Understanding the Soil-Landscape: Implications for Managing Manure

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Introduction

Application of livestock manure to land has been conducted for centuries to increase agricultural productivity by providing nutrients and organic materials that improve overall soil tilth and fertility. Manure is a valuable source of crop nutrients and organic matter provided that it is used as a nutrient amendment based on sound agronomic principles. Soil and water quality deterioration following manure addition may occur when agronomic principles are not adhered to or when manure is simply disposed of as a waste on agricultural land. It is important for the land manager to understand the pros and cons of manure application to land as well as understand the limitations of the land base to which the manure is applied.

One of the factors that influences the fate of manure applied to land is the variability of the soil-landscape. Unfortunately, the variability of soils within a given landscape is generally not well appreciated and manure (or fertilizers) is applied uniformly across a given field with little consideration given to the variability in soil and hydrologic processes within the field.
This paper presents the concept of the "soil-landscape" and describes how an understanding of this concept is important for managing manure on agricultural land.

What is the "soil-landscape"?

The term "soil-landscape" refers to the combination of soil and landscape properties within a given geographic location. Soil properties include soil profile development, chemical, physical and biological properties. Landscape properties include topography (slope gradient, slope length, slope curvature, regularity of knolls and depressions), surface water features, wildlife habitat, etc. The "soil-landscape" is more than soil and it is more than landscape, it is the complex interaction of the two. The old saying "The whole is more than the sum of its parts" is very true in this case.

All soils are not created equal

The soil-landscape is a complex phenomenon that reflects the variation in the type and magnitude of environmental processes active within the field. If we were to walk across any agricultural field within Manitoba and were to periodically stop and dig a hole we would reveal multiple layers of soil beneath our feet. This combination of layers is referred to as the "soil profile." The soil profile, at any point in the landscape, consists of layers of soil referred to as "soil horizons" (A, B and C horizons). If we were to dig deep enough (< 30 cm in some cases and > 2 m in others) we would encounter relatively unaltered material consistent with that material left behind following the retreat of the glaciers in the last ice-age. This material is referred to as the "parent material" or C horizon and represents the material from which the A and B horizons above have formed. Thus, parent material is transformed over time into A and B horizons, which collectively are referred to as the "solum." The soil profile is an excellent example of a fundamental principle operating within the natural world: "Processes acting on material over time results in form." In other words, various processes have been actively transforming the parent material over time to develop the soil profile morphology (form) that we can observe. Therefore, if we can learn to interpret the soil profile correctly, we can predict the types of processes that have been and are active in various portions of the field. In short, soil profile morphology is an indicator of environmental processes that have been and are active at that point in the landscape.

Soils within a given field therefore are not uniform, but rather show variability from place-to-place in response to variations in the processes that are forming the soil profiles. Soil variability within the field is a function of changes in the type of material from which the soils have formed (i.e. soil parent material), and a function of the type and magnitude of processes responsible for forming soil. This variability needs to be acknowledged and understood if we are to efficiently manage manure within agricultural fields.

Soil-landscape sensitivity to repeated manure application

The sensitivity of the soil-landscape to repeated manure application is related to (i) the potential for nutrient (nitrate) leaching below the rooting depth of agricultural crops and subsequent migration to groundwater; and, (ii) the potential for overland flow of water and suspended particulate matter resulting in nutrient transport (nitrate and phosphate) to surface water bodies. Soil-landscapes are considered to be sensitive when the likelihood of nutrient leaching and/or runoff is high. These soil-landscapes require more intensive management to ensure that nutrient loss is minimized. Soil and landscape properties that influence the potential for nutrient leaching and runoff are indicated in Table 1.

The soil-landscape properties that control nitrate leaching to groundwater are generally not manageable but should be considered “fixed” within any given portion of the soil-landscape. In other words, it is not feasible to manage properties such as saturated hydraulic conductivity and slope curvature. Therefore, nitrogen management needs to accommodate the variation in these soil-landscape properties.

Nutrient runoff however is more easily controlled by land management practices. Maintenance of good soil surface structure and residue cover are means to limit overland flow of runoff water. Having said this however, landscape properties such as slope gradient and length are “fixed” as mentioned previously and hence management of phosphorus needs to consider the influence of these properties on phosphorus runoff. Setback distances from sensitive water bodies should be established based on the ability of the landscape to transmit water via runoff.

Many environmental processes vary within a given agricultural field. Thus, it is important to understand these variations and attempt to fit agricultural practices into the soil-landscape rather than forcing these practices onto the soil-landscape. When agricultural practices are imposed on the soil-landscape without due care and attention to the variable environmental processes operating within the field, then inefficiency is the result and this is when we begin to see the development of environmental problems. It really comes down to harmonizing the agricultural management scale with the environmental process scale.

