Chapter

Selenium Fertilization in Tropical Pastures

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Abstract

Brazil is one of the largest meat producers. Meat along with other animal products have been responsible for its larger contribution as source of selenium (Se) for human. However, Se deficiency remains a concern because researches have indicated that this nutrient is found in low levels in Brazilian diet. Cattle in Brazil are fed basically from pasture, but there are strong evidences that soils contain low availability of Se; consequently plants and animals incorporate low Se levels. Pastures, Se fertilized, bring benefits to nutrition and health of animal consequently to humans already known in some countries. In contrast, Se fertilization on tropical weathered soils and tropical forages is little known. However, Se management as fertilizer in tropical environments requires researches involving field experiments, especially with animals, for establishing of safe and effective Se recommendations as fertilizer due to the Se toxicity potential and complexity in system of soil-plant-animal-human.

Keywords: agronomic biofortification, grazing animal nutrition, selenium fertilization, tropical forages, weathered soils

1. Introduction

Selenium (Se) benefits for health in human and animal have provided popularity for this chemical element. Selenium is a nutrient for animals since 1957 [1]; thus, it must be part of their diet. However, there are large agricultural areas containing low levels of Se in soil or it is present, but as chemical forms unavailable for plants, consequently these areas are producing vegetables or animal products with low Se contents.

In Brazil, there are some researches indicating that large agricultural areas are located in soils with low Se levels, that is, daily diet Se intake evaluated in people groups from São Paulo, Brazil, presented values below to estimated average requirement values, which shows deficiency of Se in the diets from this region [2]. A research at Rio Grande do Sul, Brazil, also resulted in marginal deficiency of Se in cattle [3]. Both data indicated the possibility of Brazilian soils contain low available Se levels.

The agronomic biofortification of food through field fertilization with Se could be a solution to provide this micronutrient for animals and humans through plants. Plants are able to absorb and incorporate Se to organic compounds as seleno-amino acids. Thus, inorganic Se is converted to organic Se compounds through the plants which can be easily absorbed by the human body and to be available where needed in the body [4]. In some countries, Se fertilization is well established, and it is annually done in New Zealand in which Se along with phosphorus fertilization is applied in pastures [5].

Selenium essentiality for plants is not convinced, but its availability for plants, as well as for the animals, could improve their performance and consequently the human health. For both animals and plants, this element acts as defense through its influence in glutathione peroxidase controlling oxygen reactive species from stress situations [6].

Large knowledge about specific rates, sources, Se dynamic in soils and plants, and even behavior of animal intake in pasture is required for a safe Se fertilization, to ensure food and environmental security. High Se levels available in soils can cause toxicity for plants and animals. Thus, for the beneficial of Se application as fertilizer commonly are required low rates, which raises concerns about risks of super dosages, what can be aggravated by complex dynamic of Se in soil and plants.

2. Selenium fertilization in tropical weathered soils

Se availability in soil is the first requirement for Se application as fertilizer. Most soils contain low Se levels, including in tropical environments, while the highest contents are found at arid areas characterized by the presence of accumulator plants [7].

Low Se levels were observed in the main eight soil types of Brazil (**Table 1**). These soils were collected at São Paulo state as well as in plant of *Urochloa decumbens* grown in them.

The contents up to 500 μg dm^{-3} characterized low Se soils [8], and confirming the relation between soil and plants, the samples of *Urochloa decumbens* comprised contents of 10.4–79.7 μg kg^{-1} Se in dry matter (unpublished data).

Besides the Se presence in soil, its availability for plants depends on oxidation state. Selenium is chemically similar to sulfur, but it occurs naturally in four oxidation states, −2 (selenide), 0 (elemental Se), +4 (selenite), and +6 (selenate) [9]; however, sodium selenate is the source recommended for Se fertilizations due its

