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# EFFECTS OF TILLAGE SYSTEMS ON THE QUALITY OF RUNOFF FROM SLUDGE-AMENDED SOILS

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## ABSTRACT

Land application of sewage sludge requires careful monitoring because of its potential for contamination of surface water and groundwater. A rainfall simulator was used to investigate the effects of freshly applied sludge on runoff of sediment and nutrients from agricultural crop lands. Rain was applied to 16 experimental field plots. A three run sequence was used to simulate different initial moisture conditions. Runoff, sediment and nutrient losses were monitored at the base of each plot during the simulated rainfall events. Sludge was surface applied and incorporated at conventionally-tilled plots and surface applied at no-till plots, at rates of 0, 75, 150 kg-N/ha. No-till practices greatly reduced runoff, sediment, and nutrient losses from the sludge treated plots, relative to the conventional tillage practices. Incorporation of the sludge was effective in reducing nutrient yields at the conventionally-tilled plots. This effect was more pronounced during the third rainstorm, with wet initial conditions. Peak loadings of nutrients appeared during the rainstorm with wet initial conditions.

Key Words : Tillage, Sludge, Land Application, Runoff, Nutrients, Water Quality

## INTRODUCTION

Application to agricultural lands is a cost-effective alternative for disposal of sewage sludge. Secondary benefits of application of sludge to agricultural lands include nutrient supply to crops, increase of soil organic matter content, and improvement of soil properties. However, the potential hazards of surface water and groundwater contamination from land disposal of sewage sludge is a major environmental concern. Potential problems of land application of sewage sludge have been reviewed by Kelley, et al. (1984). These problems include accelerated eutrophication of surface waters by phosphorus; groundwater contamination by leaching of nitrate; and health risks from transfer of pathogenic organisms to humans or animals and from the uptake of trace elements (heavy metals) by plants.

Several authors have studied the effect of sludge application on the quality of runoff water from agricultural lands. Kelling, et al. (1977) found significantly lower runoff and sediment losses from sludge treated areas, relative to untreated areas. However, orthophosphorus ($PO_4 - P$), total phosphorus ($P_t$), and nitrite plus nitrate ($NO_2 + NO_3$) loads in runoff water from the sludge treated plots increased, compared to the control plots. Dunnigan and Dick (1980) found that surface application of sewage sludge resulted in higher loadings of nitrogen (N) and phosphorus (P) in runoff water, as compared to loadings from plots in which sludge was incorporated into the soil.

The beneficial impacts of sludge applications to reduce surface runoff and soil erosion can be related to reduction of raindrop impact by the surface protective sludge layer and increased infiltration as a result of the improvement of the physical condition of the soil. (Mostaghimi et al., 1988). Significant increases in aggregation and large pore space as a result of sludge application were observed during a one year field study by Kladivko and Nelson (1979). Otis (1985), however, reported that application of waste water effluent significantly reduced the hydraulic conductivity and infiltration rate of soils due to pore clogging. He attributed pore clogging to the suspended solids in the waste water effluent, which mechanically sealed the entrances to the larger pores. In addition the nutrients in the waste water, which stimulated the the biological activity in the soil, causing break down of the structural units of the soil and, in turn, increased pore clogging. Chang et al. (1983) indicated that the amount of sludge required to cause significant changes in soil properties was much greater than the amount normally used to satisfy crop nutrients requirement.

The objective of this study was to investigate the short-term impacts of sludge application method, application rate, and tillage practice on runoff, sediment and nutrient losses from agricultural lands.

## MATERIALS AND METHODS

Sixteen experimental field plots, located at Virginia Tech's Price's Fork Agricultural Research Farm, 10 km west of Blacksburg, were used for this study (Mostaghimi et al., 1988.). Plots are located on a Groseclose silt loam soil (clayey, mixed mesic Typic Hapludult). The soil is deep and well-drained with a slowly permeable subsoil. The plowed surface (Ap) horizon is typically 25 cm thick, with a loam texture and moderately fine granular structure. Soil characteristics are presented in Table 1.

Each plot had a surface area of 0.01 ha (18.3m × 5.5m). Metal borders were installed around each plot to prevent surface and subsurface runoff from flowing across the plot boundaries. The 30 cm high borders were inserted to a depth of about 15 cm. A concrete gutter with a pipe outlet at the base of each plot collected and transported the runoff to an H-flume. All plots were planted in winter rye in the fall and sprayed with paraquat, a week before the simulation runs, in early spring of the following year. No-till treatments were established on the killed rye stand. Crop residue was measured by randomly locating a 0.6 × 0.6 m square in each plot and removing all residue in the square for laboratory analysis. Conventional tillage was represented by removing crop residue from the plots, tilling to a depth of 15-20 cm with a power-take-off (PTO) driven rototiller, and disking.

