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Rate of soil recovery following termination of long-term cattle manure applications

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ABSTRACT

Livestock manure application increases soil nutrient levels, enhancing their bioavailability, but potentially increasing environmental concerns. This study investigates the residual effects of long-term cattle feedlot manure applications to continuously cropped fields under semi-arid conditions on soil properties, crop yields and rate of soil recovery after manure application ceases. Solid cattle feedlot manure was applied to a Dark Brown Chernozemic clay loam at 0, 30, 60 and 90 Mg ha^{-1} yr^{-1} under rain-fed and 0, 60, 120 and 180 Mg ha^{-1} yr^{-1} under irrigated conditions annually for 14 years (1973–1986) followed by 16 years with no further manure application (1987–2003). Soil samples to 1.5 m were taken and analyzed. Soil organic matter (OM), total nitrogen (TN), NO_3^-, total P (TP), soil test P (STP), and electrical conductivity (EC) levels remained significantly higher in previously manured treatments than in the Control 16 years after manure application ceased. The average grain yields were similar to the Control while straw yields in irrigated treatments were higher than values for the Control over the 16 years following the last manure application. Based on a three-parameter exponential decay ($y=y_s+a*e^{-bx}$) model, the estimated recovery time for soil to return to the pre-manure treatment state increased with the previous manure application rate and was shorter under irrigation. For soil TN, TP and STP, estimated recovery time ranged from 17 to 99 years for surface soil and 0 to 157 years for the 15 to 30 cm depth, while soil NO_3^- and EC in the soil profile (0 to 150 cm) requires 182 to 297 years under rain-fed and 24 to 52 years under irrigated conditions. Thus, long lasting N and P enrichment, from excessive long-term cattle manure applications could pose environmental threats long after application ceases.

1. Introduction

Livestock manure has been used to improve soil fertility for centuries (Kapkiyai et al., 1999), by increasing soil organic matter (OM) content (Kaur et al., 2008) and improving soil physical, chemical and biological properties (Fraser et al., 1988; Clark et al., 1998; Liebig and Doran, 1999; Hao et al., 2003). Soils receiving livestock manure have higher numbers of micro fauna, and more P, K, Ca, Mg, and NO_3^- than soil receiving mineral fertilizer (Edmeades, 2003; Herencia et al., 2007). However, lower macronutrient content in soil receiving livestock manure applications has also been reported with low input organic farming (Gosling and Shepherd, 2005). Lower bulk density and higher porosity, hydraulic conductivity and aggregate stability have been associated with manure application (Edmeades, 2003) as well, related to the increases in OM content (McLaren and Cameron, 1996; Hao et al., 2003). However, despite the many benefits of manure, application at rates higher than crop requirements can lead to excessive nutrient accumulation in the soil (Chang and Entz, 1996; Whalen and Chang, 2001; Evanylo et al., 2008).

Because the ratio of nutrients in manures is different from the ratio of nutrients removed by common crops, excessive accumulation of some nutrients, particularly P, can result from long-term use of manure as demonstrated in the Rothamsted trials (Edmeades, 2003). Exacerbating the problem is the large amount of manure that has to be disposed of annually from increasingly intensive livestock operations, with most ending up on nearby agricultural lands due to the cost of transporting it further (Freeze and Sommerfeldt, 1985; Freeze et al., 1999). The resulting nutrient-rich soil poses a risk to surrounding water bodies when these nutrients are transported by wind or water erosion (Sharpley et al., 1994). Once the adverse effects of excess livestock manure are identified, the simplest solution is to stop using it. This raises the question of what happens to soil when manure application ceases under continuous crop production. Will soil return to its original state? If so, how long will this take?

Although there is considerable research on the residual effect of livestock manure on crop production (Mugwira et al., 2002; Eghball et al., 2004; McAndrews et al., 2006), few studies have addressed the residual effect on the soil. In one such study conducted in Nebraska after soil previously received four annual manure or compost applications, the residual effect on corn yield and N uptake lasted

Abbreviations: OM, organic matter; TN, total nitrogen; TP, total phosphorus; STP, soil test phosphorus; EC, electrical conductivity.

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for at least one growing season while the effects on soil properties, such as electrical conductivity (EC), NO_3^- and soil test P (STP), lasted longer (Eghball et al., 2004). Based on the same study, four years after the last compost application (with rates based on crop N needs), the STP, EC and pH of the surface soil remained significantly greater than the Control (Gilley and Eghball, 2002) even though crop P removal can significantly reduce STP levels over time (Eghball et al., 2003). Based on an exponential decay model ($y = a * e^{-bx}$), Eghball et al. (2003) predicted that 10 years of corn production would be required to return the soil P level to pre-treatment levels. There are no predictions made on the rate of recovery for soil (OM, N and other soil properties.

A long-term cattle manure application study was initiated in 1973 and the impact on soil properties and crop performance has been reported previously by various researchers over the years (Sommerfeldt and Chang, 1985; Chang et al., 1991, 1993; Chang and Entz, 1996; Chang and Janzen, 1996; Chang et al., 1998; Whalen and Chang, 2001; Hao et al., 2003). Therefore, in this study we examined the residual effect of 14 annual cattle manure applications at various rates on soil OM, N, P and EC levels for 16 years following the last manure application under both rain-fed and irrigated conditions, to assess the recovery time for soil properties to return to their pre-manure treatment levels. We hypothesize that with increasing rates of manure application, the recovery time will increase. However, the recovery time will be shorter under irrigation, which promotes microbial activity and increases crop nutrient uptake.

