Use of Manure to Wheat Production in an Argentinean Hapludoll Soil

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Abstract

Beef cattle feeding operations or feedlots generate large amounts of manure that negatively affect the environment. In order to reach an integrated farming system, setting a final destiny for these wastes not to damage the environment, the use of cattle manure in partial or total replacement of inorganic fertilizers has been evaluated. The trial was performed using wheat. Four treatments were carried out as follows: a control treatment on the one hand and other three treatments on the other, containing a 116 kg N ha⁻¹ isodose: Inorganic Fertilization (IF), Manure (M) and a mixture of Manure and Inorganic Fertilizers (M-IF) in equal parts. Results show M-IF treatment as the most efficient one, because it had the highest yield with the least negative effects over the environment.

Keywords: Manure; Land application; Soil; Wheat; Environment

Introduction

Beef cattle feeding operations or feedlots generate large volumes of manure which can negatively impact the environment [1,2]. This residue has a high concentration of nutrients (N, P and K), minerals, trace elements, organic matter and pathogens, among others. Its components can be mobilized by water dynamics and reach into surface or groundwater water sources, deteriorating its quality [3,4].

Using manure in wheat production cropland is an alternative method to reduce feedlot environmental impact [5] and thus to achieve an integrated farming system [6]. Manure provides some of the essential elements for growth and development of crops due to its high nutrient concentration, which can significantly reduce fertilizing costs [4]. Moreover, the increase in organic matter [7] (and thus, moisture retention capacity) improves and maintains the soil properties.

There are international standards and technical procedures on manure fertilization practices. Nevertheless, environmental aspects are conditioning factors over them. Local case studies are essential for developing conceptual models to predict the evolution of these practices under different soil and climate conditions, and thus avoid potential environmental damage. In this context, the aim of this study is to evaluate the use of cattle manure in partial or total replacement of inorganic fertilizers in wheat production and assess its impact on soil properties.

Materials and Methods

Study site

The study was carried out in 2010 in a crop-livestock farming system located at 61°32' west longitude and 34°11' south latitude in the Teodelina district, which belongs to the south region of the province of Santa Fe known as the sandy pampa (Figure 1). The dominant climate is sub-humid, with an average annual temperature of 16.4°C and an isohydrone regimen of 948 mm of annual rainfall [8].

The soil of the site under study has been classified as Entic Hapludoll according to USDA soil taxonomy. This soil has a well drained, sandy loam texture, with high levels of labile phosphorus and organic matter in the topsoil, according to its use track record. A moderate cation exchange capacity value and low concentrations of salts and nitrogen species were also found (Table 1). It is worth to point out that the soils of this region are essentially poor in organic materials and nutrients.

Four different treatments were used; three of them maintained an isodose of 116 kg ha⁻¹ of available N (based on the crop nitrogen requirements to achieve a production of 6700 kg ha⁻¹). Treatments were: 1) Inorganic Fertilization (IF) (190 kg ha⁻¹ urea, 80 kg ha⁻¹ ammonium sulphate and 170 kg ha⁻¹ monoammonium phosphate); 2) manure...
application (M) (40 tn ha⁻¹); 3) mixture of manure and inorganic fertilizer (M-IF) (16 tn ha⁻¹ M and 50% IF); 4) control (C) (soil without any fertilizer application).

Field tasks were made with the facilities machinery and staff. The experiment was conducted in plots of 1300 m². The design was completely randomized with three replicates per treatment. The solid manure [9] was weighed onto a tractor-pulled solid manure spreader completely randomized with three replicates per treatment. The solid measured with atomic absorption spectrometry); organic nitrogen-NKJ were: ears m⁻², grain ear⁻¹, thousand grain weight and Dry Matter (DM).