Anaerobically digested, polymer conditioned sewage sludge was obtained from the James River plant in Hampton Roads, Virginia. General characteristics of the sludge are given in Table 1. Sludge was distributed over the plots by subdividing each plot into four equal-sized subareas. The sludge was spread, as uniformly as possible within the subareas, using rakes. Within each tillage treatment two sludge application rates, representing 150 kg-N/ha and 75 kg-N/ha, and an untreated control plot, were established. Loading rates were determined using the methodology suggested by Simpson (1985). The sludge was black in color and fairly crumbly when applied. The high and low application rates provided an average sludge layer of approximately 1.0 and 0.5 cm, respectively, although no uniform cover was obtained. Sludge was surface applied to all no-till plots. For the conventional tillage plots, sludge was both incorporated and surface-applied. The plots with the incorporated treatments were retilled to incorporate the sludge into the upper 15-20 cm of the soil profile. Two replications of each treatment required a total of sixteen plots. Plot treatments are listed in Table 1. All treatments were randomly assigned to the experimental plots.

A rainfall simulator (Dillaha et al., 1987) was used to apply approximately 90 mm of rainfall to the plots over a two-day period. A 60-minute initial dry run (R1) was followed 24 hours later by a 30-minute wet run (R2), followed 30 minutes later by another 30-minute very wet run (R3). The three run sequence is a common artificial rainfall sequence used for erosion research in the U. S. to represent different initial moisture conditions (Dillaha et al., 1987). A 40-45 mm/hr rainfall rate was used for all simulations. A one-hour storm with a 40-45 mm/hr intensity has a 2-5 year return period in Southwest Virginia (Hershfield, 1961). The sludge was applied 24 hours before the first simulated rainstorm. Rainfall within the 24 to 48 hours after the application of sludge is expected to result in extremely high loadings of nutrients to surface runoff, since sludge had been applied within the previous 24 to 48 hours. The plots were covered with plastic sheets between the runs when natural rainfall appeared imminent. At all other times the plots were uncovered to dry naturally. Rainfall simulator rates and uniformity were measured for each event, using twelve volumetric raingages within each plot.

Runoff rates were recorded at the base of each plot using a 15-cm H-flume equipped with an FW-1 stage recorder. Runoff water samples were collected manually from the plots discharges at the flumes, at three-minute intervals throughout the runoff process. The samples were frozen immediately after collection and stored for subsequent analysis. Laboratory analyses were conducted to determine total suspended solids (TSS), ammonium ( $NH_4 - N$), nitrate ($NO_3 - N$), total and total filtered Kjeldahl nitrogen (TKN and $TKN_f$), orthophosphorus ($PO_4 - P$), and total and total filtered phosphorus ($P_t$ and $P_{tf}$). All nutrient analyses were conducted according to the EPA Standard Methods (U.S. EPA, 1979). No bacteriological analysis was done. Detailed information on sampling methods and sample analysis are presented by Mostaghimi et al. (1988). Sediment-bound nitrogen ($N_{sb}$) was computed by subtracting total filtered nitrogen from total Kjeldahl nitrogen. Sediment-bound phosphorus ($P_{sb}$) was obtained by subtracting $P_{tf}$ from $P_t$. Nutrient and sediment losses were calculated from the concentrations of each sample by assuming that the average flow rate was equal to the average of flow rates at beginning and end of the three-minute sampling interval. Variations in runoff, sediment and nutrient yields between the different treatments were analyzed using Tukey's studentized range test at the 5% and 10% significance level.

## RESULTS AND DISCUSSION

Runoff, sediment and nutrient yields, reported in Table 2, indicate that among the treatments investigated, surface application of sludge to no-till plots is the most preferable treatment for surface water quality protection. Runoff and sediment losses from the sludge treated plots were greatest when sludge was incorporated into the conventionally-tilled plots. Nutrient yields increased in the order of no-till (surface application) < conventional tillage (incorporated) < conventional tillage (surface application). The runoff data of the incorporated treatments compared to the data of the surface treatments do not indicate enhancement of soil physical properties by sludge incorporation. These results were expected because of the short period of time between sludge application and rainfall events. Losses of both sediment-bound and soluble nutrients from conventionally-tilled plots were greatly reduced when sludge was incorporated. The effect of the tillage system on nutrient losses is most pronounced under dry conditions, as can be seen from the fact that only 13% of the total nutrient yields from the no-till plots is lost during Run1, compared to 66% during Run3. The losses for the initial and final runs at the conventionally-tilled plots were 24% and 47% of the total losses of all three runs, respectively.

