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Crescimento biométrico e rebrota de nim em solo enriquecido com esterco bovino e calcário

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R E S U M O

No Brasil, as informações técnicas sobre o cultivo de nim ainda são limitadas. Nesse contexto, o objetivo do estudo foi avaliar o crescimento biométrico e a rebrota de plantas de nim com adubação orgânica e aplicação de calcário. O delineamento experimental foi em blocos casualizados com quatro repetições. Os tratamentos foram organizados em esquema fatorial 2 × 5, sendo: sem e com calcário agrícola e cinco doses de esterco bovino (0,00; 0,96; 1,92; 2,89 e 3,85 kg planta^{-1}). Foram avaliados a altura das plantas, diâmetro do caule, taxas de crescimento absoluto e relativo em altura e diâmetro do caule e o número de brotações nos tocos. As doses de esterco bovino aumentaram o crescimento em altura das plantas de nim em 15,4% e 24,5%, respectivamente, no solo sem e com calcário. A aplicação de calcário calcítico associada ao esterco bovino na dose de 3,85 kg planta^{-1} promoveu o maior crescimento de nim.

Palavras-chave: *Azadirachta indica* A. Juss, Fertilizante orgânico, Calagem, Taxa de crescimento

Biometric growth and regrowth of neem in soil enriched with cattle manure and limestone

A B S T R A C T

In Brazil, technical information on neem cultivation is still limited. In this context, the objective of the study was to evaluate the biometric growth and regrowth of neem plants with organic fertilization and limestone application. The experimental design was randomized blocks with four replications. The treatments were arranged in a 2 × 5 factorial scheme, as follows: soil without and with agricultural limestone and five doses of cattle manure (0.00; 0.96; 1.92; 2.89 and 3.85 kg plant^{-1}). Plant height, stem diameter, absolute and relative growth rates in height and stem diameter and the number of shoots on the stumps were evaluated. The doses of cattle manure increased the growth in height of neem plants by 15.4% and 24.5%, respectively in the soil without and with limestone. The application of calcitic limestone associated with cattle manure at a dose of 3.85 kg plant^{-1} promoted the highest neem growth.

Keywords: *Azadirachta indica* A. Juss, Organic fertilizer, Liming, Growing rate

Introduction

Neem (*Azadirachta indica* A. Juss) is a tree species belonging to the family Meliaceae, with center of origin in India (Gupta et al., 2017). For millennia, this species has been used by man; for containing several bioactive compounds, it acts in the fight against chronic diseases in humans and as biopesticides in the action on pest insects in agriculture (Campos et al., 2016). In Brazil, neem was introduced in the late twentieth century and has been found in virtually all regions of the country (Bittencourt et al., 2009; Oliveira et al., 2019).

In the Brazilian Northeast, it is cultivated in areas of small and medium farmers, being a rustic plant with easy adaptation to the edaphoclimatic conditions that prevail in the semi-arid regions (Rodrigues et al., 2017; Mesquita et al., 2019). Neem is a crop with high regrowth capacity, according to Rodrigues et al. (2017) and may be a potential alternative for the timber sector of the region (Oliveira et al., 2019). Despite the growing expansion of the crop in Brazil, technical information about the cultivation and management of neem is still scarce in the literature (Neves e Carpanezzi, 2008). Such lack of information stimulates the exploitation of the crop aiming at the economic viability of the species. In this context, research aimed at assessing the behavior of neem in the field under simultaneous fertilization of organic and mineral fertilizers should be encouraged. Among the crop management strategies, the increase of fertility by fertilization and soil correction is still the technique that most contributes to the growth and yield of food and forest species (Artur et al., 2007; Anikew, Eze and Abudialo, 2016).

Application of organic fertilizers of animal or plant origin constitutes a practice for improving physical (Karami et al., 2012), chemical (Silva et al., 2014; Chadwick et al., 2015) and biological (Das et al., 2017) properties of the soil. The chemical composition of cattle manure, mineralized or aged, with calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^{+}), contributes to the partial or total neutralization of aluminum (Al^{3+}), which has phytotoxic action in acidic soils and to increased pH, which increases the availability of nutrients to plants (Karami et al., 2012; Moreira et al., 2015). Cattle manure also acts as a soil conditioner, reducing bulk density and resistance to root penetration and increasing porous space, water storage and soil aggregation (Blanco-Caqui, Hergert and Nielsen, 2015; Agegnehu and Amede, 2017).

The titratable acidity and exchangeable aluminum content of acidic soils, in general, are corrected by liming (Fageria et al., 2014; Pauletti et al., 2014). Among the advantages of liming are the decrease in soil acidity, inhibition of the toxic effect of aluminum on plants, and increase in the exchangeable bases calcium, magnesium and potassium, contributing to improving fertility with positive effects on plant growth and production (Pauletti et al., 2014; Anikew et al., 2016). Thus, practices aimed at improving management and, in effect, increasing soil quality should adopt simultaneous application of organic input of animal origin and a source of calcium in order to increase the potential of fertility and, consequently, the development and production capacity of crops (Artur et al., 2007; Moreira et al., 2015; Otieno, Chemining'wa and Zingore, 2018).

Given the lack of technical and scientific information about the effects of soil fertilization with organomineral fertilizers on the behavior of neem developed in the field, the aim with the present study was to evaluate the biometric growth and regrowth of neem stumps after cutting the plants fertilized with cattle manure and calcitic limestone.

Material and methods

The experiment was conducted from June/2018 to February/2021 in an area of 70 m × 30 m (210 m^2), belonging to the Agriculture Sector of the Center for Human, Social and Agrarian Sciences of the Federal University of Paraíba, Bananeiras, Paraíba, Brazil. The municipality is located in the Brejo Paraibano Microregion, georeferenced by the coordinate points 6° 46' 00" South latitude and 35°38' 00" West longitude of the Greenwich meridian (Alvares et al., 2013).

The soil of the experimental area, according to the criteria of the Brazilian Soil Classification System - SiBCS (EMBRAPA, 2013), is a *LATOSSOLO AMARELO Eutrophic* (Oxisol), gently undulating relief, deep, well-drained and of sandy clay loam textural class. In the experimental area, 16 single soil samples were collected at 0.0–0.4 m depth, four per block, transformed into one composite sample per block for characterization of chemical and physical attributes (EMBRAPA, 2011), and the mean values of the area were used (Table 1).

