IMPACTS OF REPEATED MANURE ADDITIONS ON SOIL QUALITY

Jeff Schoenau, PAg

Department of Soil Science, College of Agriculture, University of Saskatchewan
Email: schoenau@sask.usask.ca

Background

Soil quality has many definitions but perhaps the simplest is the "fitness of the soil for its intended use". The intended use in an agricultural setting is to function as a medium for plant growth and also to act as an environmental filter or buffer. There are many soil properties that can be measured as indicators of soil quality (Greer and Schoenau, 1997). These range from relatively simple and easy to measure properties such as organic matter content, pH, and salinity to more complex properties such as enzyme activity, microbial biomass, aggregation and water infiltration. The simple soil properties that are measured in field research trials and reported on in this paper can also be employed by producers as tools for monitoring the effects of manure application on their own land base. This paper explores the effect of repeated manure applications on soil quality in Western Canada using recently published research findings.

Manure Constituents

The composition of manure will have a profound impact on the quality of the soil when land-applied, as different manures have different organic matter, salt, and element contents. The composition, in combination with the rate of application, can usually be directly related to the effects on a particular soil property. For example, solid manure such as cattle manure is composed of both fecal matter and bedding material such as straw or wood chips, and therefore has a high organic matter content i.e. 50%, compared to liquid hog manure where the organic matter content may be as low as 1 or 2 % by weight. It is not surprising then, that applications of solid cattle manure tend to be more effective in directly increasing the organic matter content of the soil than liquid hog manure. However, although liquid hog manure contains and adds only a small amount of organic matter, the stimulation of plant biomass production via uptake of nutrients added in the manure will increase the recent carbon additions to the soil system (King, 2002).

Salts are among the chemical constituents of manure and include sodium, calcium, magnesium, potassium, ammonium, chloride, and sulfate salts, along with other cations and anions. The level of salts in manure varies depending on factors such as the type of feed the animals are fed as well as dietary salt supplements. For example, Sutton et al. (1994) reported that dietary salt (NaCl) levels in hog rations directly affect the sodium concentrations in manure, and increases in salt levels in soils that received repeated applications of manure have been reported in several studies (Chang et al., 1991; Assefa et al., 2004).

Manure also exhibits variation in its pH value. The pH values of hog manure from various types of hog operations in south-eastern Manitoba was reported to range from 6.8 to 8.1 (Malley et al., 1999) and from 7.6 to 8.1 for hog manure in east-central Saskatchewan. In a study by Assefa (2002) in the Peace River region of Alberta, the pH of the cattle manure was reported to be around 9 while an average pH value of 7.2 was reported for cattle feedlot manure in southern Alberta (Chang et al., 1991). The ability of manure application to induce a change in soil pH will depend on its content of buffering agents such as carbonates and organic matter, as well as the production of organic acids and acidity during decomposition.

Other constituents in manure that can influence soil quality include nutrient ions, of which imbalances following application could lead to deficiencies or toxicities. Manures may also contain trace amounts of elements that are non-functional in plant metabolism, but which become of interest due to potentially enhanced accumulation in plants grown on the soils.

Impacts on Soil Properties

Chemical Properties

Organic Matter: Soil organic matter content is a key attribute in assessing the quality of prairie soils. Declines in organic matter content of prairie soils due to cultivation and erosion have been a major concern related to sustainability of agriculture. Therefore, management practices that increase the organic matter content are deemed desirable to soil quality and productivity. Many researchers have observed increases in soil organic matter following repeated applications of solid cattle manure (e.g. Campbell et al., 1986; Sommerfeldt et al., 1988; Larney et al., 2000). King (2002) found in Saskatchewan that three years of hog manure application to forage stands increased the recent, light fraction organic matter levels in the soil (0-15cm depth), but not the total soil organic carbon. In another study in east-central Saskatchewan, Assefa et al. (2004) also did not find significant increases in the total organic carbon content of Black Chernozemic soils (0-30cm depth) that received four annual applications of either liquid hog or solid cattle manure. The lack of a significant effect in this case was attributed to the large sampling depth and the inherently high level of indigenous organic matter in the Black soils. It would be anticipated that effects of manure addition on increasing soil organic matter content would be more pronounced on soils of lower organic matter content and low fertility, and it may take several years of application before significant differences can be detected. Manures provide available carbon for soil microorganisms and thus stimulate microbial respiration or activity (Loro et al., 1997). In eastern Canada, Ndayegamiye and Cote (1989) reported increased microbial activity and populations following applications of hog and cattle manure. In Saskatchewan soils, Charles (1999) reported enhanced microbial respiration following addition of manure and found that liquid hog manure organic matter was more quickly degraded by the microbial population than solid feedlot cattle manure and that cattle manure sustained the increase in microbial activity over a longer period of time. Overall, the enhancement of both stable and labile organic matter content and increases in microbial activity associated with manure application to soils are considered to be positive impacts on soil quality.

