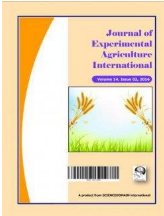

Journal of Experimental Agriculture International

27(4): 1-10, 2018; Article no.JEAI.44592
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Influence of Base Saturation on Growth and Yield Parameters of Alfalfa Cultivated in Soil of Brazilian Cerrado

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Authors' contributions

This work was carried out in collaboration between all authors. Author EMBS designed the study, wrote the protocol and scientific writing. The authors CTRS and THFMC were responsible for conducting the experiment, statistical analysis and scientific writing. The author WF corrected and improved the writing of the manuscript. The author APABD performed the translation of the manuscript and corrected the writing. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2018/44592
Editor(s):
(1) Dr. Aleksander Lisowski, Professor, Department Agricultural and Forestry Engineering, Warsaw University of Life Sciences, Poland.
Reviewers:
(1) Yahia Nourredine, University of Oran, Algeria.
(2) Peter Hric, Slovak University of Agriculture, Slovak Republic.
(3) Habu Saleh Hamisu, National Horticultural Research Institute, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/27044

Original Research Article

Received 17 August 2018
Accepted 31 October 2018
Published 05 November 2018

ABSTRACT

Alfalfa, considered one of the most important forage worldwide, requires a base saturation in the soil of approximately 80%, and this is a factor that can limit the expansion of cultivation of this crop in tropical soils that are predominantly acidic. The objective of this study was to evaluate the influence of base saturation levels on the development of alfalfa in soil of the Brazilian Cerrado. The experiment was conducted in the greenhouse, whose experimental units consisted of plastic pots with a capacity of 2 dm^3. The experimental design was a completely randomized design with six treatments and five repetitions. The treatments consisted of six levels of base saturation (10,

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30, 50, 70, 90 and 110%). The cultivar used was *Medicago sativa* L. cv. Creole. The evaluated variables were chlorophyll index, number of leaves, number of tillers, stem diameter, plant height, dry shoot mass, root dry mass and root volume. Increases in leaf number, stem diameter, shoot height, dry mass and root volume of alfalfa were observed due to the increase of base saturation in the soil. The base saturation from 80% was the one that provides better development and greater alfalfa production in Cerrado.

Keywords: Medicago sativa L.; protected cultivation; liming; oxisol; soil correction.

1. INTRODUCTION

Brazil has great potential for dairy farming and cutting. However, keep animals grazing all year round is a challenge for researchers and cattle ranchers, especially in a country with continental dimensions such as Brazil, in the face of the demand for preservation of natural resources and at the same time food security. There is still much what to advance in research on fodder production [1].

Therefore, it is fundamental to research the forage adaptability in new regions, aiming to subsidies new decision making and agricultural policies. Research has been conducted out aiming at the optimization of natural resources and inputs for the production and improvement of forage in several regions of the planet [2,3].

The state of Mato Grosso in Brazil is a highlight in the agricultural production and cattle ranching, being the leader of the cattle of the Brazilian herd, with more than 30 million head [4]. However, due to intrinsic characteristics of the region, the seasonality of forage production is one of the main problems of the traditional cattle raising to keep the animals grazing throughout the year. In general, the soils that characterize the Cerrado biome have low natural fertility, low base saturation, high acidity and aluminum toxicity [5], which compromises the crop growth without proper soil acidity correction and fertilization.

In this context, alfalfa (*Medicago sativa* L.), high added value forage, may be an option for the Brazilian Central-West cattle system, both for direct grazing and to produce hay, silage, to be used for feeding horses. Research has demonstrated the potential of alfalfa use in the supplementation of lactating cows, without short-term and long-term losses in substitution of maize silage [6].

Regarding soil fertility, the positions regarding alfalfa cultivation are controversial. Studies indicate soil preparation with base saturation above the recommended values for alfalfa (80%) [7], due to the high requirement of culture, on the other hand, research indicates that these values may be overestimated [8].

