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Trace Elements in Confined Livestock Production Systems In the Pampean Plains of Argentina

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Abstract: The presence of trace elements in manure, soils and sediments from the drainage canalizations in confined beef cattle production systems has been analyzed in a humid and in a semiarid area of Argentina. The obtained results clearly show accumulation of Cu and Zn in the pen soils of the system under study. Metals in the soil come from animal manure. Metals in manure are derived directly from the animal diet. Concentration decreases with soil depth. In the sediments from the drainage canalizations, concentration is higher due to run-off. Differences were observed between humid and semiarid regions. Nevertheless, in both cases, metal accumulation in soil is related to the age of emplacement of the establishment.

Key words: Trace elements, Livestock, Manure, Environment

INTRODUCTION

Microelements are defined as elements that are presented at trace concentrations in most soils, plants and organisms. Trace elements enter an agro-ecosystem through both natural and anthropogenic processes [1].

In soils destined to agricultural activities, heavy metals load could be attributed to atmospheric deposition, discharges, livestock manure, agrochemicals and organic fertilizers [2].

Intensive confined livestock and poultry production systems generate large quantities of manure by-products, which may potentially be used as nutrient resources and soil amendments in agricultural production systems. Manure by products are applied on land to primarily benefit from their organic carbon, N and/or P content [3]. Most of the environmental problems associated with land application of manure-by-products have centered on the contamination of groundwater and/or surface water with these two major nutrients. Less consideration has been given to metals accumulation in soil through manure application, which may cause phytotoxicity and zootoxicity problems, or may leave soils by leaching or surface-water runoff, thus causing water and sediment contamination. With increasing use of trace elements as nutritional supplement in the form of feed additive in intensive animal production systems, manure application appears as an important source of certain metals input in soils [4]. Use of manure and composted biosolids has been reported to increase total amounts of Cu, Zn, Pb, Cd, Fe and Mn in the soils [5]. Metals accumulate in soils since they are not biodegradable with the potential of eventually becoming phytotoxic [6].

Trace element content in manure of intensive animal production systems is related to feed mineral content and the animal conversion efficiency [7]. Increases in metal concentration in animal feed have often resulted in corresponding increases in their concentration in manure by-products [8].

Confined beef cattle fattening systems supplement salts that contain micronutrients as Fe, Mn, Zn, Cu, Co in the balanced food to cover the animal mineral requirements. Cattle utilization efficiency of minerals changes according to the element and the salt used in its formulation.

In Argentina, beef cattle fattening systems have been traditionally extensive, using pastures as nutritional animal source, but in the last fifteen years, an exponential increase of the agricultural surface has occurred, with the consequent decrease of the surface destined to beef cattle grazing systems and the development of confined beef cattle fattening systems, feedlots [9]. These systems have not still implemented methodologies of rational manure management. In

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general, manure accumulated in pens is used to form slopes favoring the drainage in order to avoid a humid environment development that generates a stress animal situation, decreasing its gain weight and increasing its disease susceptibility.

Since intensive confined beef cattle production systems have been emerging in Argentine in the last fifteen years, studies on micronutrients and micropollutants content in their effluents is scarce. Trace elements accumulation in different environmental matrix (soil, sediment, water, biota, etc) could generate a risk to human health due to its potential transference to the food chain [10]. In previous studies in our laboratory the relation between arsenic concentration in cattle drinking water and its concentration in dairy products has been analyzed [11].

The aim of the present work is to determine the content of trace elements (micronutrients and micropollutants) in manure of intensive confined beef cattle production systems in the pampean plains of Argentine and their potential accumulation in soils. These results will contribute to the establishment of argentine management guidelines for the safe and beneficial uses of manure in arable soils, thus potentiating the beneficial effects of its addition to overcome the deficiency of micronutrients in soils and minimizing the detrimental effect of manure-borne metals.

MATERIALS AND METHODS

Eleven confined beef cattle fattening systems (1-11) with different animal stock, age of emplacement and edafoclimatic conditions were selected (Table 1).