Soils	Localization	Depth	pH	O.M.	P	S	K	Ca	Mg	H+Al	Al	CTC	SB	V	m	B	Cu	Fe	Mn	Zn	Se
		(cm)	$CaCl_2$	g.dm^{-3}	mg.dm^{-3}		mmolc.dm^{-3}							%		mg.dm^{-3}					(µg.kg^{-1})
Arenic Hapludult	22º38,366'S	0-20	4,4	14	4	6	1,1	6	3	30	3	40	10	25	21	0,15	1,3	73	2,1	0,7	67,9
	47º49,852'W	20-40	4,5	15	3	8	0,4	7	3	24	1	34	10	30	12	0,13	1,1	60	2,9	0,3	84,6
Typic Fluvaquent	22º42,407'S	0-20	5,5	27	5	12	5,2	41	6	27	-	79	52	66	-	0,19	7,5	28	28,5	1,9	220,2
	47º37,438'W	20-40	5,2	21	4	13	3,5	24	5	29	1	62	33	53	4	0,16	6,2	15	21,1	0,9	219,4
Acroxic Dystrochept	22°38,404'S	0-20	5,5	31	7	17	1,7	58	8	35	-	103	68	66	-	0,24	1,9	75	50	3,5	108
	47°49,024'W	20-40	5,3	24	5	12	1,2	55	9	35	-	100	65	65	-	0,16	1,7	53	49,5	2,1	138,4
Typic Haplodoll	22º04,961'S	0-20	4,7	18	3	8	0,5	8	4	31	1	43	12	29	7	0,08	1,3	43	0,9	0,5	159,6
	47º34,736'W	20-40	4,4	19	3	7	0,3	4	3	41	4	48	7	15	36	0,16	1,4	51	0,6	0,9	142,1
Acroxic Dystrochept	22º 15,054'S	0-20	4	65	6	6	0,4	3	2	240	5	245	5	2	49	0,36	1,9	76	0,6	0,7	80,3
	47º52,044'W	20-40	3,9	32	4	6	0,3	5	3	105	1	113	8	7	12	0,21	2,1	34	0,2	0,3	72,9
Typic Quartzipsamment	21º56,630'S	0-20	5,5	24	4	8	1,1	39	6	23	-	69	46	67	-	0,16	1,8	39	2,9	3,4	77,6
	47º28,506'W	20-40	5,4	20	3	10	1,0	29	5	20	-	55	35	64	-	0,13	1,6	22	1,1	0,6	101,7
Typic Haplodux	21º 57,768'S	0-20	5,3	28	33	9	1,2	40	8	29	1	78	49	63	2	0,16	8,3	40	7,1	5,7	197,1
	47º26,866'W	20-40	5,3	21	9	8	0,9	21	4	27	1	53	26	49	4	0,10	6,3	22	6	1,8	158,8
Rhodic Haplodux	21º 35,278'S	0-20	4,2	12	2	5	2,6	7	4	128	1	142	14	10	7	0,10	0,8	11	2,6	0,2	97,8
	48º26,054'W	20-40	4,2	12	2	5	2,3	6	3	151	2	162	11	7	17	0,07	0,6	10	1,3	0,1	80,5

Table 1.
Chemical parameters of fertility in tropical soils and selenium levels in sampled soils at São Paulo state, Brazil.

high solubility. Unlike selenate, the mechanism of selenite uptake by plants remains unclear [10].

In weathered soils, there are low nutrient levels; high contents of Fe, Al, and Mn; and high acidity, according to soils analyzed (**Table 1**). Thus, it is necessary to know the Se dynamic in these soils. A profile of weathered soils analyzed from São Paulo observed low Se levels in soils with higher sand contents (**Figure 1**) that could indicate leaching potential.

A study of Se adsorption and desorption in soils from Cerrado, Brazil, verified low values of distribution coefficient in soils; thus, Se tended to be more in solution than in the solid phase, and in the most weathered soils, with higher clay and Al and Fe oxide contents, there are the highest affinity for Se, while in sandy and loamy soils, Se tends to be less adsorbed and can therefore be taken up by plants or easily leached, damaging the ecosystem [11].

The low natural levels of Se in soils and its absence in fertilization to crops explain the low contents in food from vegetables [12] and consequently in Brazilian diet, except for northern areas [2]. Although, in a study of hemodialysis patients from north and southeast of Brazil, both patient groups presented low Se plasma levels when compared to recommended values; independently of the region, all patients presented Se deficiency [13].