Salinity and Sodicity: The effect of repeated application of manure on soil salinity and sodicity is of interest. Salinity is assessed by measuring electrical conductivity (EC) and sodicity is determined by measuring sodium adsorption ratio (SAR). Animal manures can contain appreciable amounts of salts and excessive application of solid or liquid manures can result in salt accumulations that can damage crops and soil structure. Soils with poor drainage are most susceptible to salt build-up as the salts are not leached from the root zone. Damage to salt-sensitive crops can be expected when soil electrical conductivity reaches 2 dS/m (McCalla, 1974). Chang et al. (1990) observed a linear increase in electrical conductivity over time with increasing rates of cattle manure application in a southern Alberta soil and anticipated eventual salinization of the soil. They also observed a slow but linear increase in sodium adsorption ratio and suggested that this was indication of the potential for the soil to become sodic. In a study that was conducted in the Peace River region of Alberta, a single manure application to Gray Luvisolic soils at rates at high as 176 kL/ha of hog manure or 90 Mg/ha of cattle manure did not produce any significant changes in soil salinity (Assefa, 2002). In the same study in east-central Saskatchewan, four annual applications of cattle manure at a rate of 15 Mg / ha / yr increased the soil salinity slightly, increasing the E.C. from 0.3 dS/m to 1.6 dS/m at one site (Assefa et al., 2004). The sodicity (SAR) also increased slightly: from 0.7 to 1.7 at one site and from 0.3 to 0.8 at another site. Similarly, four annual applications of hog manure at the rate of 75 kL/ha raised the SAR from 0.4 to 1.3. While increases in soil salinity and sodicity associated with repeated manure application do not appear to be of concern when agronomically appropriate rates are used over relatively short time frames, these properties should be monitored over time in manured fields, especially under dry conditions and in soils with limited downward leaching potential. Attempts to reduce the salt content of manure, particularly sodium content, would be desirable from the standpoint of reducing salinity and sodicity concerns.

Soil Reaction: Soil pH is an easily measured soil property that is closely related to soil quality and productivity. Very low pH values, indicative of acidity, are associated with adverse soil conditions including reduced microbial activity, increased availability and toxicity of elements such as aluminum and heavy metals, and reduced availability of plant nutrients such as phosphorus. On the other hand, high pH values, indicative of alkalinity, can also pose problems by reducing the availability of many micronutrient metals and other plant nutrients. The effect of manure on soil pH is variable. Repeated applications of fertilizer N may lead to soil acidification (Ukrainetz et al., 1996) due to acidity produced in the nitrification process (microbial oxidation of ammonium to nitrate). While organic matter added as manure can act to help buffer the soil against a decrease in pH, manure that is low in organic matter and high in ammonium nitrogen may result in a decrease in pH due to acidity produced when the ammonium is oxidized to nitrate in the soil. Chang et al. (1990) observed a decrease in soil pH with time and suggested that some soils might eventually become acidic with continued application of manure. Whalen et al. (2000) in an eight week study conducted in the laboratory, reported an immediate increase in the pH of two acid soils from northern Alberta following fresh cattle manure application and concluded that the effects of manure on soil pH would depend on the manure source and soil characteristics. Manures of high organic matter and carbonate content would be most effective in raising the pH of an acid soil and also buffering against changes in pH once in the soil.