Table 1. Chemical and physical characterization of the soil, at 0.4 m depth (EMBRAPA, 2011), before the experiment, and of the cattle manure (EMBRAPA, 2009)

Soil characterization				Cattle manure characterization	
Chemical		Physical		Variable	Value
pH H_2O (1:2.5)	5.48	Sand (g kg^{-1})	652	pH	8.2
MO (g kg^{-1})	7.71	Silt (g kg^{-1})	57	OM (g kg^{-1})	323
P (mg kg^{-1})	34.60	Clay (g kg^{-1})	291	C (g kg^{-1})	187
K^+ ($cmol_c$ kg^{-1})	0.30	WDC (g kg^{-1})	34	N (g kg^{-1})	9.8
Ca^{2+} ($cmol_c$ kg^{-1})	2.12	DF (%)	88	C/N	19:1
Mg^{2+}($cmol_c$ kg^{-1})	1.77	DI (%)	12	P_2O_5 (mg kg^{-1})	101
Na^+ ($cmol_c$ kg^{-1})	0.02	BD (g cm^{-3})	1.33	CaO (mg kg^{-1})	130
SB ($cmol_c$ kg^{-1})	3.92	PD (g cm^{-3})	2.68	MgO (mg kg^{-1})	105
H^++Al^{3+} ($cmol_c$ kg^{-1})	2.61	Pt (%)	50	K_2O (mg kg^{-1})	117
Al^{3+} ($cmol_c$ kg^{-1})	0.09	mP (%)	32.4	Na_2O (mg kg^{-1})	36
CEC ($cmol_c$ kg^{-1})	6.53	MP (%)	67.6	---	---
V (%)	60.02	Ufc (%)	16.2	---	---
ECae (mS cm^{-1})	0.05	Upwp (%)	7.9	---	---
ESP (%)	0.31	AW (%)	8.3	---	---
Classification	Eutrophic	Texture	SCL	---	---

Note: Phosphorus and potassium – Mehlich 1 extractant; Calcium, magnesium and sodium – 1 mol/L KCl extractant; Aluminum and Hydrogen + aluminum (H^++Al^{3+}) – Calcium acetate 0.5 mol/L extractant; Organic matter – Walkley-Black method; Sum of Bases (SB) = ($K^+ + Ca^{2+} + Mg^{2+} + Na^+$); Cation exchange capacity (CEC) = (SB + [H^++Al^{3+}]); Base saturation (V) = (SB/CEC) × 100; ECae = Electrical conductivity of the aqueous extract (1:2.5); ESP = Exchangeable sodium percentage (ESP = 100 × Na^+/CEC); WDC = Water-dispersible clay; DF and DI = Degree of flocculation and Dispersion index; BD and PD = Bulk density and particle density; Pt, mP and MP = Total porosity, microporosity and macroporosity; Ufc and Upwp = Moisture content on volume basis at tensions of -0.033 and - 1.500 MPa; AW = Available water; SCL = Sandy clay loam.
Source: Authors.

The treatments were arranged in randomized blocks, with four replicates of five plants per plot of 20 m^2 using the 2 × 5 factorial scheme, relative to the soil without and with 0.17 kg m^{-2} of calcitic limestone (48% CaO and 2.9% MgO) with RNV of 82%, incorporated in the 0.00-0.15 m layer throughout the area, to increase soil base saturation from 60% (Table 1) to 80% (Neves e Carpanezzi, 2008), and five doses of aged cattle manure, with mass-based moisture of 6%, equal to 0.00, 0.96, 1.92, 2.89 and 3.85 kg $plant^{-1}$ (Table 1) to increase the initial organic matter (OM) content of the soil in the holes by 1.3%, 2.3%, 3.3%, 4.3%, and 5.3%.

Thirty days after incorporation of the limestone, holes were opened with dimensions of 0.4 m × 0.4 m × 0.4 m, volume of 64 dm^3 of soil at the planting distances of 2 m × 2 m. Along with the doses of cattle manure, 40 g of triple superphosphate (45% P_2O_5 and 6% Ca) and 150 g of K_2O from potassium chloride (60% K_2O) were applied. Fertilizations with P, K and cattle manure (Table 1) were applied simultaneously during the preparation of the holes, at 90 and 360 days after transplantation (DAT). Nitrogen was supplied using urea at levels of 10 and 40 g of N, at 30 and 360 DAT (Neves and Carpanezzi, 2008). Prior to the application, cattle manure was analyzed as plant material according to the methodologies contained in EMBRAPA (2009), as shown in Table 1.

The seedlings were prepared in a nursery near the experimental area, with sowing of three seeds in black polyethylene bags in a substrate consisting of the mixture of soil passed through a 4-mm-mesh sieve and cattle manure at a ratio of 3:1. Cattle manure was analyzed as plant material according to the methodologies suggested by EMBRAPA (2009) (Table 1) and was the same used in the preparation of the holes and in the top-dressing applications at 90 and 360 DAT.

Growth in height and stem diameter were measured monthly at 360 and 720 DAT, respectively with graduated ruler from the soil to the apical meristem of the plant and with a Digimess 300 digital caliper, to calculate the absolute and relative growth rates (Benincasa, 2003), by equations 1 and 2, respectively; on the last date, the values of main stem height and stem diameter of the plants were used.

$$\mathrm{AGR} = \frac{(\mathrm{V2}-\mathrm{V1})}{(\mathrm{T2}-\mathrm{T1})} \quad (1)$$

$$RGR = \frac{\ln(V1)-\ln(V2)}{(T2-T1)} \quad (2)$$

where; V2= Final value of the variable under analysis; V1= Initial value of the variable under analysis; T2= Final evaluation time (days); T1= Initial evaluation time (Days); ln = Natural or Napierian logarithm.

At 720 DAT, two plants from each plot were cut at 5 cm above ground level and, at 180 days after cutting (DAC), the number of shoots on the stump were counted.

The data were subjected to analysis of variance by the F test at 5% probability level. Means referring to soil without and with limestone were compared by the F test ($p \leq 0.05$), which is conclusive for factors with two values, and means referring to the doses of cattle manure were analyzed by regression ($p \leq 0.05$). The data were processed using the statistical software Sisvar version 5.6 (Ferreira, 2019).

Results and discussion

The interaction between cattle manure and calcitic limestone significantly influenced the growth in height of plants at 720 DAT, the absolute and relative growth rates in height from 360 to 720 DAT and the sprouting of the stumps after cutting the neem plants (Table 3). Stem diameter at 720 DAT and the absolute and relative growth rates of stem diameter responded to the effects of cattle manure doses.

