Nutrient Cycling in Agroecosystems **50:** 287–290, 1998.
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Nutrient losses in surface and subsurface flow from pasture applied poultry litter and composted poultry litter

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Key words: hydrology, solute transport, nitrate, phosphorus, polypedon scale

Abstract

Over application of poultry litter may cause pollution of surface and ground water. Spatial variability in soil characteristics makes predictions difficult. Composting poultry litter could reduce the risk of pollution by creating more stable organic components. Three rates of poultry litter and compost (10 Mg ha^{-1} litter, 20 Mg ha^{-1} litter and 10 Mg ha^{-1} litter combined with 50 Mg ha^{-1} compost) to three watersheds under pasture. The watersheds were monitored for surface and subsurface flow. Nitrate-N concentrations in subsurface flow did not exceed the U.S. Environmental Protection Agency drinking water standard of 10 mg L^{-1}. Soluble phosphorus concentrations in runoff were high, reaching a maximum of 8.5 mg L^{-1} under the compost treatment. These concentrations are generally lower than reported on smaller scale studies, which shows the need of studies at the correct scale.

Introduction

In 1993, Georgia ranked second in the U.S. in total broiler production. The total number of birds raised was estimated at almost 960 million and the total value of production at 1.5 billion dollars [2]. Significant quantities of waste are generated during production. Perkins et al. [7] estimated that 1000 broilers produce about 1460 kg of litter (bedding material consisting of mainly sawdust and woodshavings in Georgia) in their 10 week life cycle, which means Georgia produced almost 1.4 billion kg of litter in 1993. During poultry production, the manure from the broilers is mixed with the bedding material, so the result is a mixture of which the nutrient value can differ. These wastes pose a risk to the environment which is magnified by the generally concentrated production of poultry. Pollution of ground and surface water by nitrate (NO_3) and orthophosphate (PO_4) are attributed to excessive application of animal wastes. Nitrate and phosphorus are linked to eutrophication of lakes and nitrate in drinking water may be harmful to humans and animals. Composting poultry litter may limit environmental contamination, due to more stable organic compounds.

The pathways and processes involving the transport and transformations from beneficial nutrients on the field to harmful contaminants in surface and ground water are very complex. Nitrate concentrations in soil are spatially variable due to differences in microbial activity [10]. Generally nitrate is regarded as non adsorbed, but has shown to be slightly adsorbed in variable charge soils [1]. Phosphorus is generally considered to have low mobility, being strongly adsorbed. Losses are generally related to runoff and erosion [5], but prolonged application of animal wastes on sandy soils could cause leaching of phosphorus [3]. Resources often limit sampling and measurements to the horizon or pedon scale, while knowledge is needed at the polypedon or catena scale. The objective of this study was to quantify the polypedon scale nutrient losses from poultry litter and composted poultry litter using measurements at the polypedon, pedon and horizon scale.

Materials and methods

Three 0.45 ha watersheds were planted with a mixture of Coastal Bermuda grass (*Cynodon dactylon* L.) and

