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Managing Runoff Following Manure Application

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ABSTRACT: Rainfall patterns, soil factors, topography, climate, and land use may all influence runoff. To minimize environmental concerns, excessive runoff should be avoided on areas where manure has been applied. Management practices used to control runoff include contouring, strip cropping, conservation tillage, terraces, and buffer strips. In some cases, secondary containment systems, sedimentation basins, or ponds may be necessary to collect runoff. More than one runoff-control practice may be necessary for protection in areas with high runoff potential. Soil properties, including infiltration, may be improved by manure application. The method, rate and timing of manure application should be considered to reduce environmental impacts. The transport of nutrients and pathogens by overland flow is influenced by manure characteristics, loading rates, incorporation, and the time between manure addition and the first rainfall. Through proper management, manure can serve as a valuable nutrient source and soil amendment without causing environmental concerns.

Keywords: Animal waste, conservation planning, land application, manure application, manure management, manure runoff, pollution control, runoff, runoff volume

Manure produced in animal production facilities can provide an excellent source of plant nutrients such as nitrogen (N), phosphorus (P), and potassium (K). Nutrients and organic matter contained in manure can improve soil characteristics, including infiltration, porosity, and water-holding capacity. Land application of manure can also significantly reduce runoff. However, environmental concerns may arise if runoff from land application areas contains substantial amounts of nutrients or pathogens. The purpose of this report is to identify the important factors affecting runoff and to describe the control measures that can be used to reduce runoff from areas on which manure is applied. In addition, manure application procedures to minimize potential off-site difficulties are described.

Factors affecting runoff. Runoff may result from both irrigation and natural precipitation events. Because of the increased quantities of water introduced through irrigation, the potential for runoff may be greater in irrigated areas. To better manage runoff after manure application, it is important to understand the factors affecting runoff. Runoff is that portion of rainfall or irrigation that does not infiltrate nor accumulate on the surface but moves downslope. Rainfall characteristics, irrigation type and amounts, soil factors, topography, climate, and land use may all influence runoff (Ward and Elliot 1995).

Rainfall intensity influences both the rate and volume of runoff. Infiltration decreases with time during the initial stages of a storm. Infiltration capacity is exceeded by a greater margin during a-high intensity storm than a less-intense rainfall event. As a result, the high-intensity storm may produce a greater volume of runoff, even though total precipitation was similar for the two events (Schwab et al. 1993). Infiltration rate may also be reduced by raindrop-induced sealing or crusting of the soil surface.

The physical, chemical, and mineralogical properties of soils vary greatly, as do their infiltration characteristics. Infiltration is influenced by soil organic matter content, structure, and permeability. Maintaining crop residues on the soil surface to reduce sealing caused by raindrop impact can help maintain existing infiltration rates (Gilley et al. 1986).

The degree and length of slope and the watershed size and shape influence runoff rates (Haan et al. 1994). On longer slopes or in larger watersheds, the diversion of runoff from non-manured areas can reduce the amount of contaminated runoff. Runoff from melted snow and ice may be a concern in colder climates. In many colder regions, more runoff may result from snowmelt than from rainfall events (Ginting et al. 1998). If snow cover melts rapidly and infiltration does not occur, substantial runoff may result. The rapid melting that may occur when rain falls upon a snow-covered surface can also produce significant runoff.

Areas on which there is a complete ground cover throughout the year are least susceptible to runoff. On croplands, surface cover is influenced by cropping and management conditions. One of the most critical runoff periods exists after planting when residue cover is usually a minimum.

The effects of selected land uses on runoff are demonstrated in a study conducted by Carreker et al. (1978) in the southeastern United States on sites with similar slopes and soil characteristics (Table 1). The results show that runoff can be substantial on cultivated land left fallow with no vegetative cover. Considerable runoff may also occur on steep slopes planted to corn (*Zea Mays* L.) or cotton (*Gossypium hirsutum* L.). Planting row crops in rotation with grasses and legumes that maintain a dense surface cover can significantly reduce runoff.

On areas that receive sufficient precipitation, interseeding of row crops can reduce runoff. Legumes are often selected because they scavenge residual N in the soil and also provide a supplemental N source during the next cropping season (Kuo et al. 1997). However, if manure has been applied to a site, the selection of a legume to serve as a source of N may not be important. The interseeded crop can help to maintain a high infiltration rate during the critical planting period. A herbicide can be used to kill the interseeded crop before the row crop is planted.