Surface application of sludge reduced runoff, sediment and nutrient yields (Table 3). For the no-till treatments, yields of runoff, sediment and nutrients, were least for sludge application rates of 75 kg-N/ha. Exceptions were observed for the $NH_4-N$ and $N_{sb}$ yields during Run3, which were lowest for the control plots (0 kg-N/ha) and increased with increasing application rates. For the conventional tillage treatments, greatest runoff, sediment and sediment-bound nutrient yields were associated with the plots with no sludge application. Although during the third run (Run3) sediment-bound nutrient yields were greater at the plots where sludge was applied. Apparently, the significant reduction in sediment yield associated with sludge application reduced sediment-bound nutrient losses. The surface residue left at the no-till plots was found to offer a higher hydraulic resistance and a better protection against surface sealing than the surface cover provided by the sludge layer. Erosion of the sludge layer as well as clogging of the soil pores by the infiltrating sludge particles during the first run may have reduced the beneficial effects of the sludge application during the later runs. The effect of pore clogging is more prominent than the effect of erosion at the no-till sites, where less erosion of the sludge layer and higher infiltration rates enhanced infiltration of sludge particles into the larger pores. This resulted in lower runoff rates for the lower sludge application rates. At the conventionally-tilled plots more sludge eroded from the surface, relative to the no-till sites. The high sludge application rates at these plots proved more beneficial in maintaining low runoff rates, because a sufficient amount of sludge was left at the surface to protect the soil against raindrop impact and prevent excessive pore clogging.

Losses of $NH_4-N$ from the conventionally-tilled plots with surface applications of 75 kg-N/ha and 150 kg-N/ha were, respectively, 4 and 10 times greater than those from the control treatments on which no sludge was applied. Loss of nitrates, considered a serious problem with sludge application, because of potential water contamination, was not affected by sludge application rates (data not shown). The original N composition of the sludge may partially account for this result because a significant proportion of the total N in anaerobically digested sludge is present as $NH_4-N$, and very little is present as $NO_3-N$ (Mostaghimi et al., 1988). This study was not conducted long enough for nitrification to play a significant role. Losses of $PO_4-P$ from the conventionally-tilled, sludge treated plots, were approximately two to three times as high as the amounts lost from the control plots.

The surface application of sludge resulted in greater losses of nutrients during the final run than during the initial run, as is evident from Table 3. This effect was most pronounced for the no-till treatments, where 21% of the total nutrient yields from the control plots (0 kg-N/ha) appeared during the initial run, whereas 9% and 14% of the total nutrient losses from the plots with sludge applications of 75 kg-N/ha and 150 kg-N/ha, respectively, were lost during the first run. For the conventionally-tilled plots, where no sludge was applied, 31% of the total nutrient losses occurred during the first run, compared to 23% and 25% for sludge applications of 75 and 150 kg-N/ha, respectively. High runoff rates appeared immediately after the start of Run3, whereas during the initial run (Run1) significant runoff appeared only 40 minutes after the start of the rainfall. This resulted in high sediment and nutrient yields from the third run (Run3) compared to Run1. Similar results were found by Nelson and Römkens (1970) and many others during rainfall simulator studies. Sediment losses were generally least during Run2, while runoff and nutrient losses increased throughout the sequence of rainfall events. The lower application rates did not reduce nutrient availability sufficiently enough to reduce losses from the conventionallly-tilled plots during the more vulnerable conditions of the third rainstorm (Run3).

Runoff, sediment, $NH_4 - N$ and $PO_4 - P$ loadings from the 75 kg-N/ha treated plots for each five minute interval during the dry and wet runs are presented in Figure 1. This figure illustrates the impacts of tillage practices and application methods on sediment and nutrient loadings to surface water. Application of sludge to no-till plots significantly reduced runoff and sediment losses during the first 45 minutes of rainfall. Consequently nutrient loadings from all no-till plots were low during the initial part of the run. As the rainstorm progressed, $NH_4 - N$ loadings increased. Maximum loadings at the end of the run were 0.01, 0.02 and 0.11 kg/ha for the 0, 75 and 150 kg-N/ha application rates, respectively. During the third run, runoff, sediment, and nutrient loadings increased rapidly and then stabilized halfway through the run.

