SOLIDS TRANSPORT AND ERODIBILITY OF POULTRY LITTER SURFACE-APPLIED TO FESCUE

D. R. Edwards, T. C. Daniel, P. A. Moore, Jr., A. N. Sharpley
MEMBER
ASAE

ABSTRACT. *Poultry (*Gallus gallus domesticus*) litter is land-applied to make beneficial use of litter nutrients for plant growth. Runoff can transport litter particles off application sites and thus diminish the quality of downstream waters. This study assessed how solids (sediment and litter particles) yield and erodibility for fescue (*Festuca arundinacea *Schreb.) pasture are influenced by poultry litter application. The experimental variables were poultry litter application rate (0, 5.9, 11.8, and 23.5 Mg/ha), simulated rainfall intensity (50 and 100 mm/h), interval between litter application and simulated rainfall (1, 4, 7, and 14 days), and number of simulated rainfall events (four events—one each at 7, 14, 36, and 68 days following litter application). Solids yields were determined from composite runoff samples. Erodibility values were computed from the Modified Universal Soil Loss Equation. Solids yield increased with increasing rainfall intensity and litter application rate. Erodibility increased linearly ($r^2 = 0.98$) with litter application rate, but was unaffected by rainfall intensity. Neither solids yield nor erodibility was influenced by interval between litter application and first post-application rainfall. The number of rainfall events affected both solids yield and erodibility of litter-treated plots, but both approached levels observed for untreated plots by the third rainfall. The results indicate that models estimating erosion from fescue pasture treated with poultry litter should incorporate increased erodibility values to account for the presence of the litter. The adjustment, however, should be decreased with successive post-application rainfall events.*

Keywords. *Erosion, Pasture, Poultry, Manure.*

Land application of poultry (*Gallus gallus domesticus*) litter, a combination of manure and bedding material, is commonly practiced to make beneficial use of the litter nutrients for plant uptake and to prevent unacceptable in-house accumulation of the litter. Poultry litter is often surface-applied without incorporation in southeastern states to fertilize forage crops such as fescue grass (*Festuca arundinacea* Schreb.), bermudagrass [*Cynodon dactylon* (L.) Pers.] and orchardgrass (*Dactylis golmerata* L.). Crop yield increases attributable to poultry litter application have been well-documented over the past three decades (e.g., Hileman, 1965, 1973; Huneycutt et al., 1988).

Poultry litter application can increase concentrations of water quality parameters such as nitrogen (N), phosphorus (P), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total suspended solids (TSS) in runoff from rainfall occurring soon after litter application (Giddens and Barnett, 1980; Westerman and Overcash, 1980; Westerman et al., 1983; McLeod and Hegg, 1984). An increasing amount of effort is being devoted to understanding how variables such as soil, litter application rate, rainfall intensity, land slope, and drying interval influence the chemical composition of runoff from treated areas (Edwards and Daniel, 1993a, b, 1994; Huhnke et al., 1992; Storm et al., 1992). These studies have focused on the transport of N, P, COD, and BOD in runoff following the application of poultry litter and other manure types with relatively little attention given to transport of solids. Reviews of water quality impacts of animal manure application also emphasized primarily losses of nutrients and oxygen-demanding materials (Sweeten and Reddell, 1978; Khaleel et al., 1980; Edwards and Daniel, 1992). The transport of chemicals in runoff from land areas treated with poultry litter can have an immediate and direct effect in water quality degradation. The transport of solid material, however, may have a long-term impact on receiving waters. For example, solid material lost from land areas receiving poultry litter contains N and P that can subsequently be released into aquatic systems. Eroded litter particles are also rich in C and can exert a high oxygen demand. Thus, more information on transport of solids from land areas treated with poultry litter is needed.