En each case, homogeneous and representative samples were taken from pen soils (depth 0-10 cm), blank soil (depth 0-10 cm, free from any agricultural activity) and beef cattle manure. Blank soils were representative samples of each of the seven localities where beef cattle fattening systems were located.

Soil profile samples were obtained using an auger at different depths (0-10 cm, 10-20 cm, 30-40 cm and 50-60 cm). All samples from the same depth were mixed in order to obtain a homogeneous sample (1kg) that was preserved at 4 ° C in a double plastic bag.

In each system, 30 manure subsamples of ca. 0.5 kg were collected by chance with a plain shovel avoiding soil incorporation. Subsamples were mixed and a homogeneous sample (1kg) was preserved at 4°C in a double plastic bag.

They were air dried and sieved to pass 2 mm sieve and analyzed for extractable phosphorus (Bray-Kurtz 1 method), pH (1:2.5 soil water relationship), organic carbon (OC) (Walkley-Black method), electrical conductivity (EC), total nitrogen (TKN) (Microkjeldahl method), Ca, Mg, Na and K (Atomic Absorption Method), Cation Exchange Capacity (CEC) (Steam-Distillation Method) and clay content (Bouyoucous method) as previously described [12,13].

For trace elements analysis, first soil and feces samples were acid digested [14] and trace elements were determined by spectrometry of atomic emission, using an Inductively Coupled Plasma (ICP), model Optima 3100 (Perkin Elmer) [15]. The analyzed trace elements were: As, Ba, Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Pb, V and Zn. Soil and cattle feces.

In all cases, analyses were realized by triplicate with a relative error lower than 1 %.

RESULTS AND DISCUSSION

Beef cattle fattening systems were selected in localities with different agro-ecological regions in the provinces of Buenos Aires and San Luis.

Buenos Aires province is located in the central-east part of Argentina, characterized by humid-sub humid mesothermal climate [16]. Localities of systems 1, 4, 5 and 10 belong to the Rolling Pampas (*Pampa Ondulada*) while localities of systems 2, 3 and 11 are part of the Depressed Pampas (*Pampa Deprimida*) [16]. Slopes from the Rolling Pampas, in general do not reach 2 %, but favored hydric erosion, while slopes from the Depressed Pampas are practically inexistent generating drainage problems [18]. Annual average rainfall is slightly different in both regions, *ca*. 1000-1050 mm in the Rolling Pampas and *ca*. 900-950 mm in the Depressed Pampas (Table 1). Soils from the Rolling Pampas are in general well-drained, with silt loam texture, with a proper organic matter content and high exchange capacity. Soils from the Depressed Pampas are mainly hydro-halomorphic, affected by deficient drainage and water and sodic salts excess during its development and evolution [18].

San Luis province is located in the central-west part of Argentina, characterized by semiarid climate. Systems 6-9 are located in plains of Fraga, a locality of the east part of the province. Annual mean rainfall is *ca*. 500-550 mm, concentrated in spring-summer (september-march).

Results of physico-chemical analysis from blank soils of the selected localities are shown in Table 2.

Table 1: Locations and characteristics of confined beef cattle fattening systems [29]

System[a]	Locality	Lat	Long	Annual rainfall (mm)[b]	N° Pens	Pen Surface (m^2)	Age of Emplacement (years)
1	-Magdalena, BA	35° 16’	57° 46’	1160	10	35100	2.0
2	-Dolores, BA	36° 18’	57° 22’	924	16	72000	2
3	-Dolores, BA	36° 19’	57° 22’	924	12	54900	2.5
4	-Mercedes, BA	34° 42’	59° 28’	1045	12	44300	5
5	-Alsina, BA	33° 55’	59° 24’	1026	8	28000	5
6	-Fraga, SL	33° 22’	65° 53’	527	52	290400	5
7	-Fraga, SL	33° 22’	65° 52’	527	48	275000	5.5
8	-Fraga, SL	33° 23’	65° 52’	527	30	158400	6
9	-Fraga, SL	33° 23’	65° 53’	527	32	218400	6.5
10	-Baradero, BA	33° 50’	59° 27’	1026	60	320000	10
11	-Las Flores, BA	35° 51’	58° 54’	936	40	183600	12

a Systems 1, 2, 3, 4, 5, 10 and 11 are located in Buenos Aires Province (BA) while systems 6, 7, 8, 9 are in San Luis Province (SL).