Table 1. Soil and landscape properties influencing nutrient transport via leaching and runoff.

	Properties Influencing Nutrient Leaching	Properties Influencing Nutrient Runoff
Soil Properties	Soil texture Infiltration rate Field capacity Saturated hydraulic conductivity	Soil texture Surface soil structure Soil organic matter Soil residue cover
Landscape Properties	Slope curvature (water convergence vs. divergence) Water table dynamics	Slope gradient Slope length

Management scale vs. environmental process scale

Nutrient utilization

Environmental problems may occur when uniform management practices are superimposed on a variable soil-landscape. The reason for this is that environmental processes generally operate at a scale that differs from the scale at which land management practices are applied. For example, uniform application of nutrient (be it manure or chemical based) to a variable soil-landscape results in over-application in some areas and under-application in others. The apparent response to applied nutrient is not necessarily the same from place-to-place within the soil-landscape (Figure 1). Variation in the apparent crop response to nutrient is due to interactions of crop nutrient uptake with soil moisture, salinity, crop disease, etc. This results in inefficient nutrient use such that excess nutrient accumulates in some areas and lost production occurs in others where insufficient nutrient was added.

Establishment of benchmark sampling sites is an effective means of tracking changes in soil nutrient over time while at the same time minimizing the effect of spatial variation in soil nutrient values. Benchmark sampling sites are established based on the assumption that the fate of nutrient within the soil-landscape is governed by variation in local conditions. Thus benchmarks are located strategically in an attempt to account for within-field variation in soil and landscape properties. This strategy provides a means to “tailor” manure nutrient application rates to the particular soil-landscape conditions that vary from place-to-place (from benchmark-to-benchmark) within the field.

Local hydrologic variability

Variation in leaching potential also occurs at a scale that is not consistent with the usual land management scale. Local hydrologic processes and conditions within the soil-landscape govern leaching potential. The potential for downward migration of mobile nutrient such as nitrate can be determined by examining variations in natural mobile tracers common within the soil-landscape. These mobile tracers are chloride and sulfate (a surrogate for chloride and sulfate is electrical conductivity of a soil-water paste extract). These soluble, mobile tracers can be used to observe the redistribution of water within a three-dimensional landscape and thereby provide a record of historical leaching processes. This however is only true where it is reasonable to assume that the surficial geology and the mineralogy of the geologic material are relatively uniform within the area of interest. If this assumption holds, then areas of the soil-landscape depleted in chloride and sulfate (relative to background levels) indicate areas that have historically undergone net downward migration of water over time and loss of tracer (i.e. hydrologic recharge). On the other hand, portions of the soil-landscape that show accumulations of these tracers indicate areas that are not subject to leaching but rather are subject to hydrologic discharge within the soil-landscape (i.e. “negative leaching,” low potential for leaching). The concentration of chloride and/or sulfate as a function of soil depth is referred to as the “solute profile” of a particular portion of the soil-landscape.

Hydrologic processes can be highly variable on a local scale (Figure 2). The data in Figure 2 comes from an agricultural field north of Brandon in the Newdale Till-Plain region of Manitoba. Nine points were sampled along a transect approximately 400 m in length. Sample points were located based on soil-landscape attributes in an attempt to observe solute profiles in various portions of the field. The data show that there is tremendous variation in the distribution of sulfate (and electrical conductivity (EC)) with depth among the nine sample points. In general, there are three main types of solute profiles exhibited within this field. First, some sample sites exhibited high sulfate concentrations from the soil surface to depth (approximately 3 to 4 m sample depth). These sites are not susceptible to leaching but rather have experienced addition of solute to the soil profile. Secondly, there are sites that exhibit very low concentrations of sulfate to depth. These are sites that exhibit properties indicative of historical leaching. Some of the solute profiles indicate that leaching beyond 3 m has occurred since sulfate concentrations are extremely low even at depth. Finally, there are sites that are intermediate between these two extremes. They generally show reduced solute concentrations near the soil surface but exhibit increasing solute concentration to depth and therefore possess intermediate potential for downward migration of mobile nutrient.

Solute profiles are therefore useful to aid in the interpretation of hydrologic processes within the soil-landscape. However, the time required for sampling and the associated analytical costs hinder the use of solute profile data in assessing local leaching potential. Thus, it would be useful to find a relatively inexpensive way of obtaining data that would provide similar information. Fortunately, this information already exists yet few people know about it let alone know how to use it.

