Long-Term Cattle Manure Plots

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Summary

A field experiment was started in 1973 to determine the safe loading capacity of soil with cattle feedlot manure. Manure was applied annually at 0, 30, 60, and 90 tonne ha^{-1} (wet weight) under rainfed and 0, 60, 120, and 180 tonne ha^{-1} under irrigated conditions. The long-term manure applications resulted in increased levels of organic matter, N, P, salt and trace minerals in soil. This increased straw yield at all manure rates, but reduced grain yields at higher rates and affected crop quality. Increased nutrient levels also increase the potential for nutrient losses and surface and groundwater contamination. The soil enrichments were long-lasting and could pose environmental threats long after application has ceased.

Introduction

A long-term manure experiment was established at Lethbridge, Alberta in the fall of 1973 to determine the effects of repeated annual applications of beef feedlot manure on soil properties, barley production, and groundwater quality. In later years (from 1987 on), the residual effects of the long-term applications were also investigated.

The soil is a Dark Brown Chernozemic (Typic Haploborolls) clay loam. It has about 120 to 150 cm of alluvial-lacustrine material over till. Two adjacent fields were used, one rainfed and the other irrigated with about 15-cm water/yr. A description of the field layout is presented Figure 1. The selected rates were 0, 30, 60, and 90 tonnes ha^{-1}, wet weight, for the rainfed field (Treatments Mr0, Mr30, Mr60, and Mr90) and 0, 60, 120, and 180 tonnes ha^{-1} for the irrigated field (Treatments Mi0, Mi60, Mi120, and Mi180). The application rates used corresponded to one, two and three times the recommended rates for rainfed and irrigated crop production for the type of soil used[1]. To compare methods of incorporating manure into the soil, three tillage treatments: plow, rototill, and cultivator plus disc, were used. Since tillage had no effect on most soil properties investigated,[22,24] from 1987 on, manure was incorporated with a cultivator for all plots. Manure applications were ceased for the previously rototilled strip after 14 annual applications. Then in 2003, manure application ceased for the previously plowed strip after 30 annual applications. A description of all treatments is presented Table 1.

Major findings from the study

First 10 years (1973-1982)

After 8 years, the main observations were: (1) surface (0-15 cm) soil organic matter (SOM) content increased with increasing manure application rate; (2) spring-time soil (8-cm depth) temperatures were coldest in the plots that received the highest manure rate; (3) drawbar draft decreased with increasing rates of manure application; (4) surface (0-15 cm) soil bulk density decreased with increasing manure application rate; and (5) increasing manure rates on irrigated land (15-30 cm depth) tended to decrease the amount of aggregates <1 mm and increase the amount >1 mm in size[22]. These findings indicate that manure applications at the 1980 recommended rate[1] can maintain and increase SOM and ameliorate the physical properties of this soil.

After examining the enzymatic activities of soil receiving 10 consecutive annual applications of manure, Dormaar[10] reported the presence of not yet decomposed manure, which did not appear to have any detrimental agronomic effects. Soil could perhaps act as a sink and applying excess manure to soil might be the least expensive means of disposal. However, Dormaar[10] also cautioned that we should not be complacent about this. To establish criteria for feedlot manure disposal, they recommended the project be continued until detrimental effects were observed, so that application thresholds could be established.

Sustainability

During the 11th and 12th year, the effects on soil physical and chemical properties were investigated. The results for soil physical properties indicated that in the surface soil (0-15 cm) plant available water retained by the soil between 20 and 1500 kPa tension decreased with increasing manure rate, regardless of whether irrigation was used[22]. Increases in SOM generally increases the soil water holding capacity, but does not increase the capacity of a soil to store plant-available water (except in sandy soils) since much of the water stored in organic materials is held in the tension range above wilting (1500 kPa). This leads to the observed decreases in plant available water as manure rates increase. Results also showed that soil core saturated hydraulic conductivity and infiltration rate in the field were unaffected by the applied manure[23]. Tillage did not affect SOM and total soil nitrogen (TN) contents[24].

Soil chemical properties indicated that the rate of soil organic carbon and TN accumulation was similar for rainfed and irrigated conditions[24]. Soluble sodium and chloride increased at rates similar to or less than manure rates applied and soluble calcium and magnesium increased at rates greater than manure rates applied. Various soluble constituents (sodium, potassium, magnesium, chloride, sulphate) accumulated in the soil even at the recommended annual rate[6]. These findings suggested that while sustained agricultural production of this land is possible under long-term annual manure applications, the potential for leaching of various nutrients into groundwater had increased[6]. Total nitrate-N accumulation in the 150-cm depth was near 1 tonne ha^{-1}, even at recommended rates of manure. Soil phosphorus accumulated mostly in the surface soil. The recommended rates of 30 tonne ha^{-1} for rainfed and 60 tonne ha^{-1} irrigated land are in the lower end of rate ranges used by producers. These findings suggest that while sustained agricultural production of this land is possible under long-term annual manure applications, the potential for problems due to leaching into groundwater is increased[6,7]. This was the first time the sustainability of these manure applications rates had been questioned.

Effects on soil nitrogen

Soil TN and nitrate increased significantly with manure application, even at the lowest manure rate[18]. While this should be beneficial to crop production, excess soil nitrate accumulation may affect crop nutrient balance and increase the risk of surface and groundwater pollution. A nitrogen balance study conducted after 19 consecutive annual manure applications indicated that all of the N applied in manure was accounted for by crop removal and increased TN accumulation in soil under rainfed conditions, suggesting that losses via leaching, de-nitrification, and ammonia volatilization were negligible[4]. In contrast, under irrigation, particularly at higher manure rates, appreciable N was lost through leaching and volatilization. Based on soil and manure nitrate and chloride data and the amount of irrigation and precipitation over the 19 years, Chang and Entz [3] found that manure applied at one to three times the recommended rate under rainfed conditions resulted in a significant accumulation of nitrate in the rooting zone, but no leaching losses were observed below 1.5 m. However, under irrigated conditions, there was significant soil nitrate leaching beyond 1.5 m and the amount increased linearly with the rate of annual manure application. Even at the recommended rate of 60 tonne ha^{-1}, the leaching loss was 88 kg N ha^{-1} yr^{-1}. This led Chang and Entz [3] to conclude that over the long term, the maximum recommended rates of manure application were too high for annual applications.

Effects on crop yield and quality

After 16 consecutive annual applications, rainfed barley yield was depressed by 10 and 16% for the 60 and 90 tonne ha^{-1} manure rates, respectively, when moisture conditions were below normal. However, barley yield increased when manure was applied under irrigation, with the 60 tonne ha^{-1} rate producing a 20% higher average yield than the control[7]. After 18 annual applications, barley yield was depressed on both rainfed and irrigated land[5]. With or without irrigation, nitrogen, phosphorus, potassium, magnesium, sodium, copper and zinc concentrations in barley tissue (heading stage) were higher. However, calcium concentration was lower in manured the plots than the control[5]. For all elements except calcium, concentrations increased with increasing manure application rates. Calcium concentration was inversely related to manure rate. The reduction in calcium concentration and uptake observed in barley may be due to increased salinity associated with repeated manure applications. When canola was grown in 1996 after 23 annual manure applications, oil content decreased and nitrogen content increased with increasing rate of manure application. The oil and nitrogen contents were negatively related to each other under both rainfed and irrigated conditions[13].

Effects on soil salinity and solution composition

After 25 annual applications, soil electrical conductivity, soluble sodium, potassium, magnesium, bi-carbonate, sulfate and chloride concentrations increased with the manure rate applied, reflecting the soluble cation composition of the manure applied. The increases were greater under rainfed than irrigated conditions[16]. Increases were observed at all soil depths (0-150 cm) for sodium and chloride but only near the surface for potassium, magnesium, bi-carbonate and sulfate ions. This is a reflection of the extremely mobile nature of sodium and chloride. In contrast, calcium ion concentration decreased in the surface soil (0-15 cm), but increased at depths below 30-cm. The increases in potassium were greatest, changing the soil solution from calcium dominated in the control treatment to potassium dominant in the manured soil[15]. By this time, annual land applications of cattle manure at the levels studied in this experiment were clearly not sustainable over the long term, even at the recommended rates.

For every tonne of salt applied through cattle manure, the average soil electrical conductivity (0-150 cm) increased by 0.1108 dSm^{-1} under rainfed conditions[16]. The potential salinity problems due to long-term manure applications on arable land in southern Alberta are probably greater from potassium than from sodium due to the higher soluble potassium content in cattle manure and the low mobility of K in the soil. Although soil salinization due to cattle manure was less under irrigation, leaching of salt to groundwater could compromise groundwater quality over time. In either case, repeated applications of high manure rates are not sustainable.

Effects on soil physical properties

Increases in soil organic C, decreases in sand content, and increases in clay content (irrigation only) were observed in the soil after 24 annual manure treatments[11,20]. These results suggest that manure scraped from unpaved feedlots or farmyards, as was used in this long-term experiment, may modify soil physical properties via changes in soil organic C, sand or clay content. In contrast, manure derived from sources where surface soil is not scraped and mixed into the manure should mainly modify soil physical properties by increasing soil organic C.

Soil bulk density decreased with the rate of manure application, regardless of climatic or management (seeding, tillage, harvesting, and manure application operations) factors[20]. Soil temperatures under manure were lower in the spring and summer but higher in the fall and winter. In general, soil physical properties, such as soil water retention, rate of water infiltration and saturated hydraulic conductivity, except for soil temperature, generally exhibited greater effects under irrigated than rainfed conditions, suggesting that higher manure rates under irrigation caused greater changes in soil physical properties. The major benefit of manure application in terms of the physical properties is decreased soil bulk density, which corresponds to increased total soil porosity (2–17% under rainfed and 2–35% under irrigated conditions). Consequently, soil water retention and soil moisture status were also improved[21]. In particular, soil water content increased in the summer with or without irrigation, coinciding with the season of maximum crop water use. However, improved soil physical conditions did not necessarily translate into higher barley yields. An increase in infiltration and percolation in the surface soil when saturated with water sometimes occurred through large macropores which has important implications in terms of greater potential for leaching (assuming macropore continuity) and possible influence on groundwater quality. Overall, results suggested that long-term manure addition at these relatively high rates should not result in any detrimental impact on the soil's physical properties, based on the measurements conducted.

Effects on soil phosphorus

Soil phosphorus accumulations after 20 annual applications of cattle manure far exceeded crop uptake and most of this residual soil P was in plant available form[9]. A phosphorus balance of these soils under barley production indicated that the amount of phosphorus removed in barley grain and straw was between 5 and 18% of manure P applied[25].

After 28 years, the soil TP and plant available P (soil test P and water soluble P) contents in the bulk soil and in different aggregate size fractions increased with the rate of manure application[17]. The increase in P content in soil aggregates, especially the wind-erodible fraction, poses a considerable risk for surface water eutrophication because wind erosion potential is high in this region. When these P-enriched wind-erodible aggregates (<0.84 mm) were deposited in water, soluble N and P content in the water increased immediately up to 94 and 32 times, respectively, and these concentrations increased with time and did not level-off even after two years[12].

Another concern about P accumulation in the manure plots was the changes in P distribution among its various forms (phosphorusextracted by water, sodium bi-carbonate, sodium hydroxide, weak acid and strong acid), which then influences P bioavailability leading to potential negative environmental impacts[14]. Soils from the continuous 30-year manure plots, in comparison to the non-manured Controls (Mr0 and Mi0), had higher levels of all P forms. However, the largest increase occurred in the available inorganic form used by plants. The increase was greater in the irrigated than in the rainfed plots and greater in the 15-30 cm than the 0-15 cm depth.

Effects on soil trace elements

Twenty-five years of manure application at the recommended rates increased total copper and zinc levels under irrigation[2], but both total copper and zinc levels remained below the maximum acceptable concentration (MAC) set by the European Community (EC) and the U.S.A. However, a threefold increase in the manure application rate (from 60 to 180 tonne ha^{-1}) under irrigation elevated total zinc levels to 187.5 mg kg^{-1} in the surface soil. This is above the lower end of the MAC recommended by the EC. No increases in total boron, cadmium or cobalt contents were observed regardless of the amount of manure applied. However, manure applications at 120 and 180 tonne ha^{-1} yr^{-1} under irrigation increased available (EDTA-extractable) cadmium content (0-30 cm depth). Higher levels of available copper (0-30 cm depth) and zinc (0-150 cm depth) were observed with all manure treatments, with or without irrigation, relative to the Control.

Rate of soil recovery

Five years after manure applications were discontinued (after 14 annual applications), manure effects on barley tissue nutrient concentrations were considerably diminished relative to those plots that continued to receive manure[5]. Dry matter yields (heading stage) were not affected by previous manure rates. Grain yields showed a positive response to residual manure treatments, probably as a result of improved N and P fertility and reduced salinity levels.

Soil available cadmium and zinc contents were still elevated in the irrigated residual plots after 11 years of no manure application due to the higher manure rates used previously[2]. Elevated total soil P (TP), soil test P, and water soluble P content were still measurable 14 years after manure application was discontinued[13]. The soil test P (877 mg kg^{-1}) and TP (2555 mg kg^{-1}) levels in the topsoil of the plots where manure application had been discontinued were still higher than the control plots, even 16 years after the last manure application[14]. Soil organic matter, TN and nitrate-N levels and electrical conductivity also remained higher in the previously manured treatments than in the control after 16 years with no further manure application[19]. 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[19].

Using an exponential decay function, 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[19]. For total soil nitrogen and phosphorus and soil test P, estimated recovery time ranged from 17 to 99 years for surface soil and 0 to 157 years for the 15-30 cm depth, while soil nitrate-N and electrical conductivity in the soil profile (0-150 cm) could require 182 to 297 years under rainfed and 24 to 52 years under irrigation[19]. Thus, long lasting nutrient enrichment from excessive long-term cattle manure applications poses some very important challenges with respect to sustainable manure management, not to mention the environmental consequences, long after manure applications have ceased.

Future

Similar to other long-term studies, the fate of this study will depend on the availability of future funding. If funding is available, existing treatments will continue indefinitely. Future research will focus on the shifting of microbial communities in soil, which is pertinent to nutrient availability and cycling in agro-ecosystems with implication for the environment.

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Table 1. Treatment description

Field	Irrigation	Treatment	Description
Rainfed	No	Mr0	No fertilizer or manure input since 1973
	No	Mrf	Fertilizer at 50 kg N ha^{-1} yr^{-1} since 1990
	No	Mr30	Manure at 30 tonne ha^{-1} yr^{-1} since 1973
	No	Mr60	Manure at 60 tonne ha^{-1} yr^{-1} since 1973
	No	Mr90	Manure at 90 tonne ha^{-1} yr^{-1} since 1973
	No	Dr30	Manure at 30 tonne ha^{-1} yr^{-1} from 1973 to 1986 (after 14 annual applications) and application ceased in1987
	No	Dr60	Manure at 60 tonne ha^{-1} yr^{-1} from 1973 to 1986 (after 14 annual applications) and application ceased in 1987
	No	Dr90	Manure at 90 tonne ha^{-1} yr^{-1} from 1973 to 1986 (after 14 annual applications) and application ceased in 1987
	No	DDr30	Manure at 30 tonne ha^{-1} yr^{-1} from 1973 to 2002 (after 30 annual applications) and application ceased in 2003
	No	DDr60	Manure at 60 tonne ha^{-1} yr^{-1} from 1973 to 2002 (after 30 annual applications) and application ceased in 2003
	No	DDr90	Manure at 90 tonne ha^{-1} yr^{-1} from 1973 to 2002 (after 30 annual applications) and application ceased in 2003
Irrigated	Yes	Mi0	No fertilizer or manure input since 1973
	Yes	Mif	Fertilizer at 100 kg N ha^{-1} yr^{-1} since 1990
	Yes	Mi60	Manure at 60 tonne ha^{-1} yr^{-1} since 1973
	Yes	Mi120	Manure at 120 tonne ha^{-1} yr^{-1} since 1973
	Yes	Mi180	Manure at 180 tonne ha^{-1} yr^{-1} since 1973
	Yes	Di60	Manure at 60 tonne ha^{-1} yr^{-1} from 1973 to 1986 (after 14 annual applications) and application ceased in 1987
	Yes	Di120	Manure at 120 tonne ha^{-1} yr^{-1} from 1973 to 1986 (after 14 annual applications) and application ceased in 1987
	Yes	Di180	Manure at 180 tonne ha^{-1} yr^{-1} from 1973 to 1986 (after 14 annual applications) and application ceased in 1987
	Yes	DDi60	Manure at 60 tonne ha^{-1} yr^{-1} from 1973 to 2002 (after 30 annual applications) and application ceased in 2003
	Yes	DDi120	Manure at 120 tonne ha^{-1} yr^{-1} from 1973 to 2002 (after 30 annual applications) and application ceased in2003
	Yes	DDi180	Manure at 180 tonne ha^{-1} yr^{-1} from 1973 to 2002 (after 30 annual applications) and application ceased in 2003

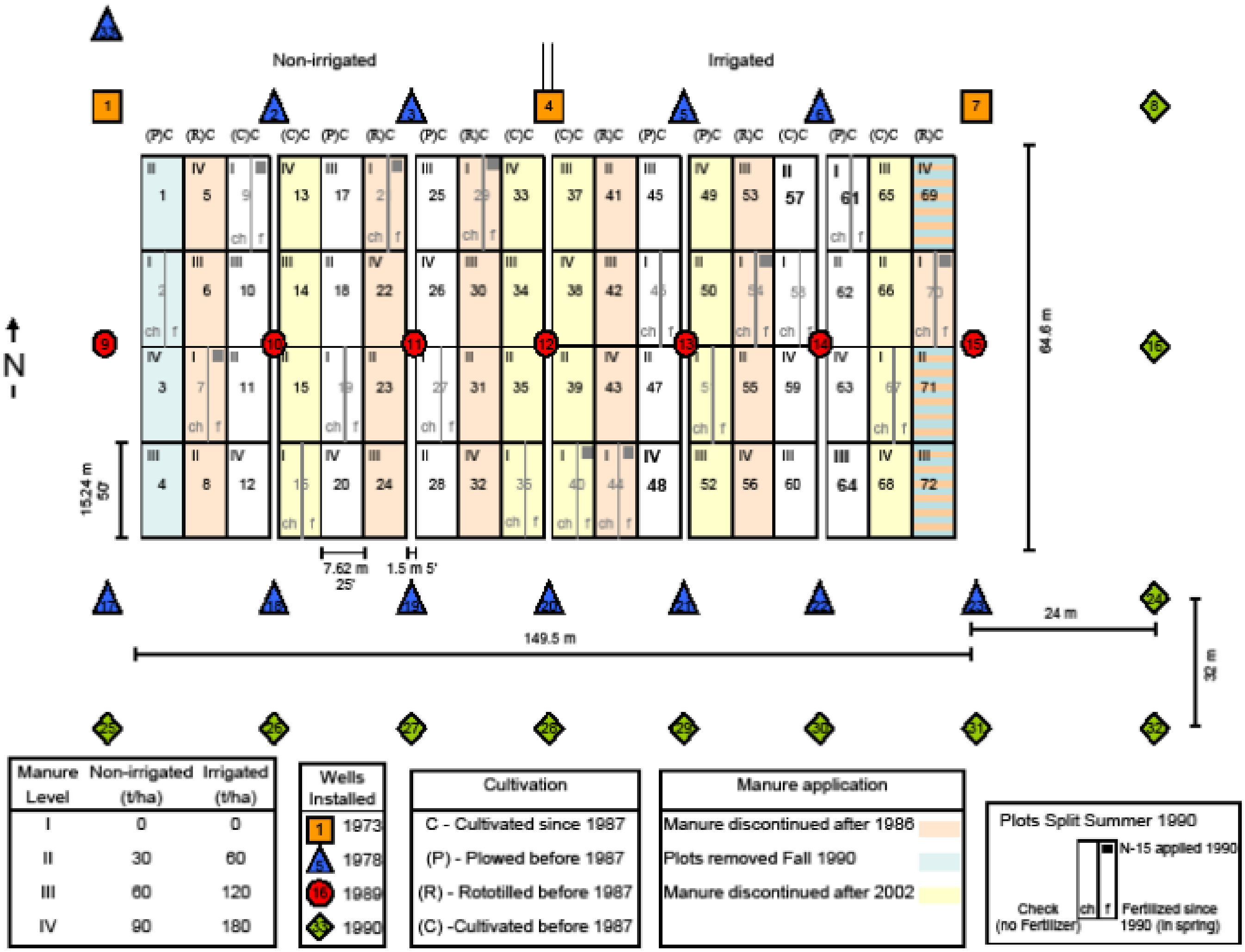

Figure 1. Field layout of the long-term manure plot

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