[b] Average annual rainfall, period 1998-2004 (SAGPyA, 2007).

Table 2: Physico-chemical characterization of blank soils from confined beef cattle fattening systems

Locality	Magdalena	Dolores	Mercedes	Alsina	Fraga	Baradero	La as Flores
Clay (%)	26.8	29	22.5	25	10	25	18
Silt (%)	58.0	34	62.5	55	45	50	49
Sand (%)	15.2	37	15	20	45	25	33
Soil texture	Silt loam	Clay loam	Silt loam	Silt loam	Loam	Silt loam	Loam
pH	6.80	7.7	6.64	6.0	7.45	6.1	6.9
EC (dS/m)	0.79	2.52	0.31	0.51	0.48	0.36	0.67
Ext P (mg/kg)	12.8	14.0	10.5	16.9	4.9	43.2	7.3
OC (%)	2.38	1.86	2.31	1.88	0.76	2.88	2.00
TKN (%)	0.23	0.22	0.25	0.21	0.05	0.25	0.22
Ca (cmol/Kg)	13.9	12.02	14.13	11.50	7.88	11.81	9.50
Mg (cmol/Kg)	2.3	1.81	1.75	1.87	1.5	1.86	1.75
Na (cmol/Kg)	0.5	0.33	0.45	0.46	0.38	0.38	0.41
K (cmol/Kg)	1.0	1.18	1.29	1.30	1.01	1.23	1.15
CEC (cmol/Kg)	16.25	16.00	19.94	17.93	11.37	17.52	16.00

Fraga’s soils show the greatest difference since this locality is placed in the west side of Argentina (San Luis Province) with edaphoclimatic conditions very different from those of Buenos Aires Province, where all the other localities are placed.

The soil from Fraga shows the highest sand content as well as the lowest clay content. The low value observed for CIC in this soil is in accordance with its low clay content and poor organic matter.

Soil and manure from confined beef cattle fattening systems with shortest age of emplacement (systems 1, 2 and 3), were analyzed in order to determine which trace elements could generate an environmental risk (Table 3).

Results described in Table 3 show higher contents of Cu and Zn in soil pens in contrast with those obtained in blank soils of the three systems even when in the three cases the age of emplacement was short (2-2.5 years). Contents of other trace elements analyzed (As, Ba, Be, Cd, Co, Cr, Fe, Mn, Mo, Ni, Pb, Se, V) were lower in pen soils in relation to blank soils. Some of them were under the detection limit technique.

These high contents of Cu and Zn in soils are originated by the presence of these two metals in feces. As has been already reported [4], metals in manure are derived directly from the animal diet and indirectly from ingestion of contaminated soil and during manure collection, with the majority coming from the diet. Samples of manure have been collected in such away to avoid soil contamination, thus animal diet should be the main source of metals in manure. In previous studies, metals associated with soil ingestion by the cattle or by manure being mixed with soil on the barn floor, have been Pb and

Table 3: Trace elements contents in soil and manure from beef cattle fattening systems with shortest emplacement age

Samples	As	Ba	Be	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Se	V	Zn
Manure system 1 (mg/kg)	0.8	28	< 0.01*	< 0.01*	0.8	5.6	37.4	1457	220	0.3	3.2	0.0	0.24	6.6	286.1
Soil Pens system 1 (mg/kg)	11.7	208	1.3	< 0.01*	15.7	27.1	22	36855	859	0.3	33	15.5	1.15	87.6	74.5
Soil Magdalena (mg/kg)	12.1	226	2.1	< 0.01*	17.1	29.9	20.4	39121	1014	0.4	37.3	15.9	1.22	103.9	37.5
Manure system 2 (mg/kg)	0.7	43	0.1	< 0.01*	2.1	10.7	9.2	4026	354	1.1	10.3	1.0	0.25	8.4	77.1
Soil Pens system 2 (mg/kg)	3.2	81	0.3	< 0.01*	5.9	11.1	8.5	12659	753	0.8	5.3	6.1	0.34	21.9	46.3
Manure system 3 (mg/kg)	0.7	41	< 0.01*	< 0.01*	1.1	9.6	13.6	3989	301	0.5	8.9	1.1	0.19	7.8	101.9
Soil Pens system 3 (mg/kg)	4.3	106	0.4	< 0.01*	8.7	12.1	9.6	17128	1120	0.8	9.2	8.8	0.93	29.5	52.2
Soil Dolores (mg/kg)	4.7	116	0.9	< 0.01*	12.6	19.2	7.5	27007	1194	0.9	25.3	13	0.95	43.1	33.2