The role of solids with respect to runoff N and P transport has been recognized and incorporated into mathematical simulation models such as: Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980); Erosion-Productivity Impact Calculator (EPIC) (Williams et al., 1983); and Agricultural Nonpoint Source Pollution (AGNPS) (Young et al., 1987). These models compute transport of particulate N and P from enrichment ratios as a function of sediment yield (Sharpley, 1985). The transport of N and P is commonly estimated from sediment yield as:

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The authors are **Dwayne R. Edwards**, Associate Professor, Biological and Agricultural Engineering Dept., **Tommy C. Daniel**, Professor, Dept. of Agronomy, University of Arkansas, Fayetteville; **Philip A. Moore, Jr.**, Soil Chemist, PPPSU, USDA-ARS, University of Arkansas, Fayetteville; and **Andrew N. Sharpley**, Soil Scientist, National Agricultural Water Quality Laboratory, USDA-ARS, Durant, Okla.

$$Y_x = C_x Y_S ER \qquad (1)$$

where

Y_x = yield (mass/area) of constituent x
C_x = concentration of the constituent in the interacting soil depth (mass/mass)
Y_S = sediment yield (mass/area)
ER = enrichment ratio

Sediment yield is usually computed from equations such as the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975):

$$Y_S = 9.05(Q\, q_p)^{0.56}\, K\, LS\, C\, P \qquad (2)$$

where

Y_S = sediment yield (Mg)
Q = runoff volume (m^3)
q_p = peak flow (m^3/s)
K = erodibility (Mg-h/ha-N)
LS = length-slope factor
C = cover factor
P = conservation practice factor

The term $(Q\, q_p)^{0.56}$ is the rainfall energy factor, a measure of kinetic energy imparted to the soil or cover due to rainfall.

Since losses of N, P, and other constituents when estimated from equation 1 are directly dependent on Y_S and thus K (eq. 2), it follows that use of inappropriate K values can lead to inaccurate estimates of N and P losses as well as of sediment yield. Even though earlier studies appear to have produced varying results, it has been established that application of animal manures can alter the erosion and solids yield characteristics of receiving land areas. Westerman et al. (1983), for example, found that solids lost from bare plots treated with poultry litter and poultry manure were greater than from untreated bare plots (clay and sandy loam soils). The proportion of solids comprised of manure/litter particles was estimated to range from 45 to 92% for a sandy soil and from 8 to 54% for a clay soil. Giddens and Barnett (1980) demonstrated an effect of poultry litter on solids loss from bare plots with sandy loam soil, but found that solids loss was reduced by as much as 50% when poultry litter was applied at up to 22.4 Mg/ha. The effects of litter application to plots established in bermudagrass were less well defined in that study.

Although the above-cited studies have shown that poultry litter application can affect solids transport in runoff, there have been few attempts to account for these effects in simulation models that estimate solids yield. Khaleel et al. (1979a) developed a soil/manure particle transport model that accounted for different erodibilities of soil and manure particles, but later (Khaleel et al., 1979b) remarked on the scarcity of reported erodibility values for manure particles.

This study was undertaken to quantify how application of poultry litter to simulated fescue pasture (typical of litter-receiving areas in Arkansas, Oklahoma, and other states) affects solids (soil and litter particles) yield and erodibility. The variables tested for significant impacts on solids yield and erodibility were (a) poultry litter application rate, (b) simulated rainfall intensity, (c) interval between litter application and first simulated post-application rainfall event, and (d) number of simulated post-application storms. The results of this study can help improve estimates of solids yield, and thus other runoff quality parameters, for pasture/rangeland areas treated with poultry litter.

METHODS AND MATERIALS

EXPERIMENTAL DESIGN

All experimental work was performed using plots constructed at the University of Arkansas Main Agricultural Experiment Station in Fayetteville, Arkansas. The soil at the site is Captina silt loam (fine-silty, mixed, mesic Typic Fragiudult). The plots have dimensions of 1.5 × 6.0 m and metal borders to isolate plot runoff. The plots were cross-leveled and have a uniform 5% slope along the major axis. The plots have had a continuous stand of fescue since the fall of 1990. Plot runoff flows into aluminum gutters installed across the bottoms of the plots.

