.138		
205	24-Jul	4.879	0.028	0.165			4.882	0.032	0.196			4.878	0.032	0.196		
211	30-Jul	0.593	0.003	0.013	4.14	0.057	0.595	0.003	0.017	2.7	0.052	0.593	0.003	0.017	2.82	0.076
268	25-Sep	34.02	0.088	0.123			34.02	0.129	0.223			34.015	0.127	0.202		
299	26-Oct	41.531	0.121	0.287	10.84	0.187	41.506	0.169	0.43	23.33	0.933	41.499	0.166	0.46	36.06	1.487
305	1-Nov	2.875	0.008	0.019	1.23	0.019	2.877	0.012	0.027	5.08	0.233	2.877	0.011	0.026	10.67	0.458
317	13-Nov	13.296	0.04	0.102	3.74	0.048	13.298	0.054	0.142	15.95	0.526	13.298	0.053	0.136	21.14	0.561
325	21-Nov	0.139	0	0.001	0.44	0.005	0.14	0.001	0.001	0	0	0.141	0.001	0.001	0	0
333	29-Nov	1.358	0.004	0.012	0	0	1.362	0.006	0.016	1.58	0.052	1.363	0.006	0.016	2.26	0.061
344	10-Dec	0	0	0	0	0	0	0	0	1.03	0.018	0	0	0	1.27	0.021
348	14-Dec	0.021	0	0	0	0	0.021	0	0	0	0	0.021	0	0	0	0
356	22-Dec	1.618	0.004	0.002	0	0	1.624	0.006	0.006	1.49	0.047	11.625	0.005	0.005	3.57	0.059
358	24-Dec	48.255	0.111	0.075	24.9	0.486	48.261		0.207	55.57	1.63	48.262	0.161	0.183	75.32	1.52
361	27-Dec	0	0	0	0	0	0	0	0	0	0	0	0	0	0.77	0.018

* o= original EPIC ; m= modified EPIC

		EPIC estimations			Observed values		EPIC estimations			Observed values	
Day of Year	Date 1997	4 Runoff (mm)	4 YAP(o) (kg P/ha)	4 YAP(m) (kg P/ha)	4 Runoff (mm)	4 DRP (kg P/ha)	5 Runoff (mm)	5 YAP(o) (kg P/ha)	5 YAP(m) (kg P/ha)	5 Runoff (mm)	5 DRP (kg P/ha)
5	5-Jan	1.886	0.026	0.261	0.8	0.008	1.884	0.026	0.262	0	0
9	9-Jan	9.633	0.128	1.25	9.75	1.11	9.633	0.128	1.256	8.22	0.367
16	16-Jan	1.417	0.018	0.171	1.58	0.089	1.416	0.018	0.172	1.85	0.04
39	8-Feb	1.422	0.016	0.142	0.79	0.012	1.419	0.016	0.142	1.34	0.028
45	14-Feb	13.104	0.145	1.29	18.21	1.83	13.1	0.145	1.293	15.43	0.766
52	21-Feb	2.036	0.022	0.185	2.26	0.116	2.033	0.022	0.185	2.95	0.076
59	28-Feb	16.784	0.181	1.547	19	1.29	16.78	0.18	1.553	14.74	0.704
118	28-Apr	11.216	0.1	0.728	4.93	0.145	11.23	0.101	0.74	2.01	0.037
145	25-May	1.59	0.011	0.062			1.59	0.011	0.063		
165	14-Jun	3.376	0.026	0.165			3.376	0.026	0.169		
205	24-Jul	4.884	0.037	0.234			4.88	0.037	0.241		
211	30-Jul	0.596	0.004	0.022	3.16	0.074	0.594	0.004	0.022	4.65	0.098
268	25-Sep	34.029	0.164	0.444			34.018	0.168	0.507		
299	26-Oct	41.496	0.209	0.674	24.8	0.956	41.501	0.214	0.749	Malfct	malfct
305	1-Nov	2.877	0.014	0.041	4.7	0.279	2.877	0.015	0.045	Malfct	malfct
317	13-Nov	13.299	0.067	0.209	14.22	0.541	13.298	0.069	0.23	Malfct	malfct
325	21-Nov	0.141	0.001	0.002	0	0	0.141	0.001	0.002	Malfct	malfct
333	29-Nov	1.364	0.007	0.023	1.45	0.051	1.363	0.007	0.075	Malfct	malfct
344	10-Dec	0	0	0	0.35	0.001	0	0	0	1.08	0.005
348	14-Dec	0.021	0	0	0	0	0.021	0	0	0.62	0.001
356	22-Dec	1.626	0.007	0.013	0.92	0.01	1.624	0.007	0.016	1.56	0.012
358	24-Dec	48.264	0.208	0.423	53.69	1.76	48.262	0.215	0.503	49.67	0.94
361	27-Dec	0	0	0	0.36	0.006	0	0	0	0.5	0.002