*Technique detection limit

Table 4: Cu and Zn contents in soil and manure from beef cattle fattening systems

Feedlot	1	2	3	4	5	6	7	8	9	10	11
Pen's age (years)	2	2	2.5	5	5	5	6	5.5	6.5	10	12
Cu (mg/kg)											
Manure	37.4	9.2	13.6	39.1	16.3	59.6	46.4	33.2	30.9	36.7	9.6
Pen soil 0-10 cm	22	8.5	9.6	24.1	31.5	19.1	24.2	20.6	25.3	34.8	29.9
Pen soil 10-20 cm	19.9	6	7.1	23.4	23.9	16.3	18.3	13.1	11.4	22.7	23.8
Pen soil 30-40 cm	17.4	5.9	6	17	19.8	13.8	13.7	11.6	10.3	18	10.4
Pen soil 50-60 cm	19.3	5.7	3.8	21.1	23.2	12.5	13.6	11.2	10.6	20.2	16.8
Blank soil 0-10 cm	20.4	7.5	7.5	15.1	19.4	12.8	12.8	10.6	10.6	19.9	10.8
) (P -B)	1.6	1	2.1	9	12.1	6.3	11.4	10	14.7	14.9	19.1
Collector Sediment	-	25.1	25.1	-	27.5	-	17.2	-	39.6	-	8.7
Zn (mg/kg)											
Manure	286.1	77.1	101.9	405.7	99.4	194	180	134	141	291.7	62.1
Pen soil 0-10 cm	74.5	46.3	52.2	112.7	105.1	75.1	109.5	92.7	106	191.2	153.7
Pen soil 10-20 cm	58.1	31.1	34.2	103.5	93.8	60.9	70.8	55.4	42.6	78.5	115
Pen soil 30-40 cm	48.8	27.8	24.4	58.3	53.5	48.7	45.2	42.3	39.4	50.6	35.3
Pen soil 50-60 cm	54.7	24.7	19	70.7	64.8	41.1	44.7	42.9	41.5	57.7	39.5
Blank soil 0-10 cm	37.5	33.2	33.2	47.1	54.2	46.1	46.1	39.5	39.5	58	31.4
) (P -B)	37	13.1	19	65.6	50.9	29	63.4	53.2	66.5	133.2	122.3
Collector Sediment	-	123.2	132.2	-	92.8	-	73	-	139	-	42.4

Cd [19] Soil ingestion has also been identified as an important source of Cd ingestion by grazing sheep and cattle in New Zealand and Australia [20,21]. In the samples analysed, the content of these metals was very low, therefore, presence of trace elements in manure can be attributed only to the animal diet.

In the analyzed systems, Cu and Zn, together with Mn and Fe were the more abundant in manure, but for the latter ones soil concentration was under the concentration of the blank soil. Therefore, manure and soil profiles were analysed for Cu and Zn content in the eleven systems (1-11). Data are shown in Table 4.

Zinc contents found in manure from the confined beef cattle fattening systems under study range from 62.1 to 405.7 mg/kg, with an average of 179.4 mg/kg, standard deviation: 107.5 mg/kg and are similar to those previously reported (from 30 to 580 mg/kg) [22,23,24,7].

Cu concentrations determined in samples of manure from the studied confined beef cattle systems ranged from 9.2 to 59.6 mg/kg with an average of 30.2 mg/kg, standard deviation: 16.3 mg/kg (Table 4) expressed in dry matter. These results are similar to those found in the literature (between 16 and 62 mg/kg) [24,22,23,7].