Crop cycle, top soil disturbed samples were collected from the first 10 cm to establish the effects of these practices over its quality. The following variables were quantified by means of standard laboratory methods [11]: pH (measured using potentiometric method, water dilution 1:2.5); electrical conductivity-EC (using conductimetric method, performed in saturated paste); organic matter-OM (determined by loss-on-ignition/combustion method); exchangeable potassium-EK (extracted with 1 M NH₄Ac pH 7 and measured with atomic absorption spectrometry); total potassium-TK (using wet digestion with oxidizing acids, measured with atomic absorption spectrometry); organic nitrogen-NOrg (determined by macro-Kjeldhal method); labile phosphorus- Bray-P and total phosphorus-TP (using Bray-Kurtz 1 extract and wet digestion with oxidizing acids respectively and measured colorimetrically with ammonium molybdate).

### Measured Parameters

<table>
<thead>
<tr>
<th>Measured Parameters</th>
<th>Soil (%)</th>
<th>Manure (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (cm)</td>
<td>0-10</td>
<td>10-20</td>
</tr>
<tr>
<td>Gravimetric moisture content (%)</td>
<td>12.5</td>
<td>13.4</td>
</tr>
<tr>
<td>Bulk density (g cm⁻³)</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Volumetric water content (%)</td>
<td>16.3</td>
<td>17.2</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>59.1</td>
<td>59.1</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>30.4</td>
<td>30.4</td>
</tr>
<tr>
<td>Total N (NPK) (%)</td>
<td>0.14</td>
<td>0.10</td>
</tr>
<tr>
<td>N-NO₃ (ppm)</td>
<td>18.1</td>
<td>7.9</td>
</tr>
<tr>
<td>N-NH₄ (ppm)</td>
<td>11.6</td>
<td>12.7</td>
</tr>
<tr>
<td>Labile P (ppm)</td>
<td>40.7</td>
<td>4.5</td>
</tr>
<tr>
<td>Total P (%)</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>pH</td>
<td>5.15</td>
<td>5.81</td>
</tr>
<tr>
<td>Electrical conductivity (dS m⁻¹)</td>
<td>0.23</td>
<td>0.13</td>
</tr>
<tr>
<td>Organic Matter (%)</td>
<td>4.5</td>
<td>3.8</td>
</tr>
<tr>
<td>Cation exchange capacity (meq 100 g⁻¹)</td>
<td>12.7</td>
<td>12.1</td>
</tr>
<tr>
<td>Cations:</td>
<td>N/D</td>
<td>N/D</td>
</tr>
<tr>
<td>Na⁺ (meq 100 g⁻¹)</td>
<td>N/D</td>
<td>N/D</td>
</tr>
<tr>
<td>K⁺ (meq 100 g⁻¹)</td>
<td>0.86</td>
<td>0.73</td>
</tr>
<tr>
<td>Ca²⁺ (meq 100 g⁻¹)</td>
<td>7.7</td>
<td>9.8</td>
</tr>
<tr>
<td>Mg²⁺ (meq 100 g⁻¹)</td>
<td>0.96</td>
<td>1.14</td>
</tr>
<tr>
<td>N/D: not detected</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Physical, chemical and biological properties of soil and manure.

Data Analysis

### Estimated yield and agronomic efficiency in N and P use

Wheat yield was calculated with data from ears m⁻², grain ear⁻¹ and a thousand grain weight. From the yield results, Nitrogen Agronomic Efficiency (NAE) [12] was calculated as:

\[ NAE = \frac{(Yield(n) - Yield(c))}{N_{av}(n)} \]

Where: yield (n) is yield of treatment n, yield (c) is yield of treatment control and Nₐ is available N for crop, applied in treatment n. For treatments with manure, Nₐ was calculated as [13]:

\[ N_{av} = [N-Org] \times 0.4 + [N-NH₄] \times 0.5 + [N-NO₃] \]

Where: [N-Org] is the concentration of organic N estimated as Nₐ; 0.4 is a coefficient that indicates the mineralization rate of N-Org from manure in a year [14]; and 0.5 is a coefficient that indicates the availability of N-NH₄ from manure in a year [15].

Also, Phosphorus Agronomic Efficiency (PAE) [16] was calculated in order to assess the potential environmental effects of excess application:

\[ PAE = \frac{(Yield(n) - Yield(c))}{P_{l}(n)} \]

Where: yield (n) and yield (c) have been already defined and Pₗ is available P for crop, applied in treatment n. For treatments with manure, Pₗ was estimated as 90% of TP [17].