* o= original EPIC ; m= modified EPIC

		EPIC estimations			Observed values		EPIC estimations			Observed values		EPIC estimations			Observed values	
Date 1998	Day of Year	1 Runoff (mm)	1 YAP(o) (kg P/ha)	1 YAP(m) (kg P/ha)	1 Runoff (mm)	1 DRP (kg P/ha)	2 Runoff (mm)	2 YAP(o) (kg P/ha)	2 YAP(m) (kg P/ha)	2 Runoff (mm)	2 DRP (kg P/ha)	3 Runoff (mm)	3 YAP(o) (kg P/ha)	3 YAP(m) (kg P/ha)	3 Runoff (mm)	3 DRP (kg P/ha)
7-Jan	7	16.343	0.034	0.014	14.59	0.171	16.343	0.052	0.036	27.2	0.46	16.347	0.052	0.029	33.89	0.412
15-Jan	15	4.544	0.008	0.002	0.21	0.001	4.546	0.012	0.004	8.93	0.176	4.546	0.012	0.004	0	0
19-Jan	19	1.363	0.002	0	0.44	0.002	1.369	0.003	0.001	4.49	0.087	1.370	0.003	0.001	malfct	malfct
22-Jan	22	0.652	0.001	0	0	0	0.656	0.001	0	2.71	0.027	0.656	0.001	0	5.24	0.073
27-Jan	27	3.699	0.003	0.001	1.56	0.018	3.710	0.007	0.001	8.34	0.129	3.712	0.007	0.001	13.58	0.169
4-Feb	35	43.995	0.015	0.014	24.11	0.322	44.018	0.062	0.02	62.07	1.26	44.021	0.059	0.02	85.17	1.28
17-Feb	48	4.825	0	0.01	1.03	0.003	4.832	0.001	0.001	8.52	0.119	4.833	0.001	0.001	16.17	0.212
23-Feb	54	2.09	0	0	1.564	0.007	2.093	0	0.001	8.64	0.103	2.093	0	0.001	13.73	0.139
27-Feb	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6-Mar	65	50.867	0.015	0.11	34.66	0.304	50.871	0.026	0.118	64.26	0.868	50.872	0.026	0.118	86.63	0.894
18-Mar	77	0.232	0	0.001	0	0	0.233	0	0.001	0	0	0.233	0	0.001	0	0
3-Apr	93	0	0	0	2.06	0.006	0	0	0	6.05	0.057	0	0	0	11.25	0.107
9-Apr	99	0	0	0	0	0	0	0	0	0	0	0	0	0	1.09	0.012
14-Apr	104	0	0	0	0	0	0	0	0	0	0	0	0	0	0.94	0.008
19-Apr	109	0.047	0	0	0.612	0.002	0.047	0	0	1.78	0.023	0.047	0	0	3.27	0.034
21-Apr	111	0	0	0	3.93	0.017	0	0	0	11.16	0.125	0	0	0	15.59	0.144
24-Apr	114	0	0	0	0	0	0	0	0	0.54	0.006	0	0	0	1.16	0.012
1-May	121	0.392	0	0.001	0	0	0.392	0	0.01	0	0	0.392	0	0.01	2.3	0.016
3-May	123	0.086	0	0	0	0	0.086	0	0	0	0	0.086	0	0	1.31	0.006
8-May	128	0	0	0	0	0	0	0	0	0	0	0	0	0	0.58	0.002
9-Aug	221	5.052	0.003	0.022			5.051	0.003	0.025			5.051	0.003	0.025		
19-Aug	231	0.51	0.001	0.004			0.516	0.001	0.005			0.516	0.001	0.005		
13-Sep	256	3.323	0.001	0.004			3.274	0.001	0.005			3.268	0.001	0.005		
21-Sep	264	0.849	0.001	0.005			0.839	0.001	0.006			0.838	0.001	0.006		
7-Oct	280	9.28	0.008	0.065	Malfct	Malfct	9.832	0.009	0.073	Malfct	malfct	9.833	0.009	0.073	7.7	0.116
24-Dec	358	0.797	0	0.001			0.789	0	0.001			0.789	0	0.001		