The significant effects of the interaction between cattle manure and calcitic limestone (Table 2) on the absolute and relative growth rates in height represent an important point of discussion when compared to previous findings in the literature. These results differ from those reported by Carnevali et al. (2020), who observed no statistical effect of the cattle manure × limestone interaction on the growth of genip trees (*Genipa americana*). In their study, the growth of these trees was influenced only by the isolated application of organic inputs, such as cattle manure, without any synergistic effects arising from the combination with limestone. This discrepancy raises questions about the variability in plant responses to soil amendments depending on species-specific characteristics, environmental conditions, or experimental setups.

On the other hand, the findings align with those reported by Moreira et al. (2015), who demonstrated that the interaction between limestone and cattle manure positively influenced nutrient availability in the soil and, consequently, the yield of soybean (*Glycine max*). This suggests that the combined use of these soil amendments may enhance nutrient dynamics, particularly in crops or plants that are more responsive to improved soil fertility conditions. The positive interaction could be attributed to limestone's role in correcting soil acidity, which can enhance microbial activity and nutrient solubility, while cattle manure provides a rich source of organic matter and essential nutrients like nitrogen, phosphorus, and potassium. Together, these inputs may create a more favorable environment for root development and nutrient uptake, ultimately promoting plant growth.

However, it is worth noting that the contrasting results between the current study and Carnevali et al. (2020) highlight the complexity of soil-plant interactions and the need for further research to understand the underlying mechanisms. Factors such as soil type, initial pH levels, the quality and quantity of organic inputs, and the specific nutritional requirements of different plant species may all play a role in determining the effectiveness of these amendments. Additionally, the duration of the experiment and the methods used to assess growth parameters could influence the outcomes.

Table 2. Summary of the analysis of variance for height (PH), stem diameter (SD), absolute growth rate (AGR_H) and relative growth rate (RGR_H) of height, absolute growth rate (AGR_D) and relative growth rate (RGR_D) of stem diameter and number of shoots (NSH) in neem plants, as a function of doses of cattle manure (M) in soil with calcitic limestone (L)

SV	DF	F test						
		PH	SD	AGR_H	RGR_H	AGR_D	RGR_D	NSH
Block	3	ns	ns	ns	ns	ns	ns	ns
Lim (L)	1	ns	ns	ns	**	ns	ns	ns
Man (M)	4	**	**	*	ns	*	*	ns
M × L	4	**	ns	*	**	ns	ns	**
Residual	27							
Total	29							
Mean		2.42	28.67	1.286	0.00636	0.123	0.00536	27.66
CV		4.54	6.41	10.15	10.71	24.34	27.12	19.11

Note: SV = Source of variation; DF = Degrees of freedom; CV = Coefficient of variation; ^{ns}, * and ** = not significant, significant at 5 and 1% probability levels by the F test, respectively.

The growth in height of neem plants, from transplantation to 720 DAT, were increased with increasing doses of cattle manure by 9.0 and 13.8 cm per unit increment in the organic input, respectively, in the soil without and with calcitic limestone (Figure 1). In both liming situations (without and with), there was a positive action of cattle manure, with superiority of 15.4% and 24.5%, respectively, between plants grown in soil without and with the highest dose of the organic input. When comparing the values of 24.5% with 15.4%, an average superiority of 59.1% was observed between the treatments without and with calcitic limestone, as a function of the doses of the organic input.

The greater increase in the height growth of plants cultivated in soil with increasing doses of cattle manure and calcitic limestone (Figure 1) can be attributed to significant improvements in edaphic properties, which encompass both physical and chemical attributes of the soil. These enhancements create a more favorable environment for plant development, particularly by promoting root growth and nutrient uptake.

Regarding physical attributes, the application of cattle manure and calcitic limestone has been shown to reduce soil bulk density while increasing hydraulic conductivity, aggregate stability, and porous space (Anikwe et al., 2016). These changes are critical for optimizing soil structure, as they enhance water infiltration and retention while reducing penetration resistance. Lower penetration resistance facilitates root elongation and exploration, enabling plants to access water and nutrients more efficiently. Furthermore, the increased porosity improves aeration, which is essential for root respiration and microbial activity. Such physical modifications are particularly beneficial in compacted or poorly structured soils, where root growth is often restricted.

In terms of chemical properties, the combined use of cattle manure and calcitic limestone significantly enhances nutrient availability in the soil. For instance, there is a notable increase in the availability of phosphorus, an essential macronutrient for energy transfer and root development. Additionally, the contents of calcium, magnesium, and potassium are elevated, with calcium and magnesium playing a pivotal role in reducing soil potential acidity (Fageria et al., 2014; Adekiya et al., 2020). The neutralizing effect of calcitic limestone on soil pH not only reduces aluminum toxicity but also enhances the solubility and uptake of other nutrients. Magnesium, a central component of chlorophyll, further supports photosynthesis and overall plant vigor. Potassium, on the other hand, contributes to enzyme activation, osmoregulation, and stress tolerance, making plants more resilient to environmental challenges.

It is important to highlight that the synergistic effects of cattle manure and calcitic limestone may vary depending on factors such as soil texture, initial fertility levels, and the specific crop being cultivated. For example, sandy soils may benefit more from the organic matter provided by cattle manure due to their inherently low nutrient retention capacity, while clayey soils might see more pronounced improvements in physical attributes like aggregation and porosity. Similarly, crops with high calcium or magnesium requirements, such as legumes or certain fruit trees, could exhibit even more pronounced growth responses to these amendments.

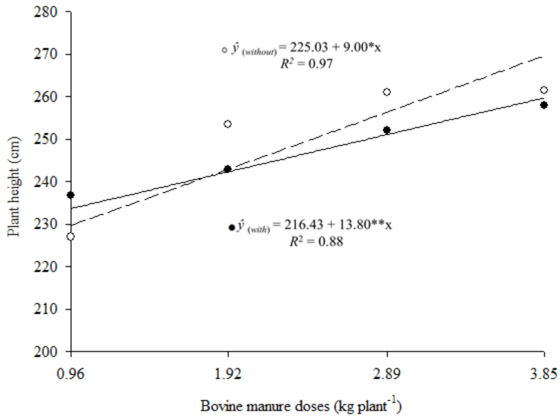

Figure 1. Plant height of neem, at 720 DAT, as function of doses of cattle manure, in the soil without (—) and with (- - -) calcitic limestone.