This information is an alert for necessity to Se fertilization in Brazil. It was incentivized in the 1980s, but its requirement was unsuccessful, while in some countries, it is well stablished already. Applications of Se in areas of low Se bioavailability have been an option with good results to supply this element to plants and, consequently to animals, improving animal performance and nutritional quality of food produced as milk and meat [11], even in environments with no deficiency symptoms [14].

However, toxic potential of selenium requires caution as fertilizer due its complex dynamic nature in soil and plants. Selenium as selenate (SeO_4^{2-}) is commonly found in alkaline and oxygen soils under high redox conditions (pe + pH > 15), and this oxidation state is predominantly absorbed by plants, while under low and milder redox conditions, species as selenite and selenide predominate [9].

Selenium fertilization must be controlled through safe doses and soil monitoring due to the possibilities of the Se dynamics in soils. Selenate can be easily absorbed by plants; thus, the doses for fertilizations must be carefully calculated, but also it could be leached with possibilities of water contamination.

Low selenate doses required for fertilization is a challenge due to concern for homogeneous application. According to the Selenium-Tellurium Development

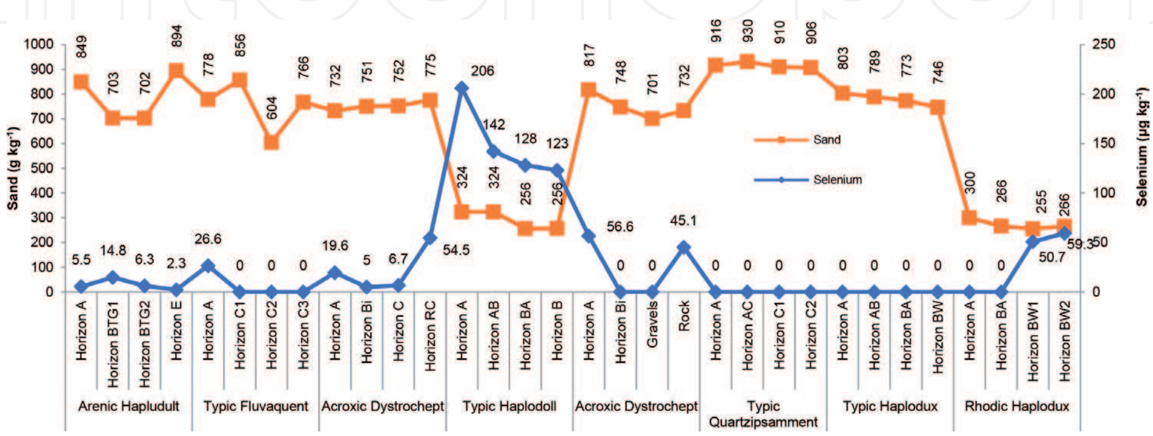

Figure 1.
Selenium levels in tropical soil profiles and, respectively, sand contents in sampled soils at São Paulo state, Brazil (unpublished data).

Association, the best way for Se application is along with other nutrients [15]. There are positive effects in Se application along with phosphorus fertilization [13].

Some technologies involving Se application along with macronutrients as coating became a technique to easy and high quality of application. Urea coated with a mix of boric acid (0.4% B), copper sulfate (0.14% Cu), and sodium selenate applied to *Urochloa brizantha* carried out in pots with weathered tropical soil resulted to desirable enrichment of plant with rate of 34.5 g ha^{-1} Se [16].

Seed pelletization seems to be a promissory tool to increase Se content in plants. Beneficial effects were observed in the evaluation of seed pelletization with increasing selenite doses on three ryegrass cultivars; however, the authors recommended it to be evaluated under field conditions in Se-deficient soils [17].

Another technology is the slow release of Se fertilizer as Selcote Ultra; however, its application in rates of up 20 g ha^{-1} Se on an Ultisol soil of Puerto Rico did not increase in the foliage Se concentrations of Guinea grass pastures [18]. According to the authors, the soil and plant interrelationships may be affecting the foliage of Se absorption potential requiring that the effects need future consideration in terms of Se movement in tropical soils.