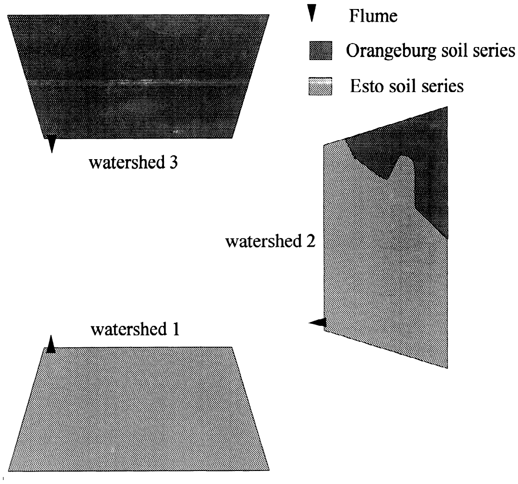

Figure 1. Locations of soil series and watersheds

Georgia 5 Fescue (*Festuca arundinacea Schreb.*). The watersheds have a slope ranging from 2 to 3.5% and the runoff contributing areas are defined by a soil berm. The experimental area consists of two different soils, the west side is a Esto sandy loam, while the east side is classified as an Orangeburg sandy loam. Both soils are fine-loamy, siliceous, thermic Typic Kandiudults. The subsurface watershed is defined by sandy clay loam layers containing plinthite starting at an approximate depth of 100 cm. These layers are slowly permeable and cause lateral flow above that depth. This layer is better developed under the Esto than under the Orangeburg. Watershed one (W1) was determined to be on the Esto, watershed three (W3) on the Orangeburg, and watershed two (W2) mainly on the Esto, but with one corner on the Orangeburg (see Fig 1.). Tile drains installed at a depth of 120 cm with gravel to a depth of 50 cm at the upper hydrological boundaries divert incoming subsurface water. Drains installed at the lower hydrological boundaries catch the lateral subsurface flow. Runoff and subsurface flow are monitored using flumes and weirs. Samples are taken automatically on a flow weighted basis. Two rates of poultry litter, 10 Mg ha^{-1} (1X) and 20 Mg ha^{-1} (2X), and a mix of poultry litter and composted poultry litter, 10 Mg and 50 Mg ha^{-1} (1X + C), are split applied in April and September. The 1X rate is the recommended application rate based on nitrogen requirements of a combination of bermuda and fescue hay (200 kg ha^{-1}). Runoff samples are analyzed for inorganic (NO_3 and NH_4) and total nitrogen, and total, bioavailable and soluble phosphorus. Subsurface samples are analyzed for inorganic nitrogen and soluble phosphorus. Large intact columns (15 cm diameter, 30 cm length) were extracted to study solute breakthrough and saturated hydraulic conductivity in each horizon for the two different soils. Moisture release curves and saturated hydraulic conductivities were measured on smaller cores (7.5 cm diameter, 6 cm length).

Results and discussion

Data for the first winter, in which all watersheds received the same application of poultry litter (1X), showed a different hydrological response among the watersheds. Differences are attributed to the two different soils. Table 1 shows selected moisture release parameters and the saturated hydraulic conductivities measured on the small soil cores. The values for the small cores can be seen as the saturated conductivities of the matrix. The slowly permeable layer in the BC of both the Esto and the Orangeburg is clearly demonstrated. The large core conductivities were generally higher for the Esto (Table 2). For the Orangeburg, the differences in conductivities between the large and small cores were less. The bigger volume of the large cores are a better representation of the full range of structural features in the soil. The Esto thus seems to have a less permeable matrix, but more structural macropores than the Orangeburg. The moisture release curves showed generally higher air entry values for the Esto (Table 1). This suggests that the Orangeburg matrix has larger pores and starts to drain earlier than the Esto after rain. Table 3 shows runoff and subsurface flow of the three watersheds as percentages of total rainfall. It clearly shows more runoff and subsurface flow from the watersheds with the Esto soil (W1 and W2). The data collected at the pedon scale suggest that this difference at the polypedon scale is mainly due to a more permeable matrix in the Orangeburg. This delays saturation, macropore flow, runoff and tile drain flow compared to the Esto.

During the first winter the highest nitrate-N concentrations in the subsurface samples were 6.1, 4.3 and 1.1 mg L^{-1} and soluble phosphorus concentrations in the runoff samples reached maximum values of 4.9, 3.3, 1.2 mg L^{-1} for W1, W2 and W3, respectively. These data show that nitrate-N concentrations in subsurface flow under the 1X treatment did not exceed the U.S. Environmental Protection Agency drinking water standard of 10 mg L^{-1}. The phosphorus levels are quite high considering recently established USEPA

Table 1. Selected moisture release parameters.

Horizon	Depth (cm)	air entry (cm H_2O)	N exponent	Ksat (cm hr^{-1})
Esto Bt2	40 - 72	102.92	1.22	0.32
Esto Bt3	72 - 91	45.16	1.13	0.52
Esto BC1	91 - 142	92.47	1.07	0.02
Orangeburg Bt2	56 - 95	16.09	1.26	3.10
Orangeburg BC1	125 - 171	75.45	1.11	0.10

Table 2. Selected solute breakthrough parameters.