The stem diameter of neem plants at 720 DAT did not respond to the effects of limestone or its interaction with cattle manure, but was influenced by the increase in the doses of the organic input, increasing from 25.98 to 31.34 mm between plants grown in soil without and with 3.85 kg of cattle manure per plant (Figure 2). This increase represents a gain of 20.6% in neem stem diameter.

The increase in stem diameter (Figure 2), similar to the observations regarding height growth, can be attributed to the improvements in soil properties driven by the application of organic inputs, such as cattle manure, and their effects on both the physical conditioning of the soil and the enhanced availability of essential nutrients for plant growth (Silva et al., 2014; Chadwick et al., 2015; Agegnehu and Amede, 2017). Organic amendments are known to enhance soil structure by increasing aggregation, porosity, and water retention while reducing compaction. These physical changes create a more favorable environment for root development, which in turn supports greater nutrient and water uptake, ultimately contributing to increased stem diameter. Additionally, the heightened availability of nutrients like nitrogen, phosphorus, potassium, calcium, and magnesium plays a critical role in cell division, elongation, and overall plant biomass accumulation.

However, these results contrast with those reported by Rodrigues et al. (2017), who observed no significant response in stem diameter with increasing doses of cattle manure when applied to neem plants (*Azadirachta indica*) grown in saline-sodic soils. This discrepancy highlights the complex interactions between soil type, plant species, and amendment efficacy. Saline-sodic soils present unique challenges, including high levels of soluble salts and sodium ions, which can negatively affect soil structure, water availability, and nutrient uptake. In such conditions, the benefits of organic inputs may be limited or delayed due to the dominance of stress factors that hinder plant growth. For instance, excessive sodium can displace essential cations like calcium and magnesium, leading to poor soil aggregation and restricted root growth, thereby counteracting the positive effects of cattle manure.

Moreover, the contrasting findings could also be linked to differences in plant species' tolerance to salinity and sodicity. Neem plants, for example, may exhibit lower adaptability to such stressful environments compared to other species, making them less responsive to soil amendments under these conditions. The effectiveness of cattle manure in improving plant growth is highly context-dependent, influenced by factors such as soil texture, initial fertility, pH, and the presence of limiting factors like salinity or alkalinity.

These observations emphasize the need for tailored soil management strategies that consider the specific characteristics of the soil and the requirements of the cultivated species. While organic inputs like cattle manure have demonstrated significant potential to improve soil health and promote plant growth in many scenarios, their application in challenging environments, such as saline-sodic soils, may require complementary measures, such as gypsum application or irrigation management, to mitigate stress factors and maximize their benefits.

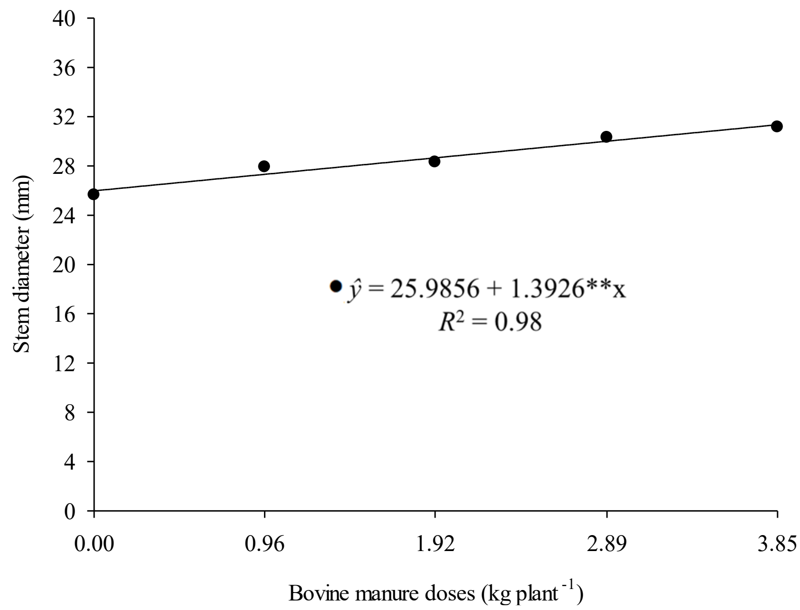

Figure 1. Stem diameter of neem plants, at 720 DAT, as a function of doses of cattle manure in the soil.

The values of absolute and relative growth rates in height of neem plants in the soil without limestone were not described by any regression model with the increase in cattle manure doses (Figure 3) and were represented by the means of 1.313 cm day^{-1} for AGR_H (Figure 3A) and 0.0068 cm cm^{-1} day^{-1} for RGR_H (Figure 3B). In plants grown in soil with calcitic limestone, AGR_H increased from 1.0403 to 1.352 cm day^{-1}, indicating a 30.0% gain between plants grown in soil without and with 2.4 kg of plant^{-1} of manure (Figure 3A). The relative growth rate in height was also stimulated by the increase in cattle manure doses, increasing from 0.0047 to 0.0070 cm cm^{-1} day^{-1}, expressing a 50% increase between plants grown in soil with the highest dose of organic input and fertilized with limestone (Figure 3B).

The highest values observed in the growth rates in height of plants fertilized with limestone and cattle manure (Figure 3) can be closely linked to the increase in soil pH, a key factor in enhancing soil fertility and plant performance. The application of calcitic limestone raises soil pH by increasing the concentration and activity of hydroxyl ions (OH^-) in the soil solution. This process precipitates and neutralizes exchangeable aluminum, a toxic element that inhibits root growth and nutrient uptake in acidic soils. By reducing aluminum toxicity, limestone not only creates a more favorable environment for root development but also enhances the availability of essential nutrients such as phosphorus, calcium, and magnesium, which are critical for plant growth. Furthermore, the improved nutrient dynamics resulting from pH correction contribute to greater root-soil contact surface, enabling plants to absorb water and nutrients more efficiently (Otieno et al., 2018; Moreira et al., 2020).

In addition to its chemical benefits, limestone also positively influences the physical properties of the soil. It promotes better soil aggregation, reduces bulk density, and increases porosity, all of which facilitate root penetration and expansion. These physical improvements are further complemented by the organic matter supplied by cattle manure, which enhances soil structure, water retention, and microbial activity. Together, these changes create an optimal environment for root development, ultimately supporting higher growth rates in plants.