Similar patterns were found for the conventionally-tilled plots, although runoff, sediment, and nutrient loadings were generally higher than those from the no-till treatments. Runoff, sediment and nutrient losses from the 75 kg-N/ha treated plots (Figure 1) started before those from the 150 kg-N/ha treated plots, and stabilized towards the end of the first rain storm, whereas losses from the 150 kg-N/ha treatment did not seem to reach steady state levels before the end of the storm (data not shown). Peak loadings for both application rates reached values of 0.55 kg/ha for $NH_4 - N$ and 0.02 kg/ha for $PO_4 - P$ when sludge was surface applied, whereas the peak loadings from the plots where sludge was incorporated averaged 0.12 kg/ha for $NH_4 - N$ and 0.01 kg/ha for $PO_4 - P$. Nutrient peak loadings from the no-till sites were similar to those from the conventionally-tilled, incorporated plots. Sediment loadings however, reached values of 175 kg/ha in the runoff from the conventionally tilled plots, whereas for the no-till plots the sediment loadings did not exceed 13 kg/ha.

## CONCLUSIONS

This study analyzes the effects of freshly-applied sewage sludge on runoff and water quality from agricultural land. Runoff, sediment and nutrient losses from sixteen field plots were monitored during a three run sequence of simulated rainfall. Rainfall was applied at a rate of 45 mm/hr over a two day period beginning 24 hours after the sludge application. Application of sludge reduced runoff and sediment losses from no-till and conventionally-tilled plots during the first 40 minutes of the storm (45 mm/hr), without significantly increasing nutrient losses. Peak nutrient losses appeared during the very wet conditions of the third rainstorm. Incorporation of sludge was found to be most effective in reducing nutrient losses from the conventionally-tilled plots during the final run. Surface application of sludge reduced the amount of runoff and sediment compared to incorporation, although the effect was less pronounced under the very wet conditions of the final rain storm.

No-till practices were found to be more effective than conventional tillage in reducing runoff and nutrient losses from sludge applied plots. Application of sludge at a rate of 75 kg-N/ha to no-till plots reduced runoff, sediment and sediment-bound nutrient losses, compared to plots on which no sludge was applied, but sludge application increased losses of $NH_4$.

A sludge application of 75 kg-N/ha on no-till plots appears to be the best alternative for sludge utilization from surface water quality standpoint, although this study did not take losses of coliform and heavy metals into consideration. The observed higher infiltration rates for the no-till plots, relative to those for the conventionally-tilled plots, increase the potential for leaching of nutrients to groundwater. The long-term effect of sludge application on steady state infiltrability and its effect on runoff and losses of nutrients, coliforms and trace elements to surface water and groundwater should be investigated.

## ACKNOWLEDGMENTS

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Table 1. Soil and sludge characteristics and plot treatments.

| Soil Characteristics | | Sludge Characteristics | |
|---|---|---|---|
| Type: Groseclose Silt Loam | | Type: Anaerobically Digested Sewage Sludge | |
| Percent* Sand: | 17.9 | Percent Solids: | 16.0 |
| Percent Silt: | 58.9 | Percent $NH_4$-N: | 0.96 |
| Percent Clay: | 23.2 | Percent TKN: | 3.02 |
| Percent Organic Matter: | 3.7 | Percent Phosphorus: | 2.0 |
| Bulk Density: | 1.39 g/cm | pH: | 7.3 |
| Initial Moisture Content: | 19.2 % | | |

Plot Treatments

| Tillage Method | Sludge Application Method | Sludge Application Rate |
|---|---|---|
| | | kg-N/ha |
| No-till | NA† | 0 |
| No-till | Surface | 75 |
| No-till | Surface | 150 |
| Conventional | NA | 0 |
| Conventional | Surface | 75 |
| Conventional | Incorporated | 75 |
| Conventional | Surface | 150 |
| Conventional | Incorporated | 150 |

* All percentages are on a dry weight basis.
† NA = Not applicable

Table 2. Runoff, sediment and nutrient losses for dry and wet runs, and totals for all three runs for two different tillage systems and two application methods*.