Research conducted in two regions of Turkey showed that crude protein and mineral content in alfalfa interacts with local and cultivars [9]. Although it exhibits good adaptability to environmental conditions, the forage is of high soil fertility requirement, with low tolerance to aluminum toxicity [10]. Considering the low natural fertility of the soils of the Brazilian Cerrado, it is necessary to study the adaptability of alfalfa to the edaphoclimatic conditions of the region, to become a cultivation option.

In this context, the objective was to evaluate the development and production of alfalfa submitted to base saturation levels in Oxisol of the Brazilian Cerrado.

2. MATERIALS AND METHODS

Alfalfa was cultivated in a greenhouse, located geographically at 16° 28' South Latitude, 50° 34' West Longitude and 284 meters altitude, at the Institute of Agrarian and Technological Sciences, Federal University of Mato Grosso, Campus Rondonópolis, from November 2017 to February 2018 (Fig. 1). The mean temperature and humidity of the air during the experiment were 27°C and 81%, respectively.

The soil used was classified as dystrophic Oxisol [11], collected in an area under Cerrado vegetation (layer 0-0.2 m), passed through a 4 mm sieve, prior to the application of treatments. The soil chemical and granulometric analyzes (Table 1) were performed according to [12].

The experimental design was a completely randomized with six levels of base saturation (10, 30, 50, 70, 90 and 110%) and five repetitions. It was used the dolomitic limestone (CaO 31%, MgO 21%) and Total Neutralizing Power (TNP) of 86%, in the base saturation levels of 30, 50, 70, 90, and 110%, respectively. After liming, the soil remained incubated for 30 days and after that period, conditioned in the experimental units, which were composed of plastic pots with a capacity of 2 dm^3.

The basic fertilization was 150 mg dm^{-3} of potassium (K_2O) using as a source the potassium chloride, divided twice, 60% at sowing and 40% after the first cut; 800 mg dm^{-3} of phosphorus (P_2O_5) in the form of simple superphosphate and micronutrients at the dose of 15 mg dm^{-3} of FTE (Fritted trace elements), containing 9% - Zn, 1.8% - B, 0.8% - Cu, 2% - Mn, 3.5% - Fe and 0.1 % - Mo), both added at the time of sowing.

The irrigation management was performed by the gravimetric method, according to [13]. At the time of irrigation, the pots were weighty, and the water required for elevation to 80% of the field capacity was added [14].

Seeding was performed using 50 seeds per pot of Creole cultivar at 1 cm depth, which emerged three days after sowing. Two thinning were then carried out at 10 and 15 days after emergence, maintaining 10 and 5 plants per pot, respectively (Fig. 2) This 5 plants per pot was used in evaluations subsequent.

At the time of sowing, soil samples were collected from each treatment, sieved (2 mm) and dried to determine pH in the laboratory.

The first measurement was performed 45 days after the emergency, followed by the others that occurred at 15-day intervals. The cuttings were performed when 50% of the plants reached the flowering stage, which occurred approximately in the interval of 30 days, totaling three cuts (Fig. 3).

At each evaluation, the chlorophyll index (SPAD reading); number of leaves; stem diameter; number of tillers; plant height and dry mass of the shoot part were analyzed. In the third and last cut of the plants the roots were collected, which were sifted (4 mm sieve) and washed to determine root volume and dry mass. For dry mass (shoot and roots parts), the material was dried in a forced air circulation oven at 65°C until the constant mass was reached, measured in semi-analytical balance of the 0.02 g of resolution.

The results were submitted to analysis of variance and when significant to regression test, both to $p < 0.05$ probability of error by means of the statistical program SISVAR [15].