2. Materials and methods

2.1. Description of the field experiment

In 1973, a long-term manure experiment was established on a well-drained Dark Brown Chernozemic Lethbridge clay loam soil (Haplic Kastanozem in the FAO Soil Classification System) located at the Agriculture and Agri-Food Canada Research Centre in Lethbridge, AB (49°42′N; 112°48′W; elevation 915 m). The experiment was divided into two main blocks, one rain-fed and one irrigated. Originally, an additional division included three tillage systems: plow, rototiller and cultivator plus disk. Because soil properties and crop production were not significantly affected by tillage methods (Sommerfeldt et al., 1988; Chang et al., 1991), starting in 1986 manure was incorporated in all subplots with a cultivator plus disk to a depth of 10 to 15 cm.

Within each tillage treatment (main plot), manure was applied to subplots (7.5 × 15 m) at the following four rates: 0, 30, 60 and 90 Mg ha^{-1} yr^{-1} (wet weight) to rain-fed soil (Treatments Mr0, Mr30, Mr60, and Mr90) and 0, 60, 120 and 180 Mg ha^{-1} yr^{-1} (wet weight) to the irrigated soil (treatments Mi0, Mi60, Mi120 and Mi180). Recommended manure application rates in this area at the initiation of the experiment were 30 Mg manure ha^{-1} yr^{-1} (wet weight) for rain-fed soils and 60 Mg ha^{-1} yr^{-1} (wet weight) for irrigated soils (Alberta Agriculture, 1980). The solid feedlot cattle manure was applied annually each fall after harvest starting in 1973 and immediately incorporated. Main and subplot treatments were assigned randomly and replicated three times. Combining three tillage systems increased the number of replicates to nine for each manure treatment. After 14 annual applications (with the last application in fall 1986), three replications for rain-fed and two replications for irrigated manure treatments received no further manure application, creating three discontinued manure treatments under both rain-fed (Dr30, Dr60 and Dr90) and irrigated conditions (Di60, Di120 and Di180). In other words, the Mr30, Mr60, Mr90, Mi60, Mi120 and Mi180 treatments continued to receive annual manure applications while Dr30, Dr60, Dr90, Di60, Di120 and Di180 received no further manure following the initial 14 annual manure applications. For the duration of the experiment, barley was grown in most years, except for canola in 1996, and triticale (rain-fed) and corn (irrigated) from 1997 to 1999. All above-ground crop biomass residues were removed except about 15 cm of stubble.

The climate in this area is semi-arid. Over the 30-year experimental period, the average annual precipitation was 384 mm, varying from as high as 702 mm in 1978 to as low as 149 mm in 2001. For the irrigated block, the amount of irrigation water averaged 160 mm yr^{-1}, with a maximum value of 432 mm in 2000 and a minimum value of 0 mm in 1995. This increased the average annual water input in this block to 544 mm. The annual mean temperature during this period was 6.0 °C and the mean pan evaporation 1404 mm.

2.2. Manure and soil analysis

All solid cattle manure used throughout this study came from a single commercial cattle feedlot. In the first 20+ years, the feedlot did not use any bedding. Later, straw was added as a bedding material in the winter months. Each fall the manure was delivered and piled near the plots. Eight manure samples were collected when the manure spreader was loaded.

Two soil samples to a depth of 150 cm were collected from each subplot after harvesting in the fall of 1973 to 2003, except 1988, 1996, 1997 and 1999 to 2002, when no soil samples were taken. Soil samples were divided into 0 to 15, 15 to 30, 30 to 60, 60 to 90, 90 to 120 and 120 to 150 cm layers. For each layer, the two samples were composited for analysis.

Manure and soil samples were air-dried and passed through a 2-mm sieve, then analyzed for OM, total nitrogen (TN), KCl-extractable NO_3-N, total phosphorus (TP), STP and EC. From 1973 to 1993, organic C content was determined using the Walkley and Black (1934) method and TN with the Kjeldahl–Gunning method (AOAC, 1950). After 1993, TC and TN were determined on fine ground samples (<150 μm) by dry combustion techniques using a Carlo Erba CN analyzer (Carlo Erba, Milan, Italy). Inorganic C was measured following the method of Amundson et al. (1988) and organic C was calculated as the difference between total and inorganic C content. Since the organic C values of Walkley and Black (1934) and TN values from the Kjeldahl–Gunning method were generally lower than the corresponding CN analyzer values, the values from 1973 to 1993 were converted to CN analyzer equivalents based on regression analysis on the data obtained in 1993 and 1994 (when soil samples were analyzed using both methods). The KCl extractable NO_3-N (1:5 soil to solution ratio shaken for 1 h) was measured using an auto-analyzer (Technicon II AutoAnalyzer, following Technicon Industrial Method No. 100-70 W/B). Total P was measured by Na_2CO_3−fusion (Jackson, 1958) up to 1991 and afterwards by the H_2SO_4 and H_2O_2 acid digestion method (Parkinson and Ellen, 1975). Available P was measured with Olsen's method (1:5 soil to solution ratio) from 1973 to 1992, and with the Kelowna method (Van Lierop, 1988) from 1993 to 2003. The amount of extracted P was measured with the modified Murphy and Riley blue-color method on an auto-analyzer (Technicon AutoAnalyzer II following Technicon Industrial Method No.155-71W for STP and Technicon Industrial Method No. 334-74 W/B+ for total P). Since the STP values determined by the Kelowna method are generally higher than those using the Olsen method, the Kelowna STP values from 1993 to 2003 were converted to the equivalent Olsen STP values based on relationships between the two methods obtained using soil samples from 1998 when over 100 soil samples were analyzed by both methods. Electrical conductivity in manure and soil was determined using the saturated paste method (Janzen, 1993).

2.3. Crop analysis

Crop grain and straw yield were determined each year. Yield data from the rain-fed block were missing for 1988 and 2001 due to crop failure from extreme drought. No grain data were collected for 1997 to 1999 as irrigated corn was harvested as forage for making silage. There