The establishment of effective and safe rates in tropical environmental still is required and unknown, regardless of the technical method applied to plant enrichment on Se. High Se availability in agriculture soils can cause toxicity to crops, but it is still more concerning if a crop shows accumulator character, i.e., if a crop has capacity to absorb high levels of selenium with no symptoms of toxicity; this could increase the possibilities to cause toxicity for animals or human.

Forage plants are classified as passive accumulators due its ability to contain 10–30 mg kg^{-1} of Se in dry matter; however, high-quantity animal intake of Se through dry matter intake could induce intoxication [19]. Although the research with *Urochloa brizantha* grown in a weathered tropical soil containing 1.8–4.6 mg dm^{-3} Se resulted in high levels of Se uptake affecting biomass production, regardless of the soil type, plants showed high levels of Se in leaves [20].

Depending of the soil, excess of Se can be in unavailable forms to plant uptake over time. Soil influence in dynamic and availability of Se was observed by isolation of Selenium rates applied followed by comparing among soils, Arenic Hapludult, Rhodic Hapludox and Typic Hapludoll, which verified differents Selenium content remaining in soil, respectively, 22, 11, and 37 μg dm^{-3} and 55, 4, and 38 μg dm^{-3} after *Urochloa brizantha* and *Stylosanthes capitata* cultivated, respectively (unpublished data).

Besides the uptake ability among plants, the difference among soils was evident. This element in soil can be fixed along with iron, complexed in organic matter, or it can be in many oxidation states depending on the pH, oxygen, and microbial activity [7]. These data confirmed different soil capacities to Se adsorption, but it can turn available for plants in pH changes, as frequently occurs with limestone application, a common practice from tropical agriculture areas.

High contents of selenate in soil, for natural or anthropogenic action, can be establish or reestablish for agricultural or livestock, avoiding the poisoning risk of plants, animals, and humans [20]; in these cases, the areas must be isolated for remediation. The use of plants to clean up contaminated soils is a technique known as phytoremediation that offers a less expensive alternative to stripping pollutants directly from the soil [21].

The management of high Se soil also can include sulfur source application. The similarity between Se and S indicates the competition for sulfate transporters of the root plasma membrane [7]. Sulfur application at 600 kg ha^{-1} as soluble sources such as ammonium sulfate and ferric sulfate reduced damages in productivity and Se uptake by Urochloa grass, while the lower solubility of calcium sulfate resulted in lower effectiveness in reducing Se uptake [20]. Plants used for phytoremediation can be used for mixture in diets of animals or used as composting to application in low Se areas.

3. Selenium fertilization for tropical grazing

The geochemistry of livestock-producing areas should be well understood to mitigate selenium-related disorders in animals [22]. In China, there are areas with selenosis occurrences; in contrast about 70% of China shows Selenium deficiency, as well as there are about 76% countries located in Se-deficient regions where the Se daily intake level is less than recommended [23].

Brazil is a country who owns the largest livestock in pastures; however, the majority of pastures are in marginal areas, under soils of low fertility. Brazil is one of the largest meat producers. In Brazilian food, the highest Se concentrations have been found to animal origin products, while vegetable food showed lower values [12]; however, some studies showed selenium deficiencies also in cattle, except in north areas [24, 25].

Cattle deficiencies have a likely relation between low Se in forage grass or supplements [26]. Thus, Se deficiency keeps as a concern, since this nutrient has been found in low levels in Brazilian diet.

Selenium fertilization could be a solution, but it is not realized in Brazil. Fertilizers containing selenium could support diet supplementation of grazing animals or animals feed with conserved forages (hay and silage), mainly considering Brazilian pasture areas with more than 160 million of hectares [27].

Selenium fertilization in pastures could increase its presence in animal and human diet besides its benefits to animal productivity. Feeding weaned beef calves for 7 weeks with alfalfa hay containing up to 3.26 mg kg^{-1} Se in dry matter harvested in fertilized fields with Se resulted to increasing whole-blood Se concentrations and body weights depending upon the Se application rate [28].