The dense sod found in pastures grown in humid areas is very effective in reducing runoff (Troeh et al. 1999). Runoff is minimal on natural rangelands where adequate surface

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cover is maintained. In regions with limited rainfall where bunch grasses are found, infiltration rates may be significantly reduced in exposed areas. Substantial runoff may also occur when vegetative cover is removed through excessive grazing.

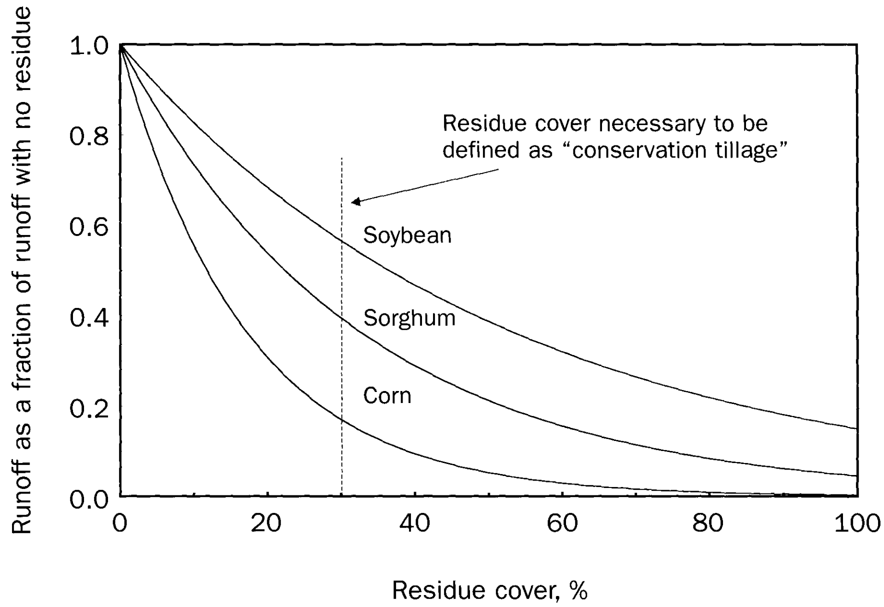
Benefits of manure application. Chemical, physical, and biological properties of soils may be impacted by land application primarily because manure contains nutrients and organic matter (Eghball and Power 1994). The addition of beef-cattle manure has been found to substantially increase the organic matter content of soils (Vitosh et al. 1973, Tiarks et al. 1974). Manure application can also affect important physical properties, such as aggregation and bulk density (Mielke and Mazurak 1976, Sommerfeldt and Chang 1985). The ability of manure to enhance the formation of aggregates has an important effect on soil structure. Soil aggregation improves infiltration, porosity, and water-holding capacity. Thus, manure-induced changes in soil properties can have significant impacts on runoff.

Manure characteristics, loading rates, incorporation, and the time between application and the first rainfall influence runoff rates (Westerman et al. 1983, Edwards et al. 1994). Runoff quantities have been reduced by the addition of cattle, poultry, or swine manure (Giddens and Barnett 1980, Mueller et al. 1984). The organic matter contained in manure serves to promote the formation of water-stable aggregates. A high percentage of water-stable aggregates increases infiltration, porosity, and water-holding capacity. The amount of time required for organic matter in manure to become incorporated and impact soil properties influences infiltration and runoff rates (Chandra and De 1982). At present, the time period necessary for beneficial soil properties to develop after manure application is not well-defined.

Field plots have been established to measure the effects of manure application on annual runoff. Long et al. (1975) found significantly less runoff over three years from natural runoff plots that were treated with dairy manure than from plots that received no manure. Less runoff was measured on cotton fields on which poultry litter was applied than on fields that received commercial fertilizer (Vories et al. 1999). Gilley and Risse (2000) found that at selected cropland locations where manure was added annually, total runoff was reduced from 2% to 62%.

Figure 1

Ratio of runoff for a given residue cover to runoff with no cover.



Runoff control measures. Contouring, strip cropping, conservation tillage, terraces, and buffer strips can be used to reduce runoff from areas where manure has been applied. Because runoff is impounded in small depressions on contoured areas, planting crops and performing tillage along land contours can effectively reduce runoff. The storage capacity of furrows is significantly increased in ridge tillage systems. Row crops are planted on the top of the same furrows each year to maintain storage capacity. The effectiveness of ridges in trapping runoff is reduced as slope gradient increases.

Strip cropping occurs when alternate parcels of different crops are grown in the same field. Strip widths are selected to allow the convenient use of farm equipment. The strips are usually planted on the contour in a rotation that shifts crops annually from one strip to the next. The strips with the greatest surface vegetative cover usually have the largest infiltration rates.