Rainfall simulators were used to produce runoff from the plots. The simulators were developed at the National Soil Erosion Research Laboratory as up-and-down slope modifications of the cross-slope simulator described by Niebling et al. (1981). Each simulator uses four VeeJet 80150 nozzles (Spraying Systems Company, Inc.) attached to a single oscillating shaft to cover an area of 1.5 × 6.0 m at intensities ranging from 0 to 150 mm/h, depending on oscillation frequency. Edwards et al. (1992) reported uniformity coefficients of from 80 to 82% for this simulator design. Simulated rainfall was applied in all cases until runoff had occurred for 0.5 h from each plot. Total rainfall applied thus varied among plots, but runoff duration was constant for all plots. Grass height in the plots was approximately 10 cm upon all applications of simulated rainfall.

Runoff was collected from the plot gutters in 1 L polyethylene containers. The gutters were covered during sampling to prevent direct entry of simulated rainfall. The sampling interval was 5 min. The times required to collect runoff samples were recorded, enabling calculation of runoff rates. Runoff rates were integrated with respect to time to calculate plot runoff volumes. Flow-weighted composite samples were prepared from the associated discrete samples and analyzed for total suspended solids (TSS) according to the standard method of analysis (Greenberg et al., 1992). Solids yield were then computed as the products of runoff volumes and TSS concentrations.

Erodibility of applied poultry litter was determined by the MUSLE, with equation 2 rearranged to solve for K for all observations of Y, Q, and q_p. Values of LS, C, and P were held constant for all plots. The value of LS was computed (Barfield et al., 1981) as 0.13 (6 m slope length with 5% slope). The value of C was taken as 0.003 (no appreciable canopy, 95 to 100% perennial ground cover) (Soil Conservation Service, 1983), and P was taken as 1.

Effects of all experimental variables were assessed using Analysis of Variance (ANOVA). When ANOVA indicated significant treatment effects, Least Significant Difference (LSD) testing was performed to separate treatment means.

ASSESSMENT OF LITTER APPLICATION RATE AND RAINFALL INTENSITY EFFECTS

Effects of litter application rate and simulated rainfall intensity were determined through a factorial experiment with four levels of application rate (0, 5.9, 11.8, and 23.5 Mg/ha) and two levels of simulated rainfall intensity (50 and 100 mm/h). The experiment was conducted in the summer of 1991 with three replications of each treatment. The litter used was collected from a broiler production facility and had a bedding material consisting of rice hulls and wood shavings, which is a typical bedding material composition. The average moisture content of the 1991 batch of litter was 18.5% (w.b.). The litter was stored at 4° C for approximately one week prior to application to the plots. The simulated rainfall was applied one day following litter application.

ASSESSMENT OF DRYING INTERVAL EFFECTS

A different (from 1991) batch of poultry litter was collected and applied to plots at 5.6 Mg/ha during the summer of 1992. The litter was collected from a broiler production facility and had a bedding material of rice hulls and wood shavings. The average moisture content of the 1992 batch of litter was 19.4% (w.b.). The litter was stored at 4° C for approximately one week prior to application to the plots. Separate treatments received simulated rainfall (50 mm/h) at intervals of 4, 7, and 14 days after litter application. Control plots (no litter applied) received simulated rainfall on the same schedule. Portable covers were placed over the plots when necessary to protect the plots from natural rainfall. Each drying interval treatment was replicated three times. The previous year's data on solids yield for the 0 and 5.9 Mg/ha litter application rates and 50 mm/h rainfall intensity were included to enable investigation of drying intervals of 1, 4, 7, and 14 days. Including the 1991 data was judged justifiable because of the similarity in properties of the two batches of litter and the comparability (within 5%) of litter application rates.

ASSESSMENT OF SUBSEQUENT STORM EFFECTS

Six of the plots (three control plots and three litter plots having simulated rainfall applied seven days following litter application) used to assess drying interval effects, were also used to determine how solids yield and erodibility are influenced by subsequent rainfall events. These plots received simulated rainfall again at 14, 36, and 68 days following litter application.