Fig. 1. View of experimental units cultivated with alfalfa (*Medicago sativa* L.) in Oxisol as a function of base saturation levels (V%)

Fig. 2. Sowing of alfalfa (*Medicago sativa* L.) on experimental units filled with Oxisol as a function of base saturation levels (V%) in the Cerrado region

Table 1. Chemical and granulometric characteristics of the dystrophic Oxisol

pH CaCl2	P	K	S	Ca	Mg	Al	H+Al	CEC	O.M.	V	m
	--mg dm^{-3}--			-------------cmol$_c$ dm^{-3}-------------					g kg^{-1}	---%---	
4.0	1.1	43	8	0.5	0.3	1.2	7.4	8.3	28.9	11	56.9
Zn	**Mn**		**Cu**	**Fe**		**B**	**Clay**	**Silt**		**Sand**	
--------------------mg dm^{-3}--------------------							-------------g kg^{-1}-------------				
0.3	7.4		1.2	152		0.20	475	100		425	

P = Phosphorus; K = Potassium; S = Sulfur; Ca = Calcium; Mg = Magnesium; Al = Aluminum; CEC = Cation exchange capacity; O.M. = Organic matter; V = Base saturation; m = Aluminum saturation; Zn = Zinc; Mn = Manganese; Cu = Copper; Fe = Iron; B = Boron

Fig. 3. Measurement of plant height (left) and stem diameter (right) of alfalfa

3. RESULTS AND DISCUSSION

Base saturation levels influenced the development and production of alfalfa from the first to sixth evaluations. There was no statistical difference ($p < 0.05$) only for the number of tillers and chlorophyll index.

The number of leaves at 45 days after emergence was adjusted to the quadratic regression model, with a greater number 11.32 at a saturation of 73.6%. An increase of 51.3% was obtained in the comparison of saturation 73.6%, with the control treatment (Fig. 4A). At 103 days after emergence, the linear regression model described the alfalfa response to basal saturation levels, with a 41.4% increase between the highest saturation (110%) and control treatment (Fig. 4B).

The lowest number of leaves observed at 103 days after emergence was due to the short time between this evaluation and the previous cut (performed 15 days before), this interval was not enough for leaf production like that observed in the other assessments.

The stem diameters were significant at 45, 87 and 103 days after emergence. At 45 days, it was significant to the quadratic regression model, with the largest diameter being 1.33 mm at base saturation of 68.3%, representing an increase of 21% in relation to the control treatment (Fig. 5A).

At 87 days after emergence, the diameter of the stem was adjusted to the linear regression model, with a 21.7% increase between the highest base saturation compared to the control treatment (Fig. 5B). At 103 days after emergence, there was an adjustment to the quadratic regression model, with a larger diameter of 1.54 mm in the base saturation of 68.8%, with an increase of 33.3% in diameter, in relation to the control (Fig. 5C). With the natural development of alfalfa, a greater thickening of the stem is expected as well as the larger diameter in response to increasing levels of base saturation. However, we observe that this response reaches the limit as well as the other observed variables. From this point, increasing levels of liming do not result in thicker stems. It is believed that this is a limitation of genetic character and may vary between alfalfa cultivars.

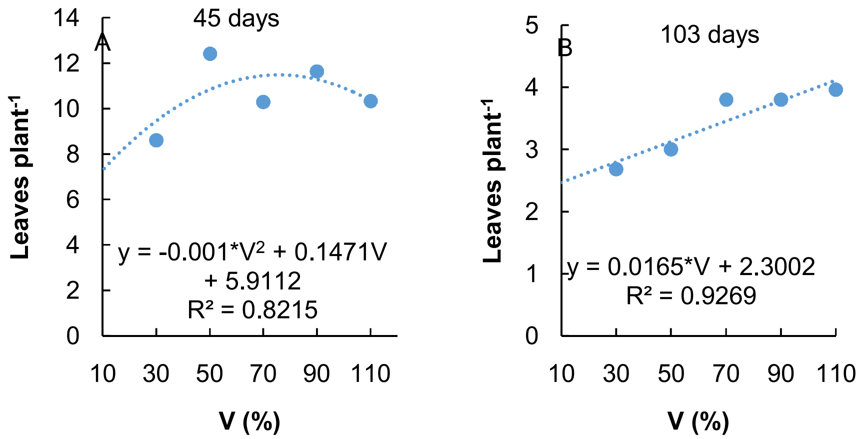

Fig. 4. Number of leaves of alfalfa (*Medicago sativa* L.) as a function of base saturation levels (V%) at 45 days after emergence (A) and 103 days after emergence (B), cultivated in dystrophic Oxisol

