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Root Growth, Nutrition and Yield of Maize with Applied Different Limestone Particle Size in the Cerrado Soil

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ABSTRACT

The limestone with smaller particle size provides rapid correction of soil acidity. However, the limestone with large particles can promote bigger root growth, and may still have a residual effect on the soil. The aim of this study was to evaluate the residual effect of the application and incorporation of different limestone with a particle size bigger than 0.30 mm in root growth, nutrition and yield of maize in Cerrado soil. A randomized completed block utilized in this experiment, with five treatments and four replications. The grain sizes of dolomitic limestone incorporated into the Oxisol were: 0 (control, no-lime), 2.00 - 0.82 mm, 0.82 - 0.56 mm, 0.56 - 0.30 mm, 0.30 - 0.20 mm, in doses of 6.5 t·ha^{-1}, 3.9 t·ha^{-1}, 2.6 t·ha^{-1} and 1.3 t·ha^{-1} respectively. The limestone applied in introduction no-tillage. The maize were evaluated of root attributes, nutrition and grain yield in two years 2009 and 2010. The use of limestone particle size of 2.00 - 0.82 mm, and the quantity of 6.5 t·ha^{-1} applied to the soil and incorporated showed elongation and root growth of maize thin depth of 20 - 40 cm in the soil. In that, same proposed management of the limestone was the highest maize grain yield in the first year. The rooting characteristics evaluated correlated with leaf Ca and Cu and maizegrain yield.

KEYWORDS

Limestone; No-Tillage; Zea Mays

1. Introduction

Systematic studies of the root system began in the eighteenth century, with the simple technique of excavation, observing the root system of cultivated plants and determining their morphology, weight and growth. With the increase of mineral fertilizers in agriculture in the second half of the nineteenth century, scientists interested in the study of agronomic roots have developed other techniques to study the dynamics of roots in the soil [1]. However, with less technological advances, root development and its influence on nutrition and crop production are little studied.

The roots constitute about 33% of the overall net primary productivity, and the inlet of carbon and nutrients in the soil from the roots is equal to or bigger than that provided by the leaves [2]. Despite its importance in understanding the terrestrial ecology, nutrient cycling and carbon, little information exists about its basic characteristics (biomass, length and surface area). This lack of studies is due mainly to the difficulties related to its determinations. Furthermore, root growth responds to soil management. Changes in the characteristics of the soil due to use of systems like no-tillage (NT) and liming changes the root growth.

The NT was installed in a systematic manner in all agricultural regions of Brazil, especially in the Cerrado. However, there are still investigations to elucidate the problem of lack of response to fertilizer and liming areas NT long term that may be linked to low efficiency of liming. According [3], in a liming experiment in NT consolidated application of gypsum with or without liming on the surface or incorporated, there was an interesting strategy for the establishment of no-tillage soybeans, since no improvement in production grain and even the very soil amendment .

The choice of species or crops used in NT depends on the adaptation of the climatic conditions of each region and the interest of the producer. In this perspective, the cultures of bigger economic interest in the Brazilian Cerrado are soybeans and maize. The maize crop rotation with soybeans in NT in central Brazil, contributes to the permanence of their trash in the winter, due to its low C: N ratio, favoring the soil cover, organic matter mineralization, and control weeds [4].

The great than the maize root lies in the depth 0 - 20 cm due to applied lime in surface soil in NT. Thus, this depth also showed too, a higher pH, higher organic carbon concentration and lower concentration of Al toxicity. Furthermore, the density of roots of maize (cm root per cm^3 of soil) was significantly correlated positively with the concentration of nutrients in surface soil [5]. The application of lime in the soil in conventional tillage causes considerable increase in maize production. The suitability of soil fertility and the correction of its acidity favor root development of maize plant [6].

The application of higher doses and bigger particle prolonged residual effect on the chemical on Oxisol [7]. The time reactivity of lime in the soil may waive the use of more liming, favoring the accumulation of organic matter by the use of no-tillage system. Thus, keeping the buffer capacity of the soil, or maintaining the pH that favors the availability of nutrients in the soil solution by providing the growth of roots.

The application of limestone with a particle size bigger than 0.30 mm (**Table 1**) in excess of the recommended dose and incorporated into the soil in tillage adoption favors the time correction of soil acidity and supply of Ca and Mg. The objective of this work was to verify the influence of the use of limestone with particle sizes bigger than 0.30 mm embedded in the soil attributes in root, the leaf contents of macro and micronutrients and productivity of maize in introduction of NT in Oxisol of Cerrado.

2. Materials and Methods

The experiment was installed in October 2009 in an experimental field near Goiânia-Goiás, located at latitude: 16˚36'6.91"S, Longitude: 49˚16'57.22"WO. The soil of this research was characterized with dystrophic Red Oxisol. The climate as classified as tropical rainy Aw savannah, having a sub-humid climate, with two distinct seasons: a drought lasting four to five months, and a rainy season occurring from late September to April, according Köppen Climate.