* o= original EPIC ; m= modified EPIC

		EPIC estimations			Observed values		EPIC estimations			Observed values	
Date 1998	Day of Year	4 Runoff (mm)	4 YAP(o) (kg P/ha)	4 YAP(m) (kg P/ha)	4 Runoff (mm)	4 DRP (kg P/ha)	5 Runoff (mm)	5 YAP(o) (kg P/ha)	5 YAP(m) (kg P/ha)	5 Runoff (mm)	5 DRP (kg P/ha)
7-Jan	7	16.355	0.066	0.095	23.17	0.458	16.347	0.069	0.118	21.18	0.259
15-Jan	15	4.547	0.016	0.007	8.3	0.223	4.546	0.017	0.013	7.44	0.058
19-Jan	19	1.371	0.005	0.001	3.72	0.09	1.369	0.005	0.001	3.2	0.026
22-Jan	22	0.657	0.002	0	1.71	0.022	0.656	0.002	0	2.4	0.04
27-Jan	27	3.715	0.010	0.002	7.92	0.138	3.712	0.011	0.002	5.33	0.036
4-Feb	35	44.028	0.099	0.029	61.65	1.35	44.021	0.106	0.035	55.89	0.75
17-Feb	48	4.835	0.005	0.001	7.39	0.128	4.833	0.006	0.002	6.2	0.027
23-Feb	54	2.095	0.001	0.001	8.038	0.091	2.094	0.001	0.001	6.68	0.03
27-Feb	58	0	0	0	0	0	0	0	0	0	0
6-Mar	65	50.873	0.05	0.127	60.93	0.773	50.873	0.055	0.119	53.29	0.425
18-Mar	77	0.233	0	0.001	0	0	0.233	0	0.001	0.51	0.001
3-Apr	93	0	0	0			0	0	0	4.94	0.013
9-Apr	99	0	0	0	Malfct	Malfct	0	0	0	Malfct	malfct
14-Apr	104	0	0	0	Malfct	Malfct	0	0	0	Malfct	malfct
19-Apr	109	0.047	0	0	Malfct	Malfct	0.047	0	0	Malfct	malfct
21-Apr	111	0	0	0	Malfct	Malfct	0	0	0	Malfct	malfct
24-Apr	114	0	0	0	Malfct	Malfct	0	0	0	Malfct	malfct
1-May	121	0.392	0	0.001			0.392	0	0.001		
3-May	123	0.086	0	0	Malfct	Malfct	0.086	0	0	Malfct	malfct
8-May	128	0	0	0	Malfct	Malfct	0	0	0	Malfct	malfct
9-Aug	221	5.049	0.003	0.026			5.043	0.003	0.028		
19-Aug	231	0.518	0.001	0.005			0.52	0.001	0.005		
13-Sep	256	3.253	0.001	0.005			3.217	0.001	0.005		
21-Sep	264	0.835	0.001	0.006			0.827	0.001	0.006		
7-Oct	280	9.831	0.009	0.077	2.024	0.03	9.823	0.009	0.08	2.1	0.017
24-Dec	358	0.787	0	0.001			0.784	0	0.001		

- o= original EPIC ; m= modified EPIC

Appendix B

Runoff volume and NH_4^+-N loss for each runoff event in 1995-1998 for plots 1-5.