** Significant at 5%*

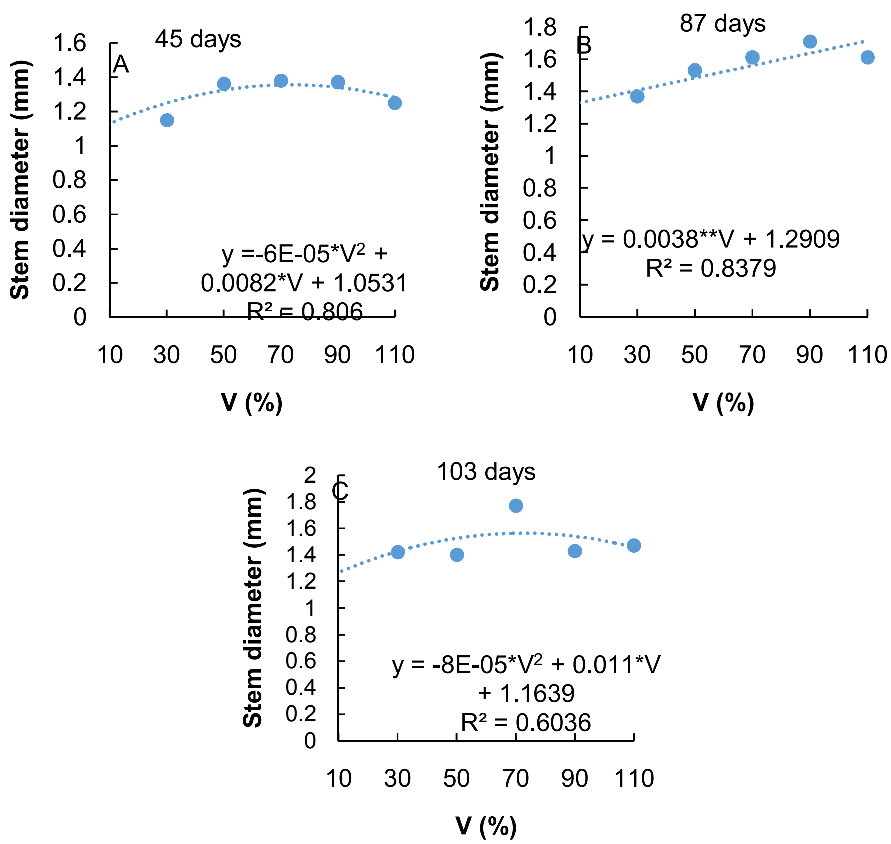

Fig. 5. Stem diameter of alfalfa (*Medicago sativa* L.) as a function of base saturation levels (V%) in the first (A), fourth (B) and fifth (C) evaluation, cultivated in dystrophic Oxisol

** Significant at 5%; ** Significant at 1%*

Besides the structural and sustentation function, the stem has a fundamental role in the storage of nutrients. Among nutrients, calcium is essential for the good development of the stem

[16]. Thus, thicker stems are more interesting from the agronomic point of view, allowing a greater reserve of photoassimilates and nutrients that can later be translocated for biomass production and higher crop productivity, besides providing greater resistance to meteorological variables of wind and rain.

Plant height presented difference only at 45 days after emergence, with adjustment to the quadratic regression model. The base saturation of 66.7% provided the highest plant height (30.29 cm), making a 33.7% increase compared to the control treatment (Fig. 6).

In a study evaluating dairy production on rotational alfalfa grazing irrigated with supplementation in the Southeast region of Brazil, the mean pre-grazing height was approximately 47 cm [6].