Regarding the relative growth in stem diameter, the data for neem plants align with the findings reported by Mesquita et al. (2019), who demonstrated that the application of liquid bovine biofertilizer to the soil significantly promoted the highest relative growth in height for neem seedlings. Although Mesquita et al. (2019) focused on height growth, their results suggest that biofertilizers, like cattle manure, play a crucial role in supplying nutrients and organic matter, which are vital for overall plant biomass accumulation. The similarity in outcomes indicates that both organic amendments and biofertilizers share common mechanisms of action, such as improving nutrient availability, enhancing soil biological activity, and fostering a conducive rhizosphere environment for plant growth.

It is worth noting that the effectiveness of these soil amendments may vary depending on factors such as soil type, initial fertility, and plant species. For instance, neem plants, known for their adaptability to marginal soils, appear to respond well to organic inputs, particularly when combined with pH-correcting agents like limestone. However, the specific responses of other species or under different environmental conditions might differ, underscoring the importance of context-specific management practices.

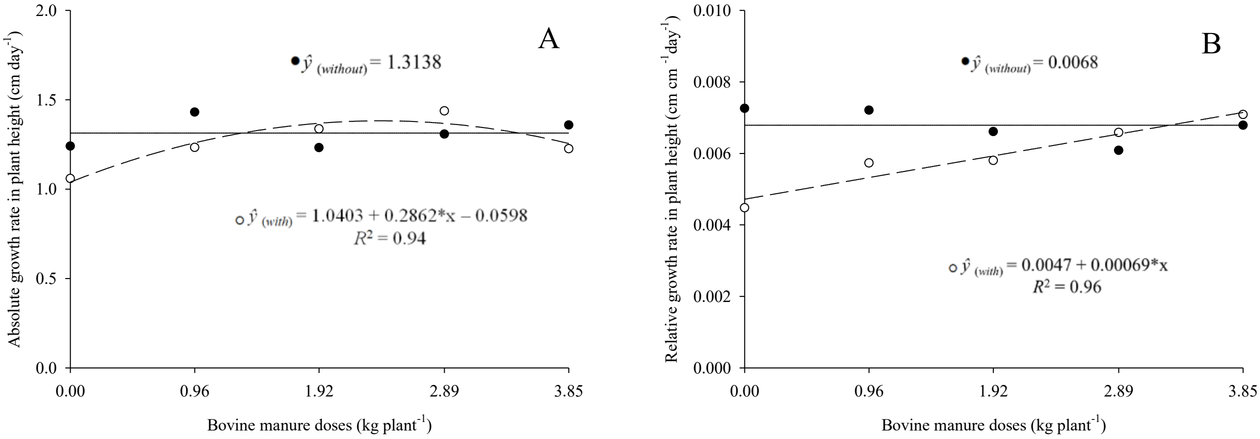

Figure 2. Absolute (A) and relative (B) growth rates in height of neem, from 360 to 720 DAT, as a function of doses of cattle manure, in soil without (—) and with (- - -) limestone.

The increase in cattle manure doses increased the absolute and relative growth rates of stem diameter in neem plants up to the respective estimated maximum doses of 1.60 and 1.83 kg plant^{-1} (Figure 4). The absolute growth rate increased from 0.01178 to 0.01421 mm day^{-1}, inducing an increase of 20.6% between plants without (dose 0.00) and with 1.60 kg plant^{-1} of organic fertilizer (Figure 4A). The relative growth rate was increased from 0.00480 to 0.00579 mm mm^{-1} day^{-1}, promoting the same increase of 20.6% between plants of the treatments without and with 1.83 kg plant^{-1} of cattle manure (Figure 4B).

The higher relative growth rate in diameter of neem plants (*Azadirachta indica*) treated with cattle manure (Figure 4) underscores the multifaceted role of this organic input in enhancing soil attributes and promoting plant growth. Cattle manure acts as a physical conditioner, improving soil structure by increasing aggregation, porosity, and water retention while reducing compaction (Blanco-Caqui, Hergert and Nielsen, 2015). These physical improvements facilitate root expansion and enhance the root-soil contact surface, enabling more efficient nutrient and water absorption. Simultaneously, cattle manure serves as a source of essential nutrients, including nitrogen, phosphorus, potassium, and micronutrients, thereby increasing the overall fertility of the soil (Chadwick et al., 2015). Furthermore, the input stimulates edaphic microbiological activity, fostering a diverse and active microbial community that contributes to nutrient cycling, organic matter decomposition, and the release of plant-available nutrients (Das et al., 2017). Together, these effects create a synergistic environment that supports the enhanced growth of neem plants, particularly in terms of stem diameter.

These findings are consistent with those reported by Souza et al. (2006), who evaluated the growth of several forest species under field conditions, including *Eucalyptus urophylla*, *Cedrela odorata*, *Schinus terebinthifolius*, and *Acacia holosericea*. Their study concluded that organic fertilization significantly promoted greater growth in stem diameter as the plants aged. This suggests that the benefits of organic inputs like cattle manure are not limited to specific species or short-term responses but can be observed across a wide range of plants and over extended periods. The gradual release of nutrients from organic matter, combined with its long-lasting effects on soil physical and biological properties, likely contributes to sustained growth improvements.

The positive impact of cattle manure on stem diameter growth may also reflect its ability to address multiple soil constraints simultaneously. For instance, in soils with poor structure or low fertility, the application of organic amendments can alleviate physical limitations while providing a steady supply of nutrients. This dual action is particularly relevant for neem plants, which are known for their resilience in marginal soils but still benefit significantly from improved growing conditions. Additionally, the stimulation of microbial activity by cattle manure enhances nutrient availability through processes such as nitrogen mineralization and phosphorus solubilization, further supporting plant growth.

It is important to recognize that the effectiveness of cattle manure in promoting stem diameter growth may vary depending on factors such as soil type, climate, and the specific nutritional requirements of the plant species. For example, fast-growing species like *Eucalyptus urophylla* may exhibit more pronounced responses due to their high nutrient demands, while slower-growing species might show more gradual improvements. Similarly, environmental conditions such as rainfall and temperature can influence the rate at which organic matter decomposes and nutrients are released, potentially affecting the timing and magnitude of growth responses.