The trace elements content of beef cattle manures is largely related to their concentrations in the feeds consumed by livestock [25,7]. The main source of trace elements is the mineral core that contains determined concentrations of each element. The percentage of mineral core added to the feed conditions the trace element content in manure. Since the mineral core used in the systems of Buenos Aires is different to that used in San Luis, Zn content in manure was plotted against Cu content. As shown in the Figure 1, the relation between Cu and Zn manure contents in systems located in Buenos

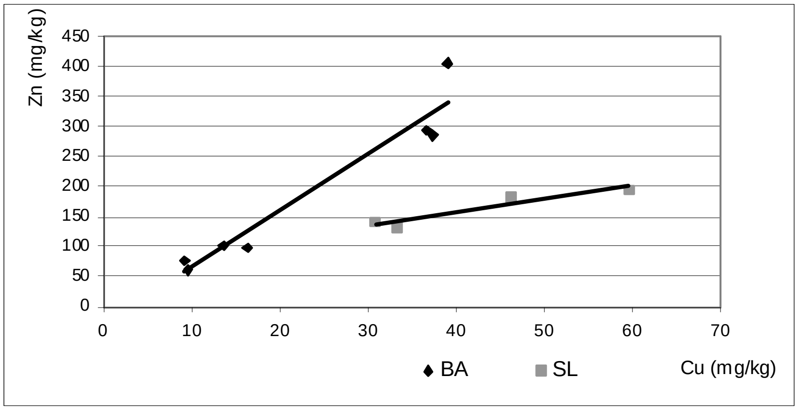

Fig. 1: Relation between Cu and Zn manure contents in systems located in Buenos Aires and San Luis provinces

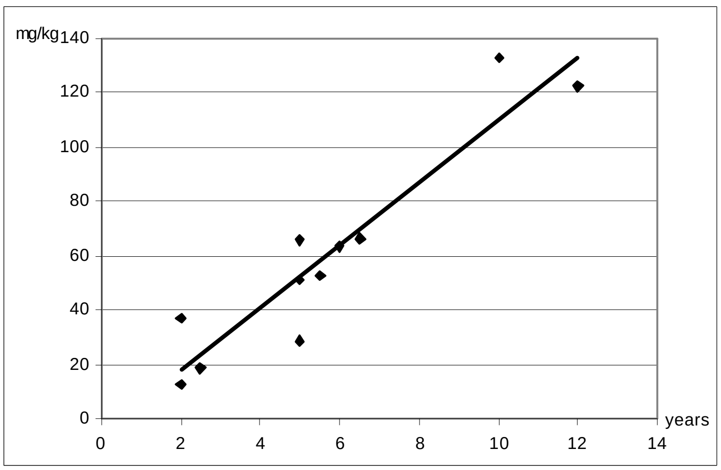

Fig. 2a: Relation between Cu) (P-B) in mg/kg and age of emplacement (years) in beef cattle fattening systems.

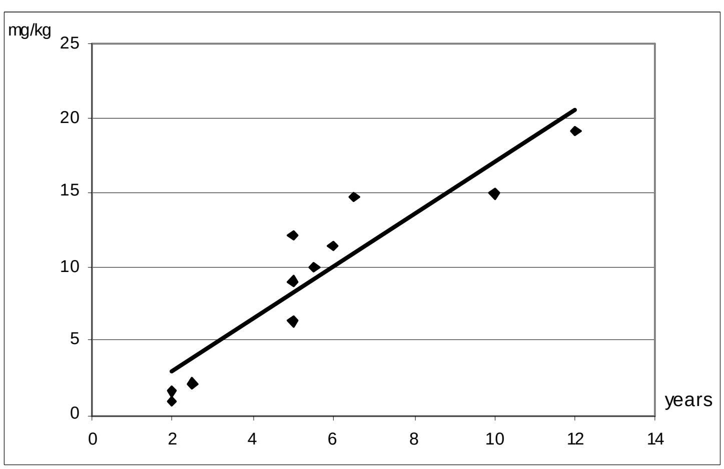

Fig. 2b: Relation between Zn) (P-B), in mg/kg and time of emplacement (years) in beef cattle fattening systems

Aires province, BA (R^2=0.9332) is different from that found in systems from San Luis province, SL (R^2=0.9245). This result should reinforce the hypothesis that the mineral core is responsible for the mineral content in manure.