The higher plant height is related to the grazing facility and the higher biomass production, in the case of hay or silage production. Although a crop with good adaptability to cultivation in several regions of the world, the low thermal amplitude recorded during the growing period may have hampered the growth in height of alfalfa plants, considering that average temperature recorded was 27°C.

The shoot dry mass of alfalfa plants presented difference only at 55, 87 and 118 days after emergence. At 55 days, the results were adjusted to the quadratic regression model, so that the increase in base saturation increased the shoot dry mass to baseline saturation of 83%, representing an increase of 39.3% in relation to the control treatment (Fig. 7A). However, at 87 and 118 days after emergence, the linear regression model describes the effect of base saturation levels on shoot dry mass of alfalfa plants, so that the increases were 23.6 and 30.1%, considering the higher base saturation and the control treatment, respectively (Figs. 7A and 7B).

It is observed that the buffering power of the soil provided over time by the higher levels of base saturation, evidencing the high nutritional requirement of the forage. Although it is considered a species with a certain rusticity [9], alfalfa (*Medicago sativa* L.), presents a high requirement in soil fertility.

Liming is fundamental for success in alfalfa cultivation. The leguminous is one of the most demanding forages as the range of pH of the soil and the extraction of Ca and Mg, which are exported by shoot part, justifying, therefore, special attention to these components for the planning and decision making during the implantation its cultivation [7].

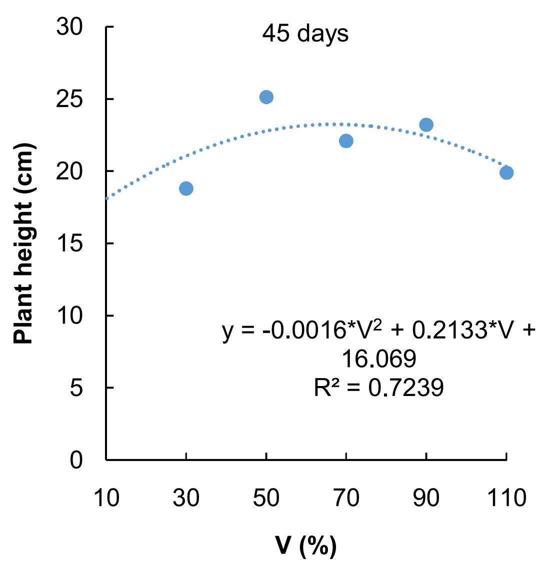

Fig. 6. Height of alfalfa (*Medicago sativa* L.) as a function of basement saturation levels (V%) at 45 days after emergence, cultivated in a dystrophic Oxisol
** Significant at 5%*