| Tillage System | Application Method | Runoff (mm) | TSS (kg/ha) | $NH_4$ (kg/ha) | $PO_4$ (kg/ha) | $N_{sb}$ (kg/ha) | $P_{sb}$ (kg/ha) |
|---|---|---|---|---|---|---|---|
| | | | Run1 | | | | |
| No-till | Surface | 1.5b† | 20b | 0.26d‡ | 0.01 | 0.09 | 0.02d |
| Conventional | Surface | 4.8a | 164ab | 1.41cd | 0.05 | 1.21 | 0.19e |
| Conventional | Incorporated | 8.9a | 544a | 0.85e | 0.02 | 0.53 | 0.15e |
| | | | Run3 | | | | |
| No-till | Surface | 6.9b | 45b | 0.62b | 0.06 | 0.87 | 0.16d |
| Conventional | Surface | 15.6a | 498a | 2.79a | 0.08 | 1.30 | 0.66e |
| Conventional | Incorporated | 16.3a | 756a | 0.65b | 0.04 | 1.51 | 0.44de |
| | | | Total | | | | |
| No-till | Surface | 10.8b | 82b | 1.11b | 0.09 | 1.15 | 0.23b |
| Conventional | Surface | 27.9ab | 841ab | 6.16a | 0.19 | 4.00 | 0.99a |
| Conventional | Incorporated | 34.8a | 1750a | 2.03b | 0.08 | 2.58 | 0.77ab |

* Data are averages of four plots: two replicates of two application rates (75, 150 kg-N/ha).
† Means within the same column and run with different letters (a,b,c) are significantly different at the 0.05 probability level according to Tukey's studentized range test.
‡ Means within the same column and run with different letters (d,e) are significantly different at the 0.10 probability level according to Tukey's studentized range test.

Table 3. Runoff, sediment and nutrient losses for dry and wet runs, and totals for all three runs from no-till and conventionally-tilled plots with sludge applied to the surface*.

| Tillage System | Application Rate | Runoff (mm) | TSS (kg/ha) | $NH_4$ (kg/ha) | $PO_4$ (kg/ha) | $N_{sb}$ (kg/ha) | $P_{sb}$ (kg/ha) |
|---|---|---|---|---|---|---|---|
| | | | Run1 | | | | |
| No-till | 0 | 6.8 | 501 | 0.06 | 0.01 | 0.13 | 0.04 |
| No-till | 75 | 1.2 | 13 | 0.08 | 0.00 | 0.04 | 0.00 |
| No-till | 150 | 1.8 | 28 | 0.44 | 0.02 | 0.15 | 0.04 |
| Conventional | 0 | 8.9 | 1279 | 0.16 | 0.01 | 3.01 | 0.51 |
| Conventional | 75 | 5.2 | 223 | 1.05 | 0.04 | 0.32 | 0.15 |
| Conventional | 150 | 4.3 | 105 | 1.50 | 0.07 | 2.09 | 0.23 |
| | | | Run3 | | | | |
| No-till | 0 | 11.7abc† | 578 | 0.06d‡ | 0.03 | 0.39 | 0.22de |
| No-till | 75 | 4.9a | 43 | 0.55de | 0.03 | 0.48 | 0.03d |
| No-till | 150 | 8.8ab | 47 | 0.70de | 0.09 | 1.25 | 0.29de |
| Conventional | 0 | 19.5c | 2460 | 0.27de | 0.03 | 0.86 | 0.37de |
| Conventional | 75 | 18.5bc | 656 | 2.64de | 0.10 | 1.26 | 0.87e |
| Conventional | 150 | 12.5abc | 341 | 2.93e | 0.07 | 1.34 | 0.43de |
| | | | Total | | | | |
| No-till | 0 | 24.1ab | 1414 | 0.16a | 0.05 | 0.78 | 0.42 |
| No-till | 75 | 7.3a | 63 | 0.69ab | 0.03 | 0.56 | 0.04 |
| No-till | 150 | 14.2a | 102 | 1.53ab | 0.15 | 1.74 | 0.42 |
| Conventional | 0 | 40.3b | 4916 | 0.60ab | 0.07 | 6.71 | 1.37 |
| Conventional | 75 | 33.3b | 1129 | 5.52ab | 0.18 | 2.16 | 1.18 |
| Conventional | 150 | 22.5ab | 555 | 6.79b | 0.21 | 5.84 | 0.81 |

* Data are averages of two plots.