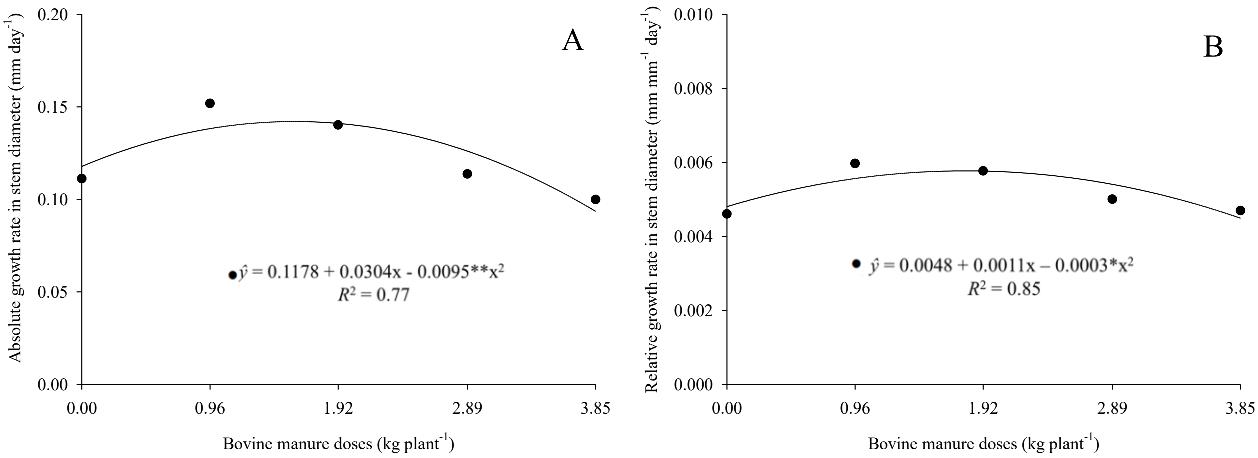

Figure 3. Absolute (A) and relative (B) growth rates in stem diameter in neem plants, from 360 to 720 DAT, as a function of doses of cattle manure.

The values of the regrowth of neem stumps after cutting the plants were not described by any regression model with the increase in the doses of cattle manure in the soil and in the absence of calcitic limestone, showing an average value of 29 shoots plant^{-1}. However, in the soil with limestone, the increase in cattle manure dose up to 2.02 g kg^{-1} in the soil with calcitic limestone stimulated the number of shoots, which increased from 18 to 32, resulting in an increase of 77.8%. When comparing the values of 32 and 29, respectively of the soil with and without calcitic limestone, an increase of 10.3% was observed in the sprouting of neem plants after cutting with the application of the corrective.

The positive action of cattle manure on the regrowth and growth of neem plants (*Azadirachta indica*) after cutting (Figure 5) has been demonstrated by Rodrigues et al. (2017), who highlighted that this organic input significantly stimulated both growth and biomass accumulation in plants cultivated in saline-sodic soils. Notably, the performance of cattle manure surpassed that of bovine biofertilizer, underscoring its superior efficacy in challenging soil conditions. This finding is particularly relevant given the constraints imposed by saline-sodic soils, which are often characterized by high levels of soluble salts and sodium ions that negatively affect soil structure, water availability, and nutrient uptake. The ability of cattle manure to enhance plant growth under such conditions highlights its potential as a robust soil amendment for improving fertility and mitigating stress factors.

The observed response of neem plants can be attributed to the residual power of cattle manure, which acts as a slow-release source of essential nutrients such as nitrogen, phosphorus, and potassium (Silva et al., 2014). Unlike synthetic fertilizers, which often provide an immediate but short-lived nutrient boost, cattle manure releases nutrients gradually over time, ensuring sustained availability for plant uptake. This slow-release mechanism is particularly advantageous for long-term growth and regrowth cycles, as it supports continuous biomass accumulation and recovery after disturbances like cutting. Additionally, the organic matter in cattle manure enhances soil structure, water retention, and microbial activity, further contributing to a favorable growing environment.

The role of calcitic limestone in this process cannot be overlooked, as it complements the benefits of cattle manure by addressing soil acidity and calcium deficiencies. Over time, calcitic limestone releases calcium into the soil, which plays a critical role in reducing potential acidity and improving soil fertility (Pauletti et al., 2014). Calcium also enhances soil aggregation and root development, facilitating better nutrient and water absorption. These improvements were observed by Pauletti et al. (2014) over a three-year evaluation period, demonstrating the long-term benefits of limestone application. When combined with cattle manure, limestone creates a synergistic effect that optimizes soil conditions for plant growth, particularly in acidic or degraded soils.

It is worth noting that the effectiveness of cattle manure and limestone in promoting regrowth and growth after cutting may vary depending on factors such as soil type, initial fertility, and environmental conditions. For instance, in saline-sodic soils, the dual action of cattle manure and limestone—addressing both nutrient deficiencies and structural limitations—can be particularly impactful. However, in soils with different characteristics, the magnitude of their effects might differ. Additionally, the timing and method of application, as well as the quality and quantity of the inputs, can influence the outcomes.

These findings reinforce the importance of integrating organic and mineral amendments in agricultural systems to address multiple soil constraints simultaneously. By combining the slow-release nutrient supply of cattle manure with the pH-correcting and calcium-supplying properties of limestone, farmers can create a more resilient and productive soil environment. Such practices not only support immediate plant growth but also contribute to long-term soil health and sustainability, making them particularly valuable for crops like neem that are often grown in marginal or degraded soils.

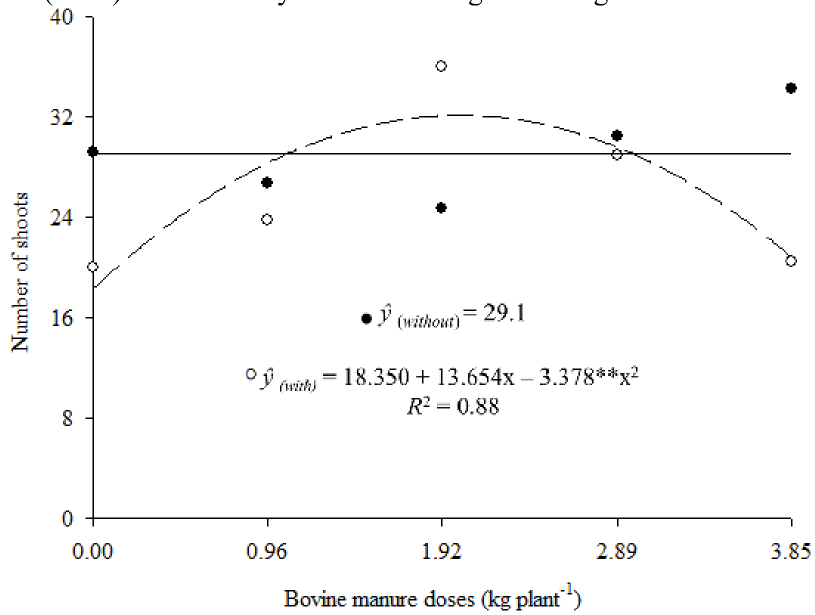

Figure 4. Number of shoots on stumps of neem plants, at 180 DAC, as a function of doses of cattle manure, in soil without (—) and with (- - -) calcitic limestone.