The practice of producing different crops simultaneously in narrow alternating strips that are located throughout the length of the field is described as strip intercropping. The strips are sufficiently wide that each can be managed independently, yet are narrow enough that the crops, which are rotated annually, can influence the yield potential of adjacent crops (Exner et al. 1999). Substantial surface cover and residue mass can be maintained within a strip intercropping system as a result of crop rotation and residue-management practices (Gilley et al. 1997).

Runoff rates may be substantially reduced if residue mulch from the previous crop is maintained on the soil surface. The type and amount of residue cover influence infiltration and runoff rates. Even small amounts of residue can cause significant reductions in runoff. It can be seen from Figure 1 that a 30% surface cover of soybean (*Glycine max* (L.) Merr.) or corn residue can reduce runoff by about 42% and 82%, respectively.

Conservation tillage is defined as any tillage or planting system that leaves at least 30% of the soil surface covered with residue after planting (Figure 1). When tillage is performed, implements are used that cause only minimal disturbance to the soil surface, thus preserving existing crop residue. For some row crops, such as soybeans, no tillage is used before planting to help maintain surface residue cover. Reduced and no-till systems may increase infiltration on some soils leading to less runoff. However, nutrient concentrations in the runoff may be higher if the manure is not incorporated.

Terraces are broad, shallow channels that are built perpendicular to the slope of steep land. The gentle grades used in terraces allow runoff to be carried around a hill at relatively low velocities, providing increased opportunity for infiltration. Terraces usually empty onto grassed waterways or into underground pipes. Crops are usually planted parallel to the terrace channels, requiring the use of contour farming. Conservation tillage is frequently used in conjunction with terracing. Farming operations are more difficult on terraced hillslopes, and a significant investment is required to construct terraces. As a result, terraces are usually used only when other control measures cannot provide adequate runoff protection.

Buffer strips contain permanent vegetation that serves to intercept runoff. A variety of positions along a landscape can be used as buffer strips. The type of vegetation used in buffer strips is influenced by local conditions. To sustain buffer-strip performance, periodic maintenance may be required. Some of the more frequently used buffer strips include contour buffer strips, filter strips and grassed waterways.

Contour buffer strips containing perennial grasses are planted along steep slopes. The grass strips serve to remove sediment from overland flow. The species of perennial grasses that are used and the spacing of the grass strips are based on local conditions. A narrow terrace may eventually form along the grass strip as a result of sedimentation. The expenses required to establish contour buffer strips are substantially less than the costs incurred in constructing terraces.

Contour buffer strips are usually several meters wide. Narrow grass hedges, less than a meter in width, can substantially reduce runoff (Gilley et al. 2000). Narrow grass hedges have been found to significantly reduce both the concentrations and total amounts of N and P in runoff from areas on which manure was applied (Eghball et al. 2000).

Filter strips can also be used to reduce runoff volume. They do not interfere with normal farming operations, because they are usually located on the edge of fields or adjacent to streams, ponds, or waterways. Filter strips are best-suited for areas with gentle slopes.

Grassed waterways serve to convey runoff from terraces or other concentrated flow areas. A stable outlet below the grassed waterway is provided to reduce runoff velocity and disperse the flow before it enters a filter strip. To maintain their effectiveness, grass waterways should not be used as roads.

Secondary containment systems and diversions may be necessary at some locations. These types of systems contain berms or ditches positioned around land-application areas to prevent runoff from contacting manure or wetlands. It is often possible to use natural or modified surface drainage systems to limit the off-site transport of nutrients and pathogens. Sedimentation basins and farm ponds that trap the contaminated runoff serve as effective management practices. Ultimately, the goal of these systems is not to treat runoff, but to provide a secondary system that prevents runoff from directly entering surface water. The need for these types of systems is dependent upon the receiving water body, because these secondary systems are not always justified economically.

A variety of runoff-control measures could be used on a particular landscape. More than one runoff-control practice may be necessary for protection on areas with high runoff potential. The appropriate control measures will be dictated by site-specific conditions. If any of the runoff-control practices are not properly implemented or maintained, effective runoff control may not be possible.

Manure application considerations. Manure should be applied at a rate required to meet crop nutrient requirements. Thus, the nutrient needs of the crop, the nutrient pool in the soil, and the nutrient content of manure should all be considered. The ratios of N, P, K, and various nutrients in manure are usually different from those required for crop growth. Nutrient imbalances may result on soils that receive manure. Depending upon which nutrient is perceived to have the greatest impact on receiving waters, nutrient-management plans are usually based on the N or P content of the manure. P-based nutrient-management plans will also control N because of the lower manure application rates required.