The experimental design was a randomized complete block with five treatments and four replications. The treatments consisted of four particle size classes limestone and a control treatment (no lime application). The limestone used in the experiment was classified as dolomite extracted from metamorphic rocks, with 38% de CaO and 13% MgO (**Table 1**). The limestone was divided into the desired particle classes through appropriate sieves.

The need for liming (*NL*) was calculated by the base saturation:

$$NL = (V2 - V1) \times T/100$$

where *V*2 is base saturation required by the crop, if we used 50%, *V*1 is base saturation current soil, *T* is the cations exchange capacity of the soil current total. The calculation of liming was based on the results of soil analysis before the experiment, the depth 0 - 20 cm depth (**Table 2**). The dose was calculated at 1.30 $Mg \cdot ha^{-1}$ whereas the depth of embedding of 0 - 20 cm and neutralization power equal 100%. The treatments had their rates adjusted as function of reactivity (**Table 1**).

The area of the experiment was no fallow crop planted for two years prior to the implementation of this experiment. Before that, it was used as a demonstration area for crops such as soybeans, maize and wheat. In both years

Table 1. Description limestone particle sizes, reactivity of lime, lime neutralization power (PN), relative power total neutralization (PRNT) and lime rates used to correct soil chemistry.

Particlesizes	Reactivity	PN	PRNT	Correction reactivity	Rates of lime applied
(mm)	--------------%----------------				($Mg \cdot ha^{-1}$)
Control	-	-	-	-	-
2.00 - 0.82	20	97.93	19.59	5× recommended rate	6.6
0.82 - 0.56	33	97.93	32.32	3× recommended rate	3.9
0.56 - 0.30	50	97.93	48.97	2× recommended rate	2.6
0.30 - 0.20	100	97.93	97.93	Recommended rate	1.3

Table 2. **Analysis results of soil in the experiment area at 0 - 20 cm depth.**

pH	Ca^{2+}	Mg^{2+}	Al^{3+}	$H^+ + Al^{3+}$	K^+	CTC[1]	P	V[2]	OM[3]	SAND	SILT	CLAY
(H_2O)	--------------$cmol_c \cdot dm^{-3}$----------------						$mg \cdot dm^{-3}$	%	----------------$g \cdot kg^{-1}$----------------			
5.8	0.6	0.5	0.2	3.9	0.19	5.2	1.7	25.0	20.0	370.0	175.0	455.0

1: Cationexchangecapacity; 2: Base saturation; 3: Organicmatter.

this area was barred annually to control invasive weeds mechanically.

The study soil was prepared with harrow of 12 × 32, or grille that has 12 discs with 32 inch, six months before the implementation of the experiment and the different doses and limestone particle size were applied two months before planting maize. Lime incorporation was performed with the aid of harrowing depth of 0 - 25 cm. The area of the experiment was fallow and soil cover was filled with weeds that grew naturally before planting. The different particle size limestone was application in the first year (2008).

The weeds that spread in the area were mostly *Urochloadecumbens*, *Panicum maximum*, *Cenchrus echinatus*, *Cyperus rotundus* and *Commelina benghalensis*. For planting maize weeds were controlled with desiccation using 3.5 $L \cdot ha^{-1}$ of glyphosate and 1 $L \cdot ha^{-1}$ 2.4-D spray volume of 100 $L \cdot ha^{-1}$. Maize was planted on December 15, 2008, in the first season 2008/2009 and on December 23, 2009 in the second season 2009/2010. The hydride was used 30A04 Yield Guard of Pioneer with spacing of 0.90 m with a population of 6 plants per meter. Maize received planting fertilization with 350 $kg \cdot ha^{-1}$ of fertilizer formulated 08-28-20 (N, P and K) with 1.5% micronutrients (B and Zn). Fertilization with N was done 30 days after planting maize where it was used 100 $kg \cdot ha^{-1}$ urea agricultural manually applied along the line of planting maize. Maize was conducted by applying cultivation as the emergence of weeds, pests and crop diseases.

Assessments of the effect of the application of different particle size of limestone were made in couple year (crop year 2008/2009 and 2009/2010). Soil sampling along with the roots was done with auger type "mug" tailored with 9.8 cm internal diameter and 60 cm in length, divided into a range of 10 cm to adjust the depth of the desired sample with a rod to facilitate the movement and force application. This method of root sampling was adapted from [1]. The auger has at its end a series of sharp edges, like a mountain, that aids in cutting the roots and the penetration of the equipment to the ground. The auger used was made of stainless steel and the iron rod. For every 10 cm depth have the ability to sample 754 cm^3 soil with roots. This sampling was done at 0 - 10