Solute profiles in relation to soil profile development

Solute profiles and soil profile development are closely related since they both are a function of local hydrologic processes within a given field. Solute profiles that exhibit low EC from surface to depth and thus indicate high leaching potential correspond with a particular type of soil profile development (i.e. kinds and arrangement of soil horizons with depth). In general, highly leached soils have experienced three fundamental processes related to leaching. These include lixiviation (removal of soluble constituents by percolating water), decarbonation (removal of Ca and Mg carbonates), and pervection (translocation of colloidal clay from soil surface to subsoil). When these three processes act on parent material over time, the resulting form (soil profile morphology) is a complex soil profile showing many different types of horizons indicative of net downward movement of water through the soil profile (Figure 3).

Soil profile development in areas of hydrologic discharge is very different from that development observed in areas with a strong leaching regime. The soil-development processes associated with leaching are not active and hence the soil profile exhibits limited horizon development and appears to be very “simple” (Figure 4). These soils contain elevated levels of sulfate and the EC is correspondingly high indicating that removal of soluble constituents has not occurred and hence leaching potential is minimal to negligible.

In areas of intermediate leaching potential, soil profiles exhibit morphologies indicating active lixiviation, decarbonation to a point and minimal pervection (Figure 5). The solute profile in such cases shows increasing solute concentration with depth indicating that solute removal from the soil surface has occurred but leaching has not been sufficiently intense to remove solute from below the root zone.

Summary

Application of livestock manure to agricultural land must begin to take into account local variation in soil and landscape properties. The spatial variability of the soil-landscape influences nutrient utilization by the crop as well as nutrient leaching and off-site transport via runoff. Identification of areas within the field that are prone to leaching and runoff is the first step in developing a field management plan that will minimize nutrient loss to the environment. Establishing benchmark soil sampling sites provides a means to fine-tune manure application rates by taking into account local variation in crop nutrient use. These strategies will increase the efficiency of nutrient use within the soil-landscape and enable livestock producers to proactively manage land resources in an environmentally sustainable manner.