Most feed grains store P as phytate (phytic acid). Monogastric animals such as poultry and swine are not able to use this form of P. As a result, the low P bioavailability in grain is offset by supplementing feeds with inorganic P. This supplementation results in added cost, results in poor P use efficiency, and produces manure containing increased amounts of P. Phytase is a commercially available enzyme that breaks down the phytate molecule, making the P available. Phytase may be added as a feed supplement to improve P-use efficiency in poultry and swine.

The use of low-phytate corn is another approach for improving the bioavailability of feed-grain P. Low-phytate corn stores a majority of its P as inorganic P rather than phytate (Ertl et al. 1998). Eliminating the need for supplements (phytase or P) and increasing naturally available P results in reduced feed costs.

To fulfill crop nutrient requirements, nutrient mineralization must be considered when manure application rates are estimated. Temperature, soil moisture, soil properties, and manure characteristics all influence mineralization. Both the inorganic N contained in manure and the organic N mineralized after application contribute to N availability. Nutrient mineralization estimates for selected types of manure are provided by Eghball et al. (2002).

To reduce nutrient runoff potential, proper application of manure is important. The timing and method of manure application are influenced by climate, cropping and management system, source and form of manure, and equipment and labor availability (Gilbertson et al. 1979). Manure is often injected or incorporated into the soil to minimize odors, improve nutrient availability, and reduce nutrient losses. Concentrations of dissolved P, bioavailable P, and ammonium-N in runoff were found to be greater from plots on which manure or compost from beef-cattle feedlots were applied and not disked (Eghball and Gilley 1999). However, total and particulate P concentrations of runoff were greater on sites where manure and compost were incorporated. Soil-erosion potential may increase substantially as a result of tillage. Thus, the suitability of tillage after manure application must be evaluated for individual sites.

To reduce the loss of nutrients and minimize environmental concerns, the period just before planting is the ideal time to apply manure to croplands. For forage systems, manure should be added immediately after each harvest or grazing cycle. A substantial nutrient runoff potential exists if manure is applied to frozen soils or to sites covered with snow. When the probability for significant rainfall is high, manure should not be applied. Management flexibility is improved when multiple crop types allow more-frequent manure application periods.

Strip-cropping or strip-intercropping systems may provide additional manure management alternatives. The crops used in either of these systems may have much different planting and harvest dates. As an example, winter wheat (*Triticum aestivum* L. cv. Pastiche) may be planted in alternating strips with either corn or grain sorghum (*Sorghum bicolor* L.). The ideal time to apply manure to the strips to be planted to a row crop would be in the spring before planting. However, if manure storage capacity were a concern, land application could also occur on the winter wheat strips after summer harvest. Additional manure application could take place on the corn or grain sorghum strips in the fall after harvest, just before the time winter wheat is planted. Thus, different manure application periods may be possible on strip-cropping or -intercropping areas.

The form of manure dictates the method of application. Manure application systems should be calibrated regularly to insure that the desired amount of material is spread uniformly. When determining proper manure application amounts, the water content of manure should be considered.

Summary and Conclusions

Rainfall characteristics, soil factors, topography, climate, and land use may all affect runoff. The degree and length of slope, and watershed size and shape influence runoff rates from land-application sites. Areas where a substantial ground cover is present throughout the year are least susceptible to runoff.

Chemical, physical, and biological properties of soils may be improved by the addition of manure primarily because it contains nutrients and organic matter. Manure characteristics, loading rates, incorporation, and the time between application and the first rainfall influence runoff rates. Runoff rates from selected cropland areas may be reduced significantly as a result of manure addition.

Contouring, strip cropping, conservation tillage, terraces, and buffer strips serve to reduce runoff from areas on which manure has been applied. At some locations, secondary containment systems, sedimentation basins, or ponds may be necessary to intercept runoff. For effective protection on areas with high runoff potential, more than one runoff-control practice may be necessary.

The period just before planting is the ideal time to apply manure to croplands. For forage systems, manure should be added immediately after selected harvest or grazing cycles. Manure application systems should be calibrated regularly to ensure that the desired amount of material is spread uniformly. The suitability of tillage after manure application must be evaluated for individual sites. By using proper management procedures, manure can be used as an effective nutrient source and soil amendment without causing environmental problems.

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