Metals: The impact of manure application on metal content in the soil is a soil quality issue that is of both agronomic and environmental interest. Manures contain plant functional nutrient metals such as copper, zinc, manganese, iron, and may contain trace amounts of non-functional elements. The effect of manure addition on bioavailability of metals in the soil may be direct and/or indirect. Direct effects would include increases in the amount of an element in soil due to that element being present in the manure added. An example of this is copper and zinc. The natural presence of these micronutrients in feed as well as their use as dietary supplements results in variable concentrations in manure and when added to the soil, can increase the total and bioavailable concentrations. A recent study in Saskatchewan (Qian et al., 2003) showed that three to five years of annual swine and cattle manure applications at low (~100 kg N/ha) and high (~400 kg N / ha) rates resulted in only small increases in total and bioavailable copper and zinc in surface soils at three study sites, but eleven annual applications of feedlot cattle manure in Alberta resulted in significant increases in soil zinc (Chang et al., 1991). As with phosphorus, prairie soils have a high capacity to fix metals like copper and zinc into relatively insoluble forms due to high pH, high content of calcium carbonate and high clay content. However, as fixation sites become saturated with repeated additions, more of the metal will remain in a soluble form. Manure, like commercial fertilizer, can indirectly influence the bioavailability of a metal already present in soil in trace amounts by influencing soil pH, salinity, ion concentrations, microbial activity, root growth and mineral weathering. For example, it has been reported that as soil salinity increases, plant availability of cadmium also increases (McLaughlin et al., 1994), especially if a high level of chloride ions are present (Weggler-Beaton et al. 2000). Interactions can be complex and there is little published research on effects of manure addition on bioavailability of non-functional metals. Recent work in Saskatchewan showed that following five to seven annual additions of swine or cattle manure, there was no significant influence of manure additions on soil or plant cadmium, arsenic or mercury concentrations compared to commercial inorganic fertilizer (Lipoth and Schoenau, 2004).

Physical Properties

Changes in physical characteristics of the soil such as density, structure and water infiltration are valuable indicators of the effect of a management practice like manure addition on soil quality and productivity. For example, density and structure of the soil affect aeration, gaseous exchange, and root development in the soil. Campbell et al. (1986) reported that soils that received repeated applications of cattle manure were more friable to the feel and less compacted under foot than those of the unmanured plots. Barnyard manure has long been known to improve soil structure, increase porosity and water holding capacity and decrease evaporation rates (Unger and Stewart, 1974; Meek et al., 1982). Mathers et al. (1977) reported that cattle feedlot manure applications to soils increased water infiltration into the soil while Nuttall (1970) reported that additions of manure decreased crust strength and increased the emergence of rapeseed. To a large extent, these benefits are related to the effect of the manure on increasing the organic matter content of the soil and thereby improving its overall tilth.

In a recent study using two field sites in the Peace River region of Alberta (Gray Luvisols) and two field sites in east-central Saskatchewan (Black Chernozems), Assefa (2002) found that a single application of hog manure on the Gray Luvisolic soils increased the aggregate size and aggregate stability of the soil at one site. A single application of cattle manure decreased the crust strength and also increased the aggregate size. Cattle and hog manure applications both increased the water infiltration rates over the unmanured control treatments, but the cattle manure had the greatest effect on enhancing the rate of water entry into the soil. In the same study, Assefa (2002) found that four annual applications of hog and cattle manure decreased the aggregate size in a sandy loam textured Black soil. This is in contrast to the effects of manure application in the Luvisolic soils, where a single application of manure increased the aggregation. The decrease in aggregate size in the Black soils following repeated manure application was attributed to possible dispersive effects at the surface from accumulated sodium. This same effect was observed in a clay textured soil receiving high rates of liquid swine manure in west-central Saskatchewan, with some evidence of aggregate dispersion at the soil surface (Zeleke, 2003). Overall, manure of high organic matter content is anticipated to be most beneficial in improving the physical condition of the soil. However, the potential deleterious effect of adding sodium, which can induce dispersion and subsequent deterioration of surface structure, needs to be considered especially for manures of high sodium and low organic matter content.

Conclusions

There are many factors to be considered when attempting to assess the overall net impact of a management practice on soil quality and productivity. Additions of manure to soils at agronomic rates to match crop nutrient requirements are expected to have a positive impact on soil quality. The benefit of increased soil organic matter is perhaps the most significant factor, as organic matter plays a role in enhancing soil fertility, microbial activity, soil structure, water relations and chemical buffering. However, salinity impacts and overloading of both functional and non-functional elements can negate these benefits when manure is over-applied or applied to soils with limitations in drainage and buffering capabilities.

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