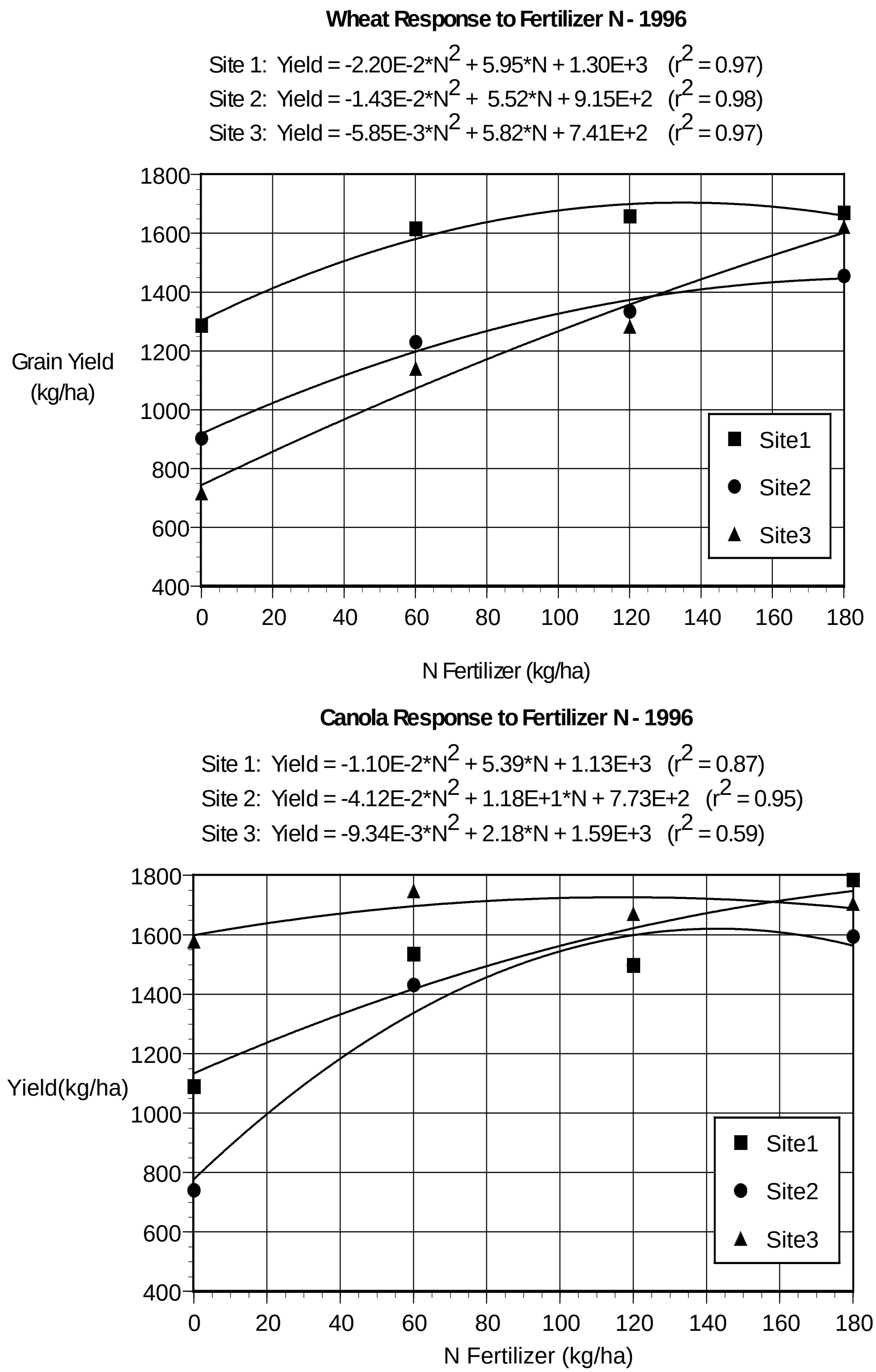

Figure 1. Variation in crop response to added N Fertilizer among three sites separated by approximately 200 m. Data originates from an agricultural field south of St. Leon, MB.

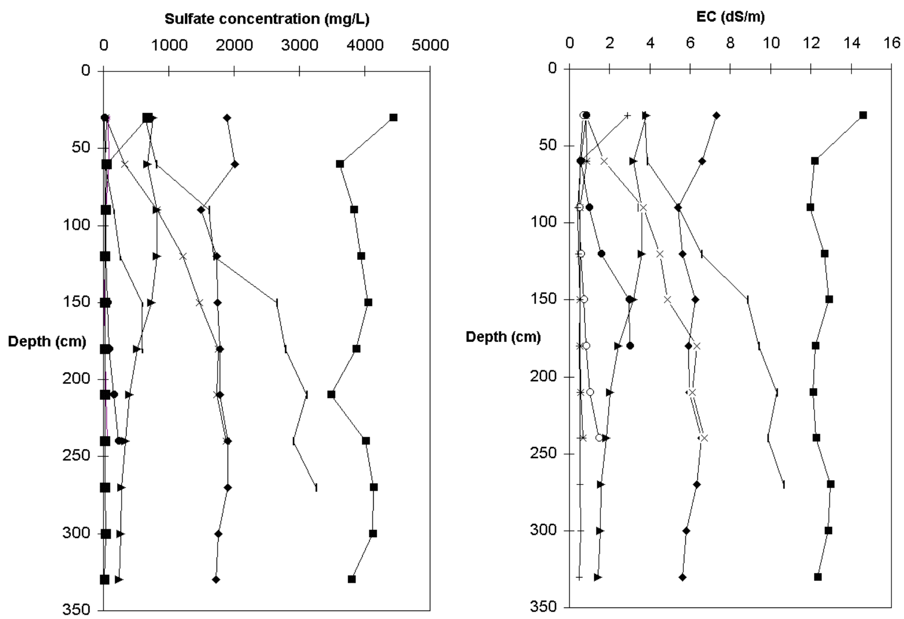

Figure 2. Solute profiles (sulfate) for 9 sample points within an undulating glacial-till landscape north of Brandon, Manitoba.

Solute Profile: Low EC From Surface to Depth

Soil Profile Development:

- Lixiviation (removal of soluble components);
- Decarbonation (removal of carbonate minerals);
- Pervection (translocation of colloidal clay to subsoil).

Soil Profile Characteristics:

- Deep soil profiles (1.2 to 2 m);
- Strongly leached, acidic pH;
- Non-saline.

Figure 3. Soil profile development associated with high leaching potential.

Solute Profile: High EC From Surface To Depth

Soil Profile Development:

- Lixiviation is absent;
- Decarbonation is absent;
- Pervection is absent.

Soil Profile Characteristics:

- Shallow soil profiles (generally < 30 cm);
- Non-leached, basic pH;
- Saline (soluble salts present).

Figure 4. Soil profile development associated with negligible leaching potential.

Solute Profile: Low EC at Surface, High EC at Depth

Soil Profile Development:

- Lixiviation has been active to a point;
- Decarbonation has removed carbonates from shallow depth;
- Pervection is absent or weakly expressed;

Soil Profile Characteristics:

- Intermediate soil profile depth (~30 – 75 cm);
- Weakly leached, neutral to slightly acidic pH;
- Non-saline A and B horizons but subsoil may be saline.

Figure 5. Soil profile development associated with intermediate leaching potential.