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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 study was done in sub-humid, *sandy pampas* region, on an Entic Hapludoll soil. The field experiment 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 16.4ºC and an isohydro 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.

The trial was performed with no-till farming system, and the former crop was corn. The beef cattle manure was collected from a stockpile stored for 4 months. The characteristics of this residue are shown in Table 1.

Experimental design

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

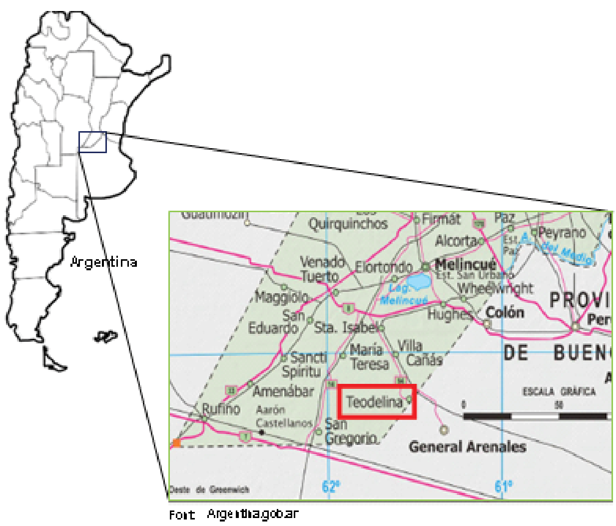

Figure 1: Location of Study site.

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Measured Parameters	Soil		Manure
Depth (cm)	0-10	10-20	
Gravimetric moisture content (%)	12.5	13.4	31.4
Bulk density (g cm^{-3})	1.3	1.3	
Volumetric water content (%)	16.3	17.2	
Sand (%)	59.1	59.1	
Clay (%)	10.5	10.5	
Silt (%)	30.4	30.4	
Total N (NKj) (%)	0.14	0.10	0.69
$N\text{-}NO_3^-$ (ppm)	18.1	7.9	0.2
$N\text{-}NH_4^+$ (ppm)	11.6	12.7	1617.8
Labile P (ppm)	40.7	4.5	1846.5
Total P (%)	0.04	0.03	0.26
pH	5.15	5.81	8.95
Electrical conductivity (dS m^{-1})	0.23	0.13	6.54
Organic Matter (%)	4.5	3.8	17.5
Cation exchange capacity (meq 100 gr^{-1})	12.7	12.1	
Cations:	*ExtracTable*		*Total*
Na^+ (meq 100 g^{-1})	N/D	N/D	10.4
K^+ (meq 100 g^{-1})	0.86	0.73	102.5
Ca^{2+} (meq 100 g^{-1})	7.7	9.8	141.1
Mg^{2+} (meq 100 g^{-1})	0.96	1.12	227.7
N/D: not detected			

Table 1: Physical, chemical and biological properties of soil and 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 m^2. The design was completely randomized with three replicates per treatment. The solid manure [9] was weighed onto a tractor-pulled solid manure spreader and applied to each plot and then, incorporated within 24 hours after application to avoid volatilization losses of nitrogen [10]. Wheat Baguette Premium 11 was used with planting density of 133 kg ha^{-1}. Manure and fertilizers were applied 10 days before and during sowing, respectively.

Sampling and laboratory analysis

Wheat was monitored throughout its cycle. The variables quantified were: ears m^{-2}, grain ear^{-1}, thousand grain weight and Dry Matter (DM). Three replicates were taken per treatment, and each replicate consisted of 10 single samples of measured variables from each plot. At the end of 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 NH_4Ac pH 7 and measured with atomic absorption spectrometry); total potassium-TK (using wet digestion with oxidizing acids, measured with atomic absorption spectrometry); organic nitrogen-N_{KJ} (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).