Date 1995	Day of Year	1 Runoff (mm)	1 NH4 (kg NH4/ha)	2 Runoff (mm)	2 NH4 (kg NH4/ha)	3 Runoff (mm)	3 NH4 (kg NH4/ha)	4 Runoff (mm)	4 NH4 (kg NH4/ha)	5 Runoff (mm)	5 NH4 (kg NH4/ha)
1/6	6	3.5026582	0.0278481	2.8362025	0.0329114	3.1445833	0.0222222	3.0257895	0.0263158	3.0017333	0.02
1/15	15	5.235443	0.0518987	8.8132911	0.064557	5.8122222	0.0520833	6.4964474	0.0236842	6.2025333	0.024
1/23	23	0.3650633	0.0037975	0.2363291	0.0025316	0.6895833	0.0291667	0.3555263	0.0052632	0.8358667	0.008
1/28	28	2.2222785	0.0097468	2.7313924	0.0146835	5.1794444	0.0222222	3.3535526	0.0139474	3.2812	0.0105333
2/10	41	22.36038	0.0810127	21.756329	0.1037975	20.249861	0.0541667	Missed	missed	19.787867	0.0466667
6/5	156	1.1411392	0.0025316	0	0	0.6843056	0.0005333	0.9778947	0.0013158	0.7354667	0.0053333
8/26	238	1.726962	0.0055063	0.8439241	0.0012658	1.3266667	0.0041667	1.6881579	0.0092105	1.5097333	0.0258133
9/14	257	0.7274684	0.0037975	Missed	Missed	missed	missed	0.8343421	0.0026316	0	0
10/4	277	15.028608	0.1088608	9.8637975	0.0746835	14.011667	0.1333333	15.5725	0.1828947	7.4057333	0.0413333
10/27	300	0.5436709	0.0002203	0.9211392	0.0025316	1.1059722	0.0027778	1.9760526	0.0078947	2.1764	0.004
11/1	305	0	0	0.5859494	0.0020253	0	0	0.6964474	0.7105263	0.6586667	0.0333333
11/6	311	6.5486076	0.078481	14.352658	0.1582278	18.597917	0.5055556	14.778816	1.3315789	10.775467	0.688
11/11	315	18.987089	0.1696203	27.400633	0.1810127	29.803611	0.3597222	26.004868	0.4578947	23.512	0.3466667
12/6	340	0	0	0	0	0	0	0.5263158	0.0157895	1.3465333	0.0030667
12/9	343	1.1292405	0.0001392	3.6087342	0.043038	5.5970833	0.0611111	5.3663158	0.0644737	3.1174667	0.0213333
12/19	353	7.6622785	0.0594937	19.004177	0.156962	23.0175	0.2472222	19.240658	0.1802632	16.502933	0.136