In an overall evaluation, the association of cattle manure with calcitic limestone demonstrates greater efficiency in promoting the growth and reestablishment of neem plants (*Azadirachta indica*) in field conditions. This synergistic combination has been particularly effective in enhancing various growth parameters, as evidenced by the recorded data for plant height from 360 to 720 days after transplanting (DAT) (Figure 1), absolute growth rate (AGR) (Figure 3A), relative growth rate in height (RGRH) (Figure 3B), and the regrowth of stumps following the cutting of plants in soils amended with both inputs (Figure 5). These findings underscore the complementary roles of cattle manure and calcitic limestone in addressing multiple soil constraints while fostering optimal conditions for plant development.

The significant improvements in plant height over time (Figure 1) can be attributed to the combined effects of cattle manure and limestone on soil properties. Cattle manure enhances soil fertility by supplying essential nutrients such as nitrogen, phosphorus, and potassium, while also improving soil structure through increased organic matter content. Simultaneously, calcitic limestone corrects soil acidity, reduces aluminum toxicity, and increases calcium availability, which are critical for root development and nutrient uptake. Together, these amendments create a favorable environment for sustained plant growth, as reflected in the consistent height increases observed between 360 and 720 DAT.

Similarly, the positive impact on the absolute growth rate (AGR) (Figure 3A) and relative growth rate in height (RGRH) (Figure 3B) highlights the dynamic interplay between improved soil conditions and plant physiological responses. The AGR represents the actual growth achieved over a specific period, while the RGRH reflects the efficiency with which plants convert available resources into biomass. The enhanced AGR and RGRH observed in plants treated with cattle manure and limestone suggest that the amendments not only increase resource availability but also improve the plants' capacity to utilize these resources effectively. This is likely due to the dual action of nutrient supply and soil physical conditioning, which together support robust root systems and efficient nutrient absorption.

Furthermore, the regrowth of stumps after cutting (Figure 5) provides additional evidence of the resilience conferred by the combined use of cattle manure and limestone. The residual effects of cattle manure, which slowly releases nutrients over time, ensure sustained support for regrowth even after the stress of cutting. Meanwhile, the long-term benefits of limestone, such as improved soil aggregation and reduced acidity, contribute to a stable and fertile rhizosphere environment that facilitates rapid recovery. This ability to promote regrowth is particularly valuable in agroforestry systems, where the cyclical harvesting of plant material requires quick and vigorous regeneration.

It is important to emphasize that the observed efficiencies are context-dependent and influenced by factors such as soil type, initial fertility levels, and environmental conditions. For instance, in acidic or degraded soils, the corrective effects of limestone and the nutrient-enriching properties of cattle manure are likely to have a more pronounced impact. Conversely, in fertile or well-structured soils, the incremental benefits may be less dramatic but still significant. Additionally, the timing and method of application, as well as the quality of the inputs, can influence the outcomes, highlighting the need for tailored management practices.

These results reinforce the value of integrating organic and mineral amendments in agricultural systems to address multiple soil limitations simultaneously. By combining the slow-release nutrient supply of cattle manure with the pH-correcting and structural benefits of limestone, farmers can optimize soil health and productivity, ensuring not only immediate growth improvements but also long-term sustainability. Such integrated approaches are particularly relevant for crops like neem, which are often cultivated in marginal or challenging environments where soil constraints can limit yield.

In this way, the main results highlighted in the graphical summary of Figure 6 can be evidenced.

Figure 6. Main results highlighted for the biometric growth and regrowth of neem plants with organic fertilization and lime application.

Conclusion

Application of cattle manure and calcitic limestone has significant effects on the growth in height at 720 DAT, on the absolute and relative growth rates in height from 360 to 720 DAT, and on the regrowth of stumps after cutting the plants at 180 DAC.

Increasing soil saturation by exchangeable bases from 60% to 80% with calcitic limestone improves the efficiency of cattle manure for the growth in height, absolute and relative growth rate in height and sprouting of stumps, after cutting the plants.

Cattle manure at a dose of 3.85 kg plant^{-1} in association with calcitic limestone results in greater growth of neem plants until 720 days after transplantation.

Application of 1.92 kg plant^{-1} and calcitic limestone stimulates the regrowth of neem after the first cut.

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References

Adekiya, A.O., Ejue, W.S., Olayanju, A., Dunsin, O., Aboyeji, C.M., Aremu, C., Akinpelu, O. 2020. Different organic manure sources and NPK fertilizer on soil chemical properties, growth, yield and quality of okra. Scientific Reports, 10(1), 16083. https://doi.org/10.1038/s41598-020-73291-x

Agegnehu, G., Amede, T. 2017. Integrated soil fertility and plant nutrient management in tropical agro-ecocystems: A review. Pedosphere, 27(4), 662-680. bhttps://www.sciencedirect.com/science/article/abs/pii/S1002016017603825

Alvares, C.A., Stape, J.L., Sentelhas, P.C., Gonçalves, J.L. de M., Sparovek, G. 2013. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, 22(6), 711-728. https://www.schweizerbart.de/papers/metz/detail/22/82078/Koppen_s_climate_classification_map_for_Brazil

Anikew, M.A.N., Eze, J. C., Abudialo, A.N. 2016. Influence of lime and gypsum application on soil properties and yield of cassava (*Manihote sculenta* Crantz.) in a degraded Ultisol in Agbani, Enugu Southeastern Nigeria. Soil & Tillage Research, 158(1), 32-38. https://doi.org/10.1016/j.still.2015.10.011

Artur, A.G., Cruz, M.C.P., Ferreira, M.E., Barretto, V.C. de M., Yagi, R. 2019. Esterco bovino e calagem para formação de mudas de guanandi. Pesquisa Agropecuária Brasileira, 42(6), 843-850. http://dx.doi.org/10.1590/S0100-204X2007000600011

Benincasa, M.M.P. 2003. Análise de crescimento de plantas. Jaboticabal: FUNEP.