Grazing Se fertilizer has been shown to be more effective and safe treatment than animal dosing [13]. Selenium intake by ruminants in organic form, especially as selenoamino acids, needs to be release from proteins until through inorganic forms to be metabolized while Se in milk is from organic Se supply or converted by ruminal microorganisms [29].

Experiment with tropical grass has been shown large differences between Se contents in leaves and stem + sheath. *Urochloa brizantha* had desirable increased Se in leaves (0.4 mg kg^{-1} Se in DM) even in smaller evaluated dose of 10 g ha^{-1} Se up to 30 days, while the proportion of stem + sheath (0.1 mg kg^{-1} Se in DM) however for safe and required concentration in dry matter for cattle along with prolonged effect of two cuts, the authors recommended Se fertilization of 34.5 g ha^{-1} [16].

The fast answer of Se fertilization in tropical pastures can be positive to allow the low and safe doses of Se application along with nitrogen rates during rainy season, including for intercropped pastures with legumes. The concerning of intercropped pastures is explained by legume higher ability to produce protein, which can be apparently favorable to Se absorption.

Thus, this fact probably will require lower Se doses for fertilization in intercropped pastures, including caution with palatability and proportion of legumes in pastures. For example, in three different weathered soils carried out in pots, fertilization of 20 g ha^{-1} Se showed desirable concentrations to legume *Stylosanthes capitata* (136 μg kg^{-1} Se in DM), while it was insufficient to grass *Urochloa brizantha* (49.1 μg kg^{-1} Se in DM); however, it showed negative influence in content of crude protein from legume, probably by influence in nitrogen biological fixation (unpublished data).

High Se contents in leaves from tropical grass and in legumes comprise another fact to be analyzed for Se fertilization rate establishment although with few data. Usually, grass leaves and legumes are preference fractions for cattle according to its intake selective behavior, mainly in tropical pastures due to high accumulation of stem portions and its low digestibility. Selenium is one of few elements absorbed by plants in enough quantities which enable to intoxicate domestic animals [30].

Evaluating in vitro degradability of two cuts of *Urochloa brizantha* produced using fertilization rates of 0, 10, 20, 40, and 80, and 160 g ha^{-1} Se verified effects on gas production by truly degraded organic matter, amounts of acetic by propionic acids, some short-chain fatty acids and ammonia amounts [31]. The authors suggested that high levels of Se in forage can affect negatively ruminal microorganism activities but indicates positive effects of Se fertilization in 20 and 80 g ha^{-1} on chemical composition, in vitro degradability, short-chain fatty acids, and gas production.

In superior plants dual effects can be exerted by Se; at low concentrations it acted as an antioxidant, inhibiting lipid peroxidation, whereas at higher concentrations, it was a prooxidant [6]. Applied doses of selenate above 71 g ha^{-1} Se exceed maximum recommendation of 5 mg kg^{-1} Se in dry matter of the leaves of *Urochloa brizantha* to avoid toxicity problems in cattle [32] however with no damages in dry matter production [16]. Thus, even the plant is aparently normal, is necessary attempt that the recommendation for nutritional requirements of animals are values between 0.1 to 0.3 mg kg^{-1} in the dry matter required by cattle [20].

The effect of high Se diet concentration (60–70 μg kg BW^{-1} d^{-1}) provided from wheat to steers indicated the negative effects of Se level used in this study on productive performance of feedlot which were not expected [25]. Low forage digestibility can contribute to low Se effects in animals, mainly in tropical forages, while high Se content in forage can reduce its digestibility. Undegraded residues from in vitro incubation contained 25–66% of Se from *Urochloa brizantha* Se enriched [31].

4. Final considerations

Selenium fertilization in tropical low Se soils, as Brazil agricultural areas, is an emergent necessity for animal and human health, also could be beneficial for plants. Thus, Se fertilization in pastures is an alternative to collaborate for animal supplementation and human nutritional demands.

Generally, Se quantities required as fertilizer are low, and there are already available technologies to application but is an extremely necessary soil monitoring.

Nevertheless, more researches in tropical environments is required to establishment of Se rates, plants, and animal answers and reduces or even neutralizes toxicity risks, even though the benefits already are known.

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