Date 1996	Day of Year	1 Runoff (mm)	1 NH4 (kg NH4/ha)	2 Runoff (mm)	2 NH4 (kg NH4/ha)	3 Runoff (mm)	3 NH4 (kg NH4/ha)	4 Runoff (mm)	4 NH4 (kg NH4/ha)	5 Runoff (mm)	5 NH4 (kg NH4/ha)
2-Jan	2	1.1664557	0.0102532	0	0	4.5273611	0.0277778	3.1634211	0.0197368	2.3885333	0.0181333
7-Jan	7	0.8436709	0.0024177	0.5144304	0.000962	8.1376389	0.0513889	7.5026316	0.0460526	5.308	0.0333333
9-Jan	9										
11-Jan	11	0	0	0.5064557	0.0013544	0.7977778	0.0054167	0.8207895	0.0018026	0.9545333	0.0026667
19-Jan	19	0	0	0	0	0	0	0	0	0	0
24-Jan	24	0	0	0.963038	0.0067089	1.1627778	0.0064444	0.8801316	0.0113158	1.4684	0.0078667
27-Jan	27	8.5551899	0.0481013	21.211266	0.0962025	19.87125	0.1527778	17.734342	0.0855263	15.8568	0.0973333
31-Jan	31	5.0805063	0.0189873	10.656709	0.0367089	15.586389	0.0805556	11.087237	0.0407895	11.2292	0.0373333
2-Feb	33	17.984051	0.0556962	5.1087342	0.0189873	38.554722	0.1194444	35.674211	0.0802632	35.680667	0.0906667
28-Feb	59	1.27	0.0139241	0.87	0.0189873	1.53	0.0263889	0.91	0.0052632	1.47	0.016
6-Mar	66	4.01	0.7683544	5.7	2.7075949	9.07	6.3708333	5.5859211	3.3052632	4.3	2.4773333
7-Mar	67	0	0	0	0	43.7	15.893056	35.214868	15.711842	37.431333	16.274667
17-Mar	77	0	0	Missed	Missed	0.6940278	0.0083333	0.57	0.0026316	0.8093333	0.0093333
19-Mar	79	2.38	0.0556962	Missed	Missed	6.89	0.3569444	4.79	0.1973684	2.7	0.088
27-Mar	87	1.31	0.0531646	4.59	0.2025316	7.01	0.475	4.78	0.1105263	3.5681333	0.0506667
6-Apr	97	0	0	0.7691139	0.0050633	0.9745833	0.0097222	0.8072368	0.0065789	1.23	0.0693333
30-Apr	121	0	0	0	0	0	0	0	0	0.5990667	0.0013333
28-May	149	1.41	0.0037975	0.8063291	0.0025316	0.9545833	0.0041667	1.0382895	0.0039474	0.8688	0.008
16-Jul	198	0	0	0.5125316	0.0007595	missed	missed	0	0	0	0
2-Aug	215	0.5065823	0.0025316	0.5855696	0.0010127			1.11	0.0065789	0.8008	0.008
11-Aug	224	0	0	0	0	missed	missed	1.6748684	0.0078947	1.41	0.0186667
8-Oct	282	missed	missed	0	0	0.7198611	0.0027778	0	0	missed	missed
1-Dec	336	2.97	0.0265823	1.6311392	0.0113924	missed	0	2.12	0.0157895	3.07	0.0253333
13-Dec	348	0	0	0	0	0	0	0	0	1.0882667	0.004

Date 1997	Day of Year	1 Runoff (mm)	1 NH4 (kg NH4/ha)	2 Runoff (mm)	2 NH4 (kg NH4/ha)	3 Runoff (mm)	3 NH4 (kg NH4/ha)	4 Runoff (mm)	4 NH4 (kg NH4/ha)	5 Runoff (mm)	5 NH4 (kg NH4/ha)
5-Jan	5	0.838	0.004	0.57	0.005	1.11	0.011	0.8	0.077	0	0
9-Jan	9	0.926	0.003	6.94	0.045	17.9	0.229	9.75	0.093	8.22	0.051
16-Jan	16	1.15	0.023	1.52	0.038	3.13	0.08	1.58	0.022	1.85	0.018
8-Feb	39	0	0	0.56	0.005	1.19	0.012	0.79	0.007	1.34	0.008
14-Feb	45	2.99	0.013	16.91	0.11	31.76	0.276	18.21	0.126	15.43	0.092
21-Feb	52	2	0.014	3.22	0.041	6.38	0.068	2.26	0.02	2.95	0.022
28-Feb	59	12.7	0.086	18.95	0.113	26.35	0.065	19	0.091	14.74	0.04
28-Apr	118	2.41	0.023	malfct	Malfct	2.29	0.039	4.93	0.043	2.01	0.04
30-Jul	211	4.14	0.192	2.7	0.094	2.82	0.117	3.16	0.179	4.65	0.126
26-Oct	299	10.84	0.061	23.33	0.184	36.06	0.234	24.8	0.146	malfct	malfct
1-Nov	305	1.23	0.005	5.08	0.054	10.67	0.07	4.7	0.037	malfct	malfct
13-Nov	317	3.74	0.013	15.95	0.085	21.14	0.07	14.22	0.06	malfct	malfct
21-Nov	325	0.44	0.002	0	0	0	0	0	0	malfct	malfct
29-Nov	333	0	0	1.58	0.011	2.26	0.009	1.45	0.01	malfct	malfct
10-Dec	344	0	0	1.03	0.004	1.27	0.003	0.35	0.001	1.08	0.0023
14-Dec	348	0	0	0	0	0	0	0	0	0.62	0.0009
22-Dec	356	0	0	1.49	0.007	3.57	0.012	0.92	0.004	1.56	0.005
24-Dec	358	24.9	0.066	55.57	0.179	75.32	0.197	53.69	0.166	49.67	0.141
27-Dec	361			0	0	0.77	0.002	0.36	0.0004	0.5	0.0004