Soils receiving repeated applications of livestock manure for many years have been shown to contain high concentration of trace elements, particularly near the soil surface [26]. On the other hand, land application of farm effluents with high contents of Cu and Zn is likely to result in the accumulation of these metals in soils [27].

Soil profile of pens from confined beef cattle systems were analysed for their content of Zn and Cu (Table 4). In the profiles of pen soils, in all cases, a decrease in Cu and Zn concentration with depth was observed, as may be expected because of the interaction of metals with organic matter and clays. Since major contents were observed for the older pens, a relation was established. The difference of Cu and Zn content was calculated between blank soils and surface samples from pen soils,) (P-B), in each system (Table 4). A lineal relation was observed between the) (P-B) and the age of emplacement of the beef cattle fattening systems for both elements (Zn: R^2=0.877 and Cu: R^2=0.8549) (Figure 2, a and b). The above result is a clear indication that the presence of Zn and Cu in soil is due to the manure content of these two metals.

Sediments collected from drainage canalizations from pen soils of beef cattle fattening systems contained high levels of Cu and Zn (Table 4), being their concentrations higher in some cases than those determined in manure and/or soil. This is not the case for systems 7, 8 and 9, which are located in a semiarid area. This result indicates clearly an important transport of these elements by runoff. Surface runoff losses of trace elements have often been associated with transport of particulates that contain adsorbed trace elements and organic-metal complexes [1].

According to regulations from the Argentine Hazardous Residues Law [28], the concentration of Cu determined in soil and sediments is in both cases under the maximum guideline level in agricultural soils (150 mg/kg) and residential soils (100 mg/kg). Levels of Zn in soil and sediments were also under the maximum guideline level recommended in the Law 24051 (600 mg/kg for agricultural soils and 500 mg/kg for residential soils).

Although until now, manure from these systems may be used as amendment for agricultural soils, two facts must be taken into considerations: a) that concentration of Cu and Zn in soils is directly proportional to the age of emplacement of the establishment and b) that metal absorption from manure by-products is largely controlled by organic matter and metals bioavailability is expected to persist for longer times.

CONCLUSIONS

These are the first studies in our country that analyse the presence of trace metals in manure, soils and sediments from the drainage canalysations, in intensive confined beef cattle production systems. Metal-enriched feces have resulted in elevated concentrations of metals in soils, mainly Cu and Zn, which become subject to adsorption, complexation, reduction, leaching and surface runoff. Concentration decrease with depth for all the pen soils analysed due to adsorption. Run-off is associated directly with climatic conditions.

Metal accumulation appears to be directly proportional to the age of emplacement of the establishment and indicate the necessity of best management practices for these bovine intensive productive systems in our country.

The concentrations of metals in manure by-products depend primarily on their concentrations in the diet, since a major portion of the metals ingested is excreted in feces and urine.

These studies indicate a potential for manure-treated soils to serve as a non-point (i.e., diffused) source of metal pollution through leaching and runoff.

Sewage sludge has received much attention with respect to metals enrichment of soils but there are some factors such as inappropriate setting of phytotoxicity thresholds, inconsistent results due to varying edaphic and environmental factors and limited information on metals toxicity resulting from direct intake of contaminated sludge and pasture herbage by grazing animals that remain debatable about guidelines for regulations of sewage sludge and other organic amendments application.

Greater emphasis is given for N and P in the best management practices (BMP) protocols developed for land application of manure by-products. With increasing use of metals as feed additives, manure by-products are getting ever enriched with some of these metals.

Research is needed to quantify the dietary requirement of trace elements as a nutrient and feed additive. This will enable the industry to develop precise dietary formulation and conversion, thereby reducing the concentration of many metals in animal manure. Future research should also focus on the long-term implications of manure application on metals dynamics in the soil-plant system, including plant bioaccumulation and losses through leaching and surface runoff.

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