Horizon	Depth (cm)	θ_m/θ	Dispersivity (cm)	Ksat (cm hr^{-1})
Esto Bt2	40 - 72	0.55	10.92	3.08
Esto Bt3	72 - 91	0.52	6.78	3.50
Esto BC1	91 - 142	0.26	12.36	2.94
Orangeburg Bt2	56 - 95	0.35	7.82	2.23
Orangeburg BC1	125 - 171	0.36	30.74	0.08

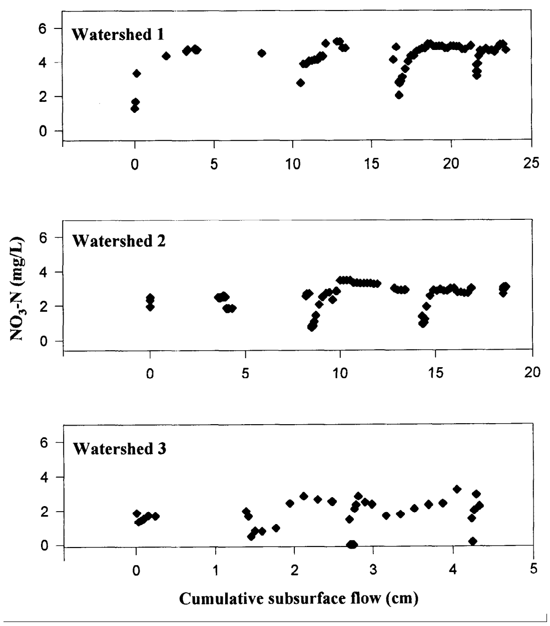

Figure 2. Nitrate concentrations in subsurface flow March 1995 to March 1996

guidelines of 0.05 and 0.1 mg L^{-1} phosphorus for lakes and streams, respectively [8].

In the following year of variable treatment application, the summer was extremely dry and no significant runoff or subsurface flow occurred until after the second part of the split application was completed. Nitrate-N concentrations in subsurface flow, however, only reached 4.8, 3.5 and 2.9 mg L^{-1} as a maximum on the 1X + C (W1), 2X (W2) and the 1X (W3) treatments, respectively. The generally lower concentrations could be explained by a much larger role of crop uptake in this year, due to a better developed forage. All concentrations remained under the drinking water standard even after addition of 400 kg ha^{-1} of total nitrogen with the compost. Figure 2 shows the nitrate-N concentrations in the subsurface flow of the three treatments. The concentrations follow a distinct pattern during the storms, which can be explained by preferential flow. The earliest subsurface flow consists mainly of relatively nitrate-free water traveling through preferential flow paths. Later arriving water has traveled more slowly through capillary-sized pores where solutes can more easily diffuse into the water from stagnant regions [6]. The increase in saturated hydraulic conductivity between the small and large cores on the Esto soil (Table 1 and Table 2) suggests the existence of these preferential flow paths. Breakthrough experiments on the large cores showed non-equilibrium flow in all horizons of both soils, with mobile water contents ranging from 26 to 55% (Table 2). Note also that the dispersivities are large, considering that Jury et al. [4] report the range for field scale values as 5-20 cm. This is also an indication of preferential flow paths.

Soluble phosphorus concentrations in the runoff reached 8.5, 3.8 and 1.6 mg L^{-1} on the 1X + C, 2X

Table 3. Runoff and drainage as a percentage of total rainfall, September 1994-March 1996

	W1 (Esto) %	W2 (Esto/Orangeburg) %	W3 (Orangeburg) %
Runoff	9.8	7.4	3.3
Subsurface flow	18.7	16.6	4.3

and the 1X treatments, respectively. Here the addition of about 800 kg ha^{-1} of phosphorus with the compost treatment, increased the concentration of soluble phosphorus in the runoff on W1. Plant available phosphorus in the upper 30 cm of the profile also increased, with the highest increase on W1. Total and bioavailable phosphorus levels showed that, for all treatments, the concentrations mainly consisted of soluble phosphorus. This suggests that conventional measures, like filter strips and riparian zones, will not lower the concentration in the runoff substantially. Only increasing plant uptake, or stabilizing the phosphorus in litter with the use of additives, like alum [9], could decrease these concentrations. These results, in general, show that composting works well in reducing the amount of nitrogen being lost, but does not reduce the amount of phosphorus. All of the phosphorus concentrations in the runoff are lower than earlier reported values [5, 9] which were found in small plot runoff studies. This is probably due to differences in scale (pedon vs polypedon) and timing of rainfall (natural vs. simulated). These results reconfirm the importance of studies at the polypedon scale under natural conditions if guidelines for application of animal wastes are to be developed. Up scaling these results to the farm or catena level will require considering land use patterns and border effects like riparian zones.

Acknowledgements

This research was supported in part by funds from the CSREES water quality research program competitive grants/USDA, grant # 92-34214-7354 and the Southeastern Poultry & Egg Association, project # 131

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