Date 1998	Day of Year	1 Runoff (mm)	1 NH4 (kg NH4/ha)	2 Runoff (mm)	2 NH4 (kg NH4/ha)	3 Runoff (mm)	3 NH4 (kg NH4/ha)	4 Runoff (mm)	4 NH4 (kg NH4/ha)	5 Runoff (mm)	5 NH4 (kg NH4/ha)
7-Jan	7	14.59	0.054	27.2	0.12	33.89	0.14	23.17	0.094	21.18	0.087
15-Jan	15	0.21	0.0001	8.93	0.02	0	0	8.3	0.014	7.44	0.011
19-Jan	19	0.44	0.001	4.49	0.009	Malfct	malfct	3.72	0.007	3.2	0.006
22-Jan	22	0	0	2.71	0.004	5.24	0.011	1.71	0.003	2.4	0.004
27-Jan	27	1.56	0.002	8.34	0.017	13.58	0.032	7.92	0.019	5.33	0.01
4-Feb	35	24.11	0	62.07	0.07	85.17	0.102	61.65	0.077	55.89	0.063
17-Feb	48	1.03	0.001	8.52	0.014	16.17	0.084	7.39	0.016	6.2	0.01
23-Feb	54	1.564	0.002	8.64	0.016	13.73	0.028	8.038	0.016	6.68	0.012
6-Mar	65	34.66	0.057	64.26	0.186	86.63	0.173	60.93	0.101	53.29	0.095
18-Mar	77	0	0	0	0	0	0	0	0	0.51	0.001
3-Apr	93	2.06	0.009	6.05	0.078	11.25	0.214			4.94	0.035
9-Apr	99	0	0	0	0	1.09	0.015	malfct		malfct	
14-Apr	104	0	0	0	0	0.94	0.015	malfct		malfct	
19-Apr	109	0.612	0.002	1.78	0.013	3.27	0.021	malfct		malfct	
21-Apr	111	3.93	0.009	11.16	0.04	15.59	0.048	malfct		malfct	
24-Apr	114	0	0	0.54	0.002	1.16	0.004	malfct		malfct	
1-May	121	0	0	0	0	2.3	0.015				
3-May	123	0	0	0	0	1.31	0.011	Malfct		malfct	
8-May	128	0	0	0	0	0.58	0.006	Malfct		malfct	
7-Oct	280	malfct		malfct		7.7	0.086	2.024	0.031	2.1	0.027

Vita

Sarah Catherine Tyson was born to her parents on April 18, 1970 in Macon, GA, and was followed by two boys 3 and 5 years later. They resided in Cochran, GA, where Sarah's father is still a professor of biology at Middle GA College. Sarah lived in Cochran for the first twenty years of her life, graduating from the local high school in 1988, and from Middle GA College in 1990. Sarah majored in Agronomy at the University of GA. She was hired as a student worker under Dr. Miguel Cabrera her first quarter there. She started an MS program under Miguel Cabrera upon completion of her BS from UGA in 1992. In the summer of 1994, Sarah married Drew Pierson and completed her MS degree. Drew persuaded Sarah to pursue further education at VA Tech, where he would begin studies in Animal Reproduction. Their stay in VA was short since Sarah's major professor, Vivien Allen, took at position at Texas Tech and Drew chose the non-thesis MS option. In 1996, they moved to Drew's home in GA, where he had plenty of work and Sarah could finish her degree "long-distance". It was difficult being away from the mental stimulation found in and around major universities. Several "wild goose chases" and two children later, Sarah had finally completed her research. Her plans are to give undivided attention and devotion to her husband and daughters. Sarah's next pursuit in academia will be to homeschool her own children.