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:

$$NAE = \frac{\left[Yield\left(n\right) - Yield\left(c\right)\right]}{N_{Av}\left(n\right)}$$

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

$$N_{Av} = [N\text{-}Org] \times 0.4 + [N\text{-}NH_4^+] \times 0.5 + [N\text{-}NO_3^-]$$

Where: [N-Org] is the concentration of organic N estimated as N_{KJ}; 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 $N\text{-}NH_4^+$ 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:

$$PAE = \frac{\left[Yield\left(n\right) - Yield\left(c\right)\right]}{P_L\left(n\right)}$$

Where: yield (n) and yield (c) have been already defined and P_L is available P for crop, applied in treatment n. For treatments with manure, P_L 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 $tnha^{-1}$ 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 Eghball 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

Treatments	Grain Yield (kg ha^{-1})	DM (tn ha^{-1})	NAE	PAE
C	4659.9^a	12.5^a	-	-
IF	6249.9^b	13.3^a	12.7^a	34.7^a
M-IF	7235.7^c	15.0^a	23.8^b	42.5^a
M	7535.8^c	18.2^b	25.0^b	30.5^a

Different letters into each column indicates significant differences (α=0.05).
C: control; IF: inorganic fertilization; M-IF: mix application of manure and inorganic fertilizer; M: manure application; DM: dry matter; NAE: N agronomic efficiency; PAE: P agronomic efficiency

Table 2: Treatment effects over crop measured variables.

Vanlauwe et al. [19], who analyzed more than 700 cases. The high NAE value of manure application corresponds to the higher performance achieved, highlighting the beneficial effects of adding manure for crop growth. The lower NAE of IF plots may cause negative effects on the environment (such as pollution of underlying waters with nitrates) due to N excess in soil.

Regarding PAE, no significant differences were found ($p>0.05$), unlike findings by Mujeeb et al. [20]. The absence of such differences can be related to soil nutrient background (Table 1).

Effects on soil

Treatment effects on soil variables are shown on Table 3. Although statistically significant differences were found in pH, changes below the unit were not sufficiently important considering the normal geochemical changes. The values ranged between 5.25 and 5.92, reaching a mean value of 5.53. Similar results were found by Turner et al. [21].

The greatest value of EC was found in M treatment (0.51 dS m^{-1}) and the lowest one in control plots (C) (0.14 dS m^{-1}), resulting the first one 3.6 times greater than the second. Also, the value found in M was 2.69 and 2.15 times higher ($p<0.05$) than M-IF and IF respectively. Morari et al. [22] and Turner et al. [21] reported similar variations among the treatments, like in this study. Sorted from lower to higher concentration of soluble salts, the treatments were: C<IF=M-IF<M. Notably, the salinity level reached in M treatment did not exceed the threshold value (0.75 dS m^{-1}) established by FAO [23] from which soil begins to be slightly saline. However, increase of salts in M could represent a serious problem considering its effect from a single application to a well-drained soil and under a rainfall regime of 950 mm. Data and literature analysis show that under such management condition, this organic fertilizer behaves as a salinity potential source 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, N_{KJ}, TP, TK variables were statistically less sensitive ($p>0.05$) in different treatments than EC. These results were also found by Chivenge et al. [24] Indraratne et al. [25], Odlare 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 P_L 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

Treatments	pH	EC (dS m^{-1})	OM (%)	Nkj (%)	TP (ppm)	TK (meq100 g^{-1})	EK (meq100 g^{-1})	Bray-P (ppm)
C	5.51^{ab}	0.14^a	5.09^a	0.103^a	495.4^a	7.58^a	0.83^a	35.6^a
IF	5.33^a	0.19^b	5.52^a	0.098^a	512.5^a	7.55^a	0.83^a	52.5^b
M-IF	5.52^{ab}	0.24^b	5.19^a	0.106^a	522.8^a	7.59^a	0.79^a	68.7^c
M	5.76^b	0.51^c	5.40^a	0.106^a	595.9^a	7.64^a	1.19^b	102.1^d

Different letters into each column indicates significant differences (α=0.05).
C: control; IF: inorganic fertilization; M-IF: mix application 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

Table 3: Treatment effects on soil variables under study.

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

C: control; IF: inorganic fertilization; M-IF: mixture of manure and inorganic fertilizer; M: manure; TLP In: Total labile phosphorus at the beginning of crop; TLP In = soil labile P + applied labile P; ELP: Extracted labile P by crop (wheat crop requires 5 kg.tn^{-1}); LP Fi: Labile P at the final of crop; P Rep: P Reposition in soil; P Rep= LP Fi - (TLP In - ELP); P Balance = LP Fi-TLP In.

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

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 potentially 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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