RESULTS

LITTER APPLICATION RATE AND RAINFALL INTENSITY EFFECTS

Increases in both rainfall intensity and litter application rate were accompanied by increases ($p < 0.05$) in solids yield (fig. 1). The significant effect of rainfall intensity was expected and reflects increased erosive energy at the higher intensity. Mean values of the rainfall energy factor in equation 2 were 6.4×10^{-4} and 2.8×10^{-3} at the 50 and 100 mm/h rainfall intensities, respectively. As solids yield from the control (0 Mg/ha litter application rate) plots were relatively small (0.3 to 1.6 kg/ha), solid material lost from the litter-treated plots was primarily litter. The eroded litter consisted almost exclusively of manure particles, as virtually no bedding material was observed in the runoff. The separation of manure and bedding material particles might have occurred because of a tendency of the grass to prevent movement of the relatively large bedding material particles. In comparison to amounts applied, litter lost through erosion was relatively small. Solids yield as proportions of litter applied ranged from 0.06 to 0.11% and 0.25 to 0.30% for the 50 and 100 mm/h rainfall intensities, respectively, after subtracting solids yield from corresponding untreated plots (i.e., assuming that the average amount of soil lost from litter-treated plots was the same as from the control plots).

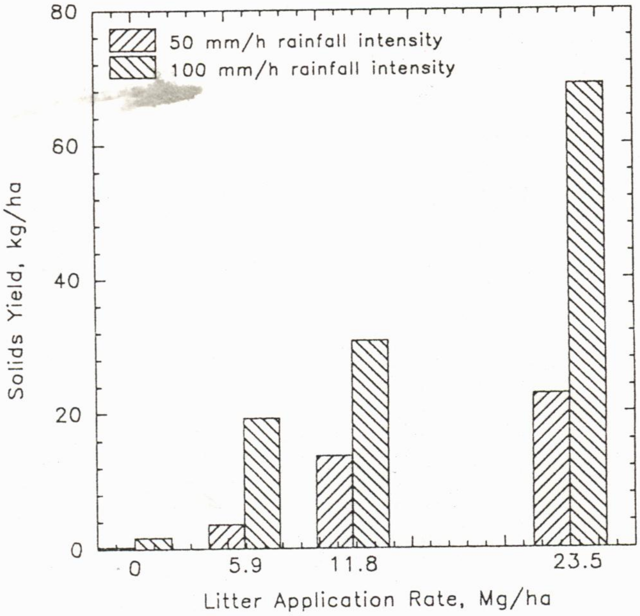

Figure 1–Effects of poultry litter application rate and rainfall intensity on solids yield. Value of LSD (p = 0.05) is 30 kg/ha for both within-rainfall intensity treatment and within-litter application rate treatment comparisons.

Rainfall intensity had no significant ($p < 0.05$) effect on erodibility, indicating that the rainfall energy factor of the MUSLE adequately described rainfall intensity effects on solids yield. Litter application rate, however, did significantly ($p < 0.05$) influence erodibility with values increasing linearly with litter application rate (fig. 2). The erodibility computed for the zero application rate (0.16 Mg-h/ha-N) was quite low, particularly in comparison to the previously reported (Soil Conservation Service, 1983) value of 0.57 Mg-h/ha-N. Values of K computed for the litter-treated plots (fig. 2) were, in contrast, quite high. The dependence of K on litter application indicates adjustments to K are justified when estimating solids yield from grassed areas recently treated with poultry litter.