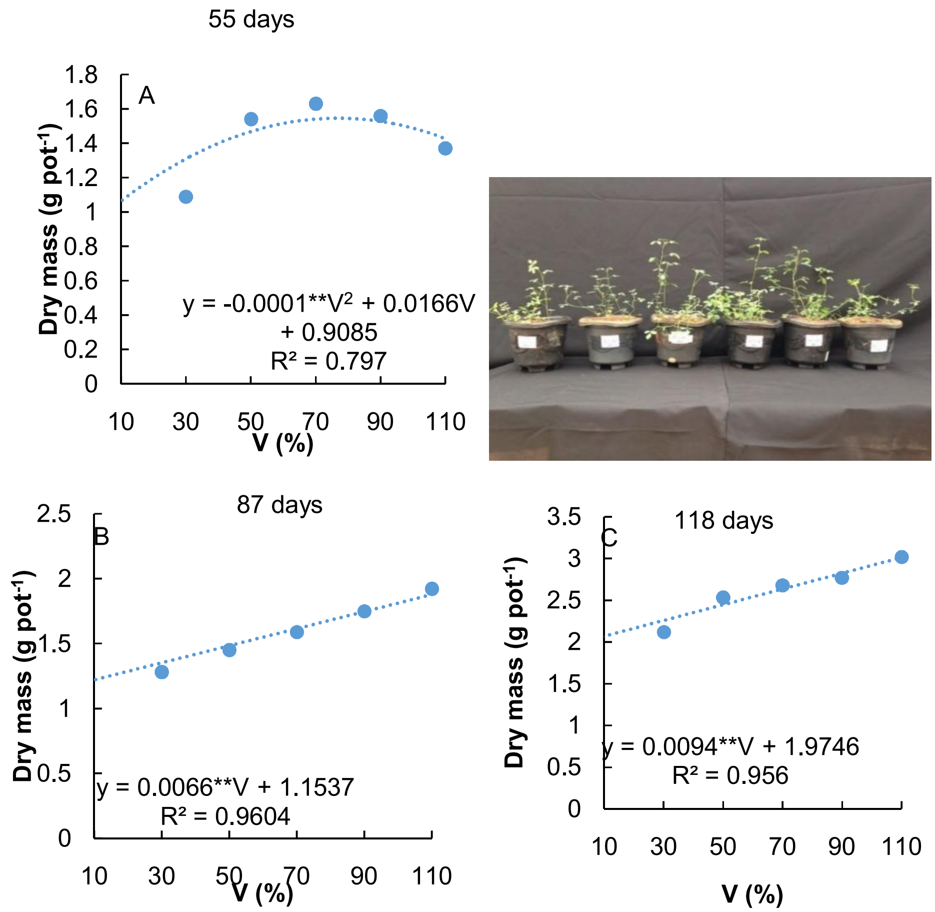

Fig. 7. Shoot dry mass of alfalfa (*Medicago sativa* L.) as a function of base saturation levels (V%) at 55 days after emergence (A), 87 days after emergence (B) and 118 days after emergence (final cut) (C), cultivated in a dystrophic Oxisol
*** Significant at 1%*

Research in a greenhouse, with alfalfa cultivated in Entisol with acid pH, evaluating the influence of liming on soil chemical characteristics and alfalfa production, evidenced higher forage yield at base saturation of 57% at the dose of limestone of 4 g dm^{-3} [17]. In addition, it was evident the reduction of shoot dry mass production of the alfalfa from the second cut, independently of the evaluated treatment.

Forage implantation in areas with medium to low fertility will result in unsuccessful production [10], further burdening production costs, especially considering the reality of Mato Grosso soils, low fertility and base saturation [5].

The root volume of alfalfa, with the final cut of the plants (118 days), was adjusted to the quadratic regression model, with a higher volume of 38.44 mL at a saturation of 79.3%, an increase of 39.1%, as compared to the control treatment (Fig. 8).

The higher root volume in response to base saturation levels evidences the improvement in the chemical quality of the soil for the good growth and vegetal development, providing greater soil volume exploitation, greater absorption of water and nutrients, as well as better support plant.

In a research conducted evaluating the influence of liming and gassing on the alfalfa production and root development cultivated in the field in dystrophic Oxisol also from the Brazilian Cerrado with three evaluation periods, verified that the higher doses tested (gypsum and limestone) did not provide the highest biomass yields, interfering with root growth, especially in depth, when using gypsum [18].

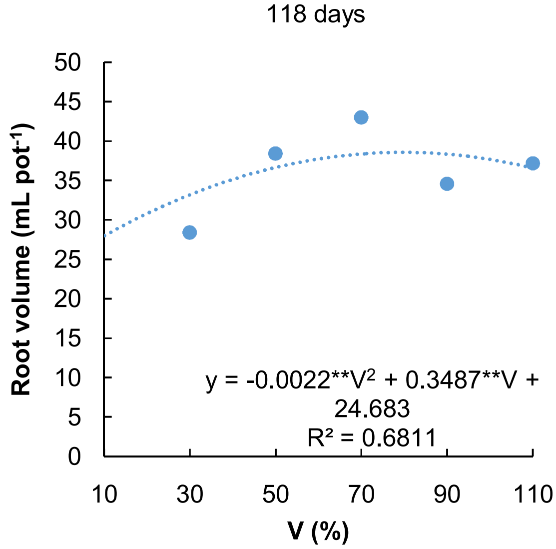

Fig. 8. Root volume of alfalfa (*Medicago sativa* L.) as a function of base saturation levels (V%) at 118 days after emergence (cut), cultivated in a dystrophic Oxisol
*** Significant at 1%*