† Means within the same column and run with different letters (a,b,c) are significantly different at the 0.05 probability level according to Tukey's studentized range test.

‡ Means within the same column and run with different letters (d,e) are significantly different at the 0.10 probability level according to Tukey's studentized range test.

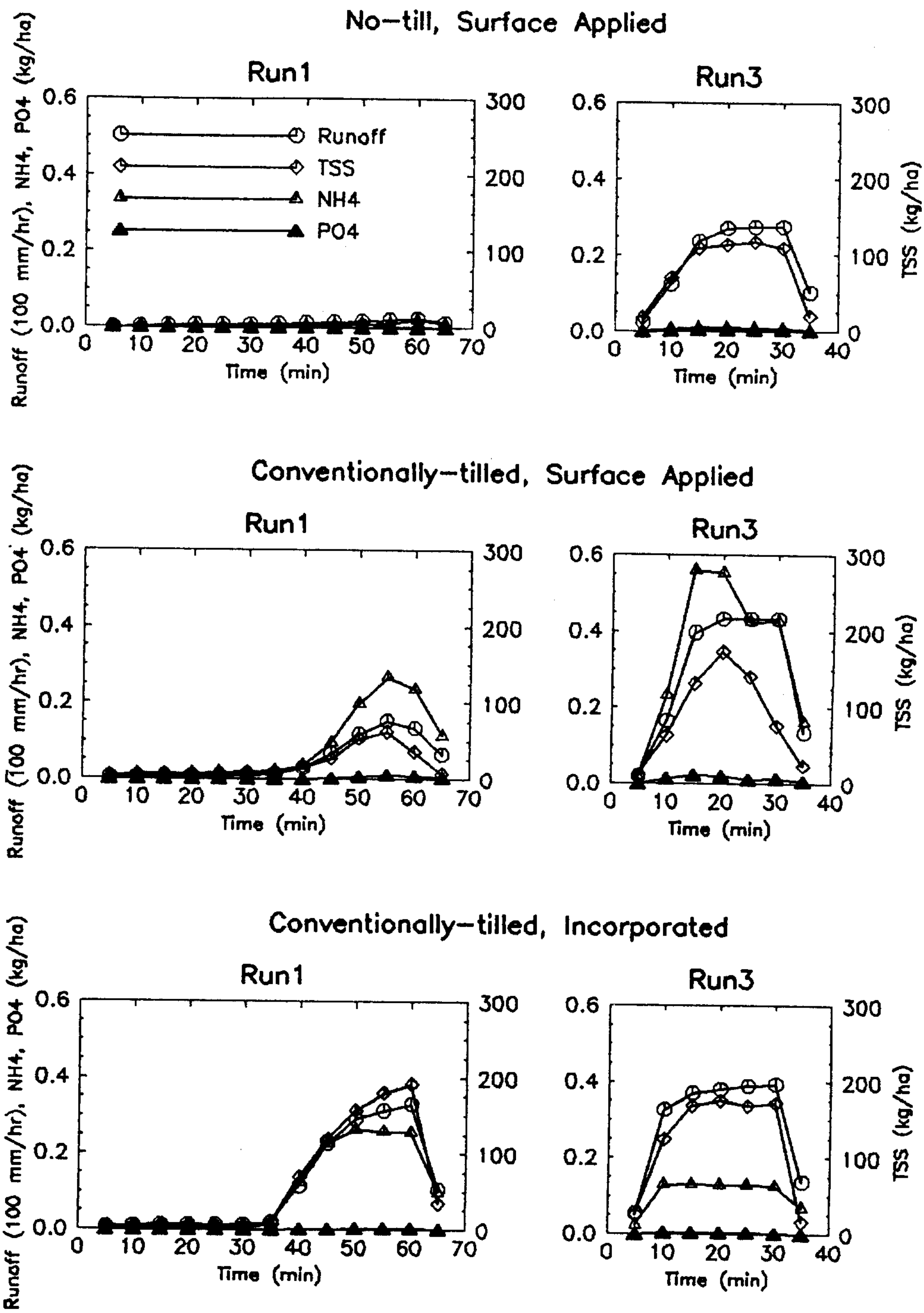


Figure 1. Runoff, total solids (TSS), $NH_4$ – N and $PO_4$ – P loadings per 5 minute interval during the first (dry) and third (wet) run from no-till and conventionally-tilled plots with surface applied and incorporated sludge treatments of 75 kg-N/ha.