The high erodibility of the poultry litter is linked to the physical properties of the litter and the method of application. The manure particles (the predominant constituent of the eroded material) have both a small effective particle diameter and a low particle density. Khaleel et al. (1979b) reported an effective particle diameter of 0.035 mm and a particle density of 1.44 g/cm^3. Sobel (1966) found an effective particle diameter of

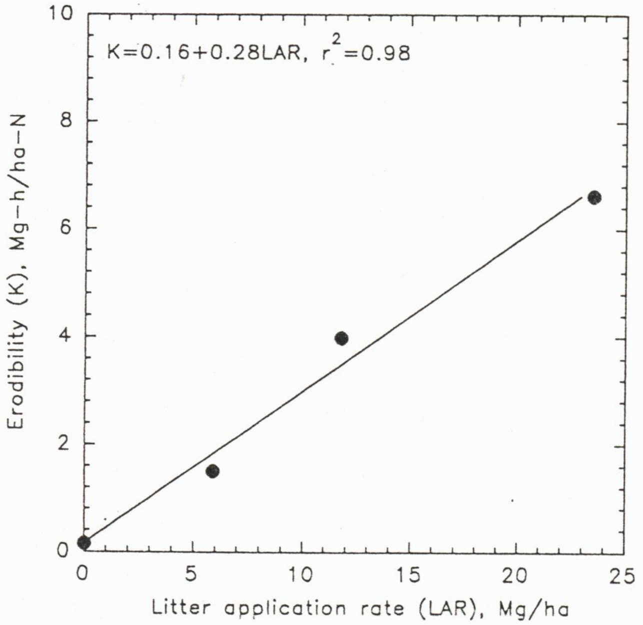

Figure 2–Effects of poultry litter application rate on erodibility.

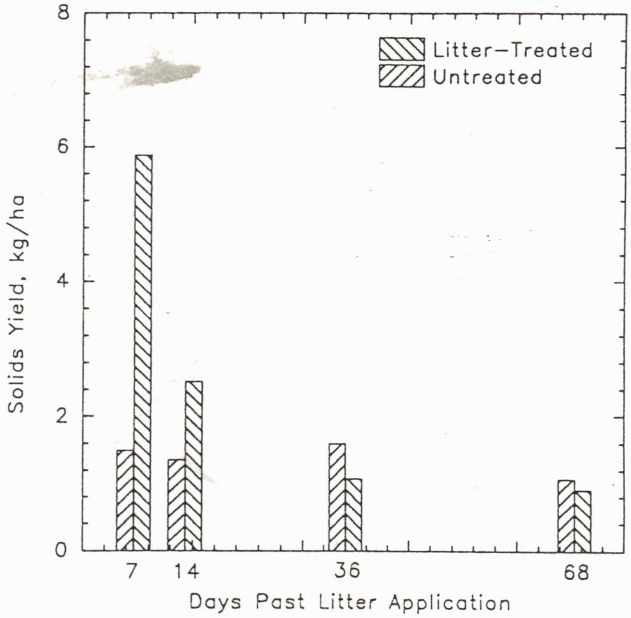

Figure 3–Effect of successive rainfall events on solids yield. Value of LSD (p = 0.05) is 2.2 kg/ha for both within-fertilizer treatment and within-rainfall event treatment comparisons.

0.075 mm and a particle density of 1.7 g/cm^3. The manure particles are also susceptible to erosion because the material was surface-applied and thus not well protected by the grass cover.

DRYING INTERVAL EFFECTS

An interval of up to 14 days between litter application and rainfall did not significantly ($p < 0.05$) affect either solids yield or erodibility. Both mean solids yield and erodibility for the litter-treated plots were significantly ($p < 0.05$) greater than for the untreated plots. Mean observed solids yields (averaged over all drying intervals) were 4.54 kg/ha for the litter-treated plots and 0.86 kg/ha for the control plots. Mean computed erodibilities (averaged over all drying intervals) were 1.52 Mg-h/ha-N for the litter-treated plots and 0.29 Mg-h/ha-N for the control plots. The quantity of manure particles readily available for transport appears not to have been significantly diminished by microbial decomposition, the most applicable mechanism of litter particle degradation. This may have been due to the initially dry condition of the applied litter and continued drying prior to rainfall, which would have depressed microbial activity.