Bittencourt, A.M., Santos, A.J., Hoeflich, V.A., Berger, R. 2009. O cultivo do nim indiano (*Azadirachta indica* A. JUSS.): Uma visão econômica. Floresta, 39(3), 629-642. http://dx.doi.org/10.5380/rf.v39i3.15362

Blanco-Caqui, H., Hergert, G. W., Nielsen, R.A. 2015. Cattle manure application reduces soil compactibility and increases water retention after 71 years. Science Society of America Journal, 79(1), 212-223.https://dl.sciencesocieties.org/publications/sssaj/abstracts/79/1/212?access=0&view=pdf

Campos, E.V.R., Oliveira, J.L., Pascoli, M., Lima, R., Fraceto, L.F. 2016. Neem oil and crop protection: From now to the future. Frontiers in Plant Science, 7(1494), 1-8. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5061770/

Chadwick, D., Wei, J., Yan'an, T., Guanghui, Y., Qirong, S., Qing, C. 2015. Improving manure nutrient management towards sustainable agricultural intensification in China. Agriculture, Ecosystems and Environment, 209(1), 34-46. https://doi.org/10.1016/j.agee.2015.03.025

Das, S., Jeong, S.T., Das, S., Kim, P.J. 2017. Composted cattle manure increases microbial activity and soil fertility more than composted swine manure in a submerged rice paddy. Frontiers in Microbiology, 8(1702), 1-10. https://www.ncbi.nlm.nih.gov/pubmed/28928727

Carnevali, N.H. de S., Paes, V.L., Ramos, D.D., Botelho, L.S., Carnevali, T.O. 2020. Desenvolvimento inicial de mudas de Jenipapo submetidas ao uso de esterco bovino e calagem. Cadernos de Agroecologia, 15(2), 1-5. https://cadernos.aba-agroecologia.org.br/cadernos/article/view/3846

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. 2009. Manual de análises químicas de solos, plantas e fertilizantes. (2 ed). EMBRAPA SOLOS.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. 2011. Manual de métodos de análise de solos. (2 ed). EMBRAPA SOLOS.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. 2013. Sistema Brasileiro de Classificação de Solos. (3 ed). EMBRAPA.

Fageria, N.K., Moreira, A., Moraes, L.A.C., Moraes, M.F. 2014. Influence of lime and gypsum on yield and yield components of soybean and changes in soil chemical properties. Communications in Soil Science and Plant Analysis, 45(3), 271-283. https://doi.org/10.1080/00103624.2013.861906

Ferreira, D.F. 2019. SISVAR: Um sistema de análise computacional para projetos do tipo split plot com efeitos fixos: Sisvar. Revista Brasileira de Biometria, 37(4), 529-535. https://doi.org/10.28951/rbb.v37i4.450

Gupta, S.C., Prasad, S., Tyagi, A.K., Kunnumakkara, A.B., Aggarwal, B.B. 2017. Neem (*Azadirachta indica*): An indian traditional panacea with modern molecular basis. Phytomedicine, 34(1), 14-20. https://doi.org/10.1016/j.phymed.2017.07.001

Karami, A., Homaee, M., Afzalinia, S., Ruhipour, H., Basirat, S. 2012. Organic resource management: Impacts on soil aggregate stability and other soil physico-chemical properties. Agriculture, Ecosystems and Environment, 148(1), 22-28. https://doi.org/10.1016/j.agee.2011.10.021

Mesquita, F.O., Cavalcante, L.F., Oliveira Filho, F.X., Rodrigues, R.M., Campos, V.B., Souza, J.K.C. 2019. Neem relative growth under supplementary irrigation with saline waters and biofertilizer. Comunicata Scientiae, 10(1), 45-53. https://doi.org/10.14295/cs.v10i1.2936

Moreira, A., Sfredo, G.J., Moraes, L.A.C., Fageria, N.K. 2015. Lime and cattle manure in soil fertility and soybean grain yield cultivated in tropical soil. Communications in Soil Science and Plant Analysis, 46(9), 1157–1169. https://doi.org/10.1080/00103624.2015.1033542

Moreira, V.O.G., De Assis Júnior, R.N., Aragão, T.C. 2020. Crescimento e fotossíntese do milho cultivado sob estresse salino com esterco e polímero superabsorvente. Irriga, 25(3), 603-616.https://doi.org/10.15809/irriga.2020v25n3p603-616

Neves, E.J.M., Carpanezzi, A.A. 2008. O Cultivo do nim para produção de frutos no Brasil. Colombo, EMBRAPA FLORESTAS.

Oliveira, L.F.R., Santos, P.H.R., Silva, L.G., Correia, L.P.S., Oliveira, B.L. 2019. Cultivo de meliáceas arbóreas no Brasil. Revista Brasileira de Tecnologia Aplicada nas Ciências Agrárias, 12(2), 2019. http://dx.doi.org/10.5935/PAeT.V12.N2.14

Otieno, H.M.O., Chemining'wa, G.N., Zingore, S. 2018. Effect of farmyard manure, lime and inorganic fertilizer applications on soil pH, nutrients uptake, growth and nodulation of soybean in acid soils of Western Kenya. Journal of Agricultural Science, 10(4), 199-208. http://www.ccsenet.org/journal/index.php/jas/article/view/72772

Pauletti, V., Pierri, L., Ranzan, T., Barth, G., Motta, A.C.V. 2014. Efeitos em longo prazo da aplicação de gesso e calcário no sistema de plantio direto. Revista Brasileira de Ciência do Solo, 38(2), 495-505. http://dx.doi.org/10.1590/S0100-06832014000200014

Rodrigues, R.M., Cavalcante, L.F., Souto, A.G.L., Gheyi, H.R., Mesquita, F.O. 2017. Growth and regrowth of neem after cutting in saline - sodic soil treated with organic inputs. Revista Caatinga, 30(1), 116–124. http://dx.doi.org/10.1590/1983-21252017v30n113rc

Silva, V.B. da., Silva, A.P., Dias, B.O., Araújo, J.L., Santos, D., Franco, R.P. 2014. Decomposição e liberação de N, P e K de esterco bovino e de cama de frango isolados ou misturados. Revista Brasileira de Ciência do Solo, 38(5). http://dx.doi.org/10.1590/S0100-06832014000500019

Souza, C.A.M., Oliveira, R.B., Martins Filho, S., Lima, J.S.S. 2006. Crescimento em campo de espécies florestais em diferentes condições de adubações. Ciência Florestal, 16(3), 243-249. http://dx.doi.org/10.5902/198050981905