Root growth is damaged under low availability of calcium, consequently affecting plant growth and development. On the other hand, nodulation in leguminous is favoured by the availability of calcium. Thus, with adequate liming and increased availability of calcium and magnesium, alfalfa cultivation has increased production. In addition, magnesium has a fundamental role in the constitution of chlorophyll molecules, is one of the main enzymatic activators and is still associated with the absorption of phosphorus by the plants [16].

The pH of the soil at the time of sowing was significant, adjusting to the linear regression model, obtaining a maximum pH of 6.3, so that the increment was in the order of 34.8% comparing the pH at the highest base saturation (110%) with the control treatment (Fig. 9).

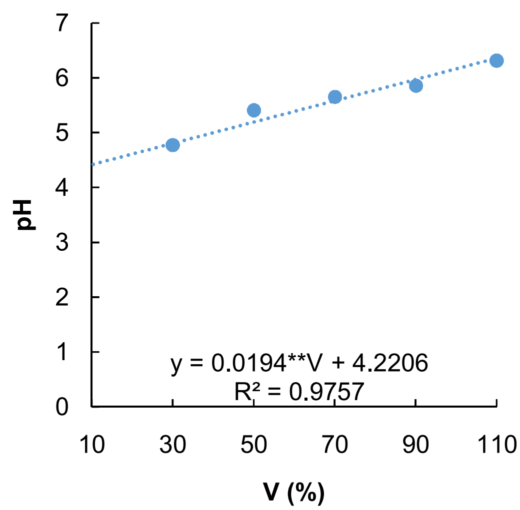

Fig. 9. Soil pH in alfalfa (*Medicago sativa* L.) as a function of base saturation levels (V%), cultivated in a dystrophic Oxisol
*** Significant at 1%*

The nutrient availability is directly dependent on soil pH, so the optimal pH range for most crops is between 5.5 and 6.5 [19]. Very high pH tends to decrease the availability of micronutrients, being necessary the application via foliar in cases of observation of symptoms of deficiency. However, for alfalfa cultivation, soil pH in the range of 6.5 has provided the highest dry matter yield. In addition, pH influences the mineralisation of organic matter and biological nitrogen fixation [7]. Please note that it is between pH 6.5 and 7.0 in which there is the greatest availability of phosphorus in the soil, a fundamental nutrient in the energy metabolism of plants.

A study evaluating the interaction between liming, gassing and phosphating in an experiment conducted out on Oxisol, evidenced the influence of soil pH on alfalfa production since the forage did not develop under conditions of high levels of aluminum in the soil and low availability of phosphorus (30 mg dm^{-3}) [20].

In general, after application of the treatments, the pH increased and may have compromised the availability and absorption of micronutrients, and consequently compromised alfalfa production, as observed in the first cut (Fig. 7A). However, with consecutive cuts, absorption and exportation of Ca and Mg, tends to acidify the soil, so that the higher levels of base saturation provided the greater expression of the components evaluated (Figs. 7B and 7C). The absorption of cationic nutrients (Ca^{2+} and Mg^{2+}) by plants leads to the release of hydrogen ions into the soil solution, thus reducing the pH of the soil [21].

4. CONCLUSION

Base saturation levels influenced the development and production of alfalfa.

Up to the first cut of alfalfa, saturations between 60 and 75% provided greater crop development. From the second cut, the development of alfalfa is favoured at higher saturation, due to the residual effect of soil correction by the provision of high doses of Ca and Mg from liming.

In general, base saturation from 80% is the one that provides the best growth, development and higher production of alfalfa, cultivated in Oxisol in the Cerrado.

ACKNOWLEDGEMENT

The authors thank Prof. Dr. Antonio Rodrigues da Silva for the donation of alfalfa seeds.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/27044