SUBSEQUENT STORM EFFECTS

Both solids yield and erodibilities for litter-treated plots exhibited a significant ($p < 0.05$) decrease with successive rainfall events (figs. 3 and 4). Neither solids yield nor erodibility as affected ($p < 0.05$) by the number of rainfall events applied to the untreated plots (figs. 3 and 4). For the first two rainfall events, both solids yield and erodibility were significantly ($p < 0.05$) greater for the litter-treated than for the untreated plots; afterward, there were no significant differences between treated and untreated plots. As proportions of the amount applied, losses of poultry litter solids were very low. Only 0.1% of the mass of applied litter was eroded from the treated plots during the first two rainfall events, and 80% of that occurred during the first rainfall event.

The data indicate that a K value that has been adjusted for the presence of poultry litter should be decreased as the number of post-application storms increases, approaching the "background" K value after about three runoff-producing storms. The causes of decreasing erodibility are probably due in part to the loss of lighter organic particles initially, with heavier, less-erodible particles remaining that will not be transported except at higher rainfall intensities. Also, microbial decomposition of organic solids may have occurred along with changes in physical properties of the litter/soil medium in response to increasing rainfall energy.

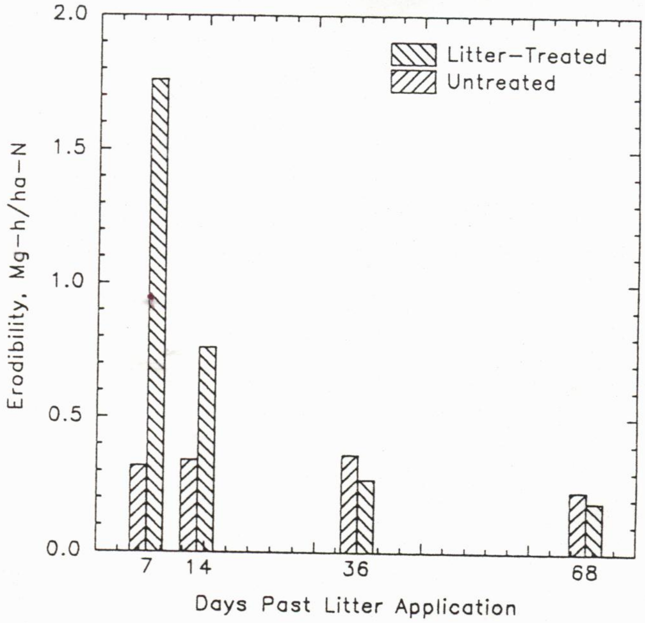

Figure 4–Effect of successive rainfall events on erodibility. Value of LSD (p = 0.05) is 0.3 Mg-h/ha-N for both within-fertilizer treatment and within-rainfall event treatment comparisons.

SUMMARY AND CONCLUSIONS

The relationships between solids yield and erodibility of poultry litter particles and litter application rate, rainfall intensity, interval between litter application and first rainfall event, and number of post-application rainfall events were determined for simulated fescue pasture. Solids yield increased with both litter application rate and simulated rainfall intensity; the increases were attributed to relatively high erodibility of poultry litter particles in comparison to soil. Neither solids yield nor erodibility was affected by interval between litter application and the first rainfall event. Both solids yield and erodibility decreased with increasing number of post-application rainfall events.

The findings of this study indicate that the relatively greater erodibility of poultry litter particles in comparison to underlying soil should be accounted for in estimating erosion from litter-treated areas. Failure to appropriately increase the K value for the first few post-application storms might lead to solids yield estimates that are much less than would be observed. Estimates of other water quality parameters such as total N and total P would be similarly affected by neglecting poultry litter effects on erodibility, as these parameters are estimated as functions of solids yield (Sharpley, 1985). This article provides information that can be useful in determining the appropriate K values to be used after poultry litter application. Since this study did not yield information on the processes by which erodibility declines with number of post-application storms, additional work will be necessary to better quantify the influences of litter aggregate breakdown, microbial decomposition, and other processes on erodibility of litter particles.

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