### Statistical analysis

Descriptive statistic (mean and standard deviation) was applied using statistical software. Under the assumptions of normality and homogeneity of variance, ANOVA model was applied to establish the treatments effect on each variable analysis. Comparison of means was performed using Tukey's test (α=0.05).

### Results and Discussion

#### Effects on crop

Treatment effects impacted on the following variables: grain yield, Dry Matter (DM), agronomic efficiency in N use (NAE) and P (PAE) (Table 2). Comparing different treatments, it could be established that plots with fertilization had significantly superior yields than control (C) plots (p<0.05). IF yielded 34% more than C while the increase for M and M-IF was 59%. The lower availability of nutrients present in unfertilized soil could explain these results. Also, yields in treatments M and M-IF were 18% higher (p<0.05) than IF. Similar results were found by Lupwayi et al. [18], who applied manure under a dose of 30 tn ha⁻¹ using wheat in a dry farming system.

Treatments M and M-IF were designed to provide the same dose of available N as in IF. However, yields obtained by them were markedly different from IF (Table 2). Manure as organic matter has the ability to retain water by its numerous functional groups, and it is capable of enhancing crop water status during grain filling stage, generating higher yields. Furthermore, the contribution of other macronutrients such as Ca, Mg and Na, and micronutrients in manure may have influenced these differences.

DM was not as sensitive to different treatments as yield. Only M differed significantly (p<0.05) from the rest with a mean value of 18 tn ha⁻¹, being 1.3 times higher than others. Similar results were found by Egghall et al. [1].

Table 2 shows that NAE did not differ significantly (p>0.05) for the two treatments which received organic fertilizers, with a mean value of 24.4 kg of grain kg⁻¹ of available N applied. This value doubled the NAE of IF treatment (p<0.05). Similar results were found by
The replenishment of P from manure mineralization to soil solution

when high doses are used (≥ 40 tn ha⁻¹). Application doses combining manure and inorganic fertilization (M-IF) may not be as harmful as the exclusive use of manure, taking into account that EC values do not show differences from those resulting from Inorganic Fertilization (IF) (Table 3).

OM, N₄, TP, TK variables were statistically less sensitive (p>0.05) in different treatments than EC. These results were also found by Chivenga et al. [24], Indraratne et al. [25], Odlaire et al. [26] and Riley [27]. The lack of variation could respond to a good soil status according to its use track record and to a dose of manure with concentrations that did not affect the total content of these nutrients.

Regarding EK, only a high dose of manure (40 tn ha⁻¹) was capable of changing its concentration (Table 3), similar results were reported by Turner et al. [21]. However, Khodaeijoghan et al. [28] and Eghball et al. [29] showed different behaviors for this variable, possibly due to differences in the initial conditions of soil and manure. K is one of the main causes of soil salinity problems, affecting crop assimilation of other nutrients [30].

Bray-P was sensitive to different treatments, showing a similar behavior to EC. The lowest value was found in the control soil (C treatment) (35.6 ppm), being three times lower (p<0.05) than M (Table 3). The latter treatment left postharvest Bray-P concentrations of 1.5 and 2 times greater than M-IF and IF respectively. Over long-term crop rotation, Morari et al. [22] also obtained significant differences similar to those found in this study. The observed variability is mainly characterized by the added amount of P from manure or mineral fertilizer, the degree of mineralization of manure, and the soil's ability to retain this nutrient.

Nevertheless, some important reactions have occurred in the different fractions of soil P (moderate labile P). Performing a phosphorus balance for each treatment (Table 4), it can be observed that 13.5 ppm was found in the restock of Pᵥ in the control soil. Meanwhile, only 1.3 ppm was replenished from the soil in IF treatment whereas M reloaded 18.6 ppm, twice as much P as M-IF. The gap between these treatments is mainly due to the different concentrations of available P. In organic and mixture plots, more than 93% of P was replenished to soil solution from manure mineralization. In all cases, there was a loss of P from the initial status of the system due to strong nutrients removal of crop.

The replenishment of P from manure mineralization to soil solution

### Table 3: Treatment effects over crop measured variables.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>pH</th>
<th>EC (dS m⁻¹)</th>
<th>OM (%)</th>
<th>NKJ (%)</th>
<th>TP (ppm)</th>
<th>TK (meq100 g⁻¹)</th>
<th>EK (meq100 g⁻¹)</th>
<th>Bray-P (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>5.51a</td>
<td>0.14a</td>
<td>5.09a</td>
<td>0.103a</td>
<td>495.4a</td>
<td>7.58a</td>
<td>0.83a</td>
<td>35.6a</td>
</tr>
<tr>
<td>IF</td>
<td>5.33a</td>
<td>0.19a</td>
<td>5.52a</td>
<td>0.098a</td>
<td>512.5a</td>
<td>7.55a</td>
<td>0.83a</td>
<td>52.5a</td>
</tr>
<tr>
<td>M-IF</td>
<td>5.52a</td>
<td>0.24a</td>
<td>5.19a</td>
<td>0.106a</td>
<td>522.8a</td>
<td>7.59a</td>
<td>0.79a</td>
<td>68.7a</td>
</tr>
<tr>
<td>M</td>
<td>5.76a</td>
<td>0.51a</td>
<td>5.40a</td>
<td>0.106a</td>
<td>595.9a</td>
<td>7.64a</td>
<td>1.19a</td>
<td>102.1a</td>
</tr>
</tbody>
</table>

### Table 4: Labile phosphorus balance for each treatment during wheat crop cycle.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>TLP In (ppm)</th>
<th>ELP (ppm)</th>
<th>TLP In - ELP (ppm)</th>
<th>LP Fi (ppm)</th>
<th>P Rep (ppm)</th>
<th>P Balance (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>40.0</td>
<td>17.9</td>
<td>22.1</td>
<td>35.6</td>
<td>13.5</td>
<td>-4.4</td>
</tr>
<tr>
<td>IF</td>
<td>75.2</td>
<td>24.0</td>
<td>51.2</td>
<td>52.5</td>
<td>1.3</td>
<td>-22.7</td>
</tr>
<tr>
<td>M-IF</td>
<td>86.6</td>
<td>27.8</td>
<td>58.8</td>
<td>68.7</td>
<td>9.9</td>
<td>-17.9</td>
</tr>
<tr>
<td>M</td>
<td>112.5</td>
<td>29.0</td>
<td>83.5</td>
<td>102.1</td>
<td>18.6</td>
<td>-10.4</td>
</tr>
</tbody>
</table>

C: control; IF: inorganic fertilization; M-IF: mixture of manure and inorganic fertilizer; M: manure application; EC: electrical conductivity; OM: organic matter; NKJ: N Kjeldhal; TP: total P; EK: exchangeable K; TK: total K
can be seen as a positive aspect. Soils in humid area of the *sandy pampa*, are inherently low in P, so yields can be enhanced by manure application. However, continuous manure applications at a nitrogen-based rate in low adsorption capacity soils (such as in this region) could cause a buildup of P in soil and allow for continued discharge of phosphorus from the cropland. Consequently, P discharges from these areas may not be adequately controlled, adversely affecting the environment should P reach water bodies [31].

**Conclusions**

In this work, it was possible to identify the M-IF treatment as the most efficient one, because it showed the highest yield with the least negative effects over soil compared to the other treatments performed. The lowest NAE found in IF and the great accumulation of salts in M, showed potential negative effects of these treatments on the environment.

Our results suggest that applications of manure to sandy loam soil could improve soil water retention and field soil water status, as well as contribute with other macro and micro nutrients, making up for the differences between IF and manure treatment yields.

Evidently, manure represents a significantly significant nutrient source for agricultural production. However, the slower release of residual nitrogen from manures, as well as the buildup of P and K in soil solution, may lead to potential environmental implications under humid conditions. Future research for the recycling of manure in sandy loam soil is needed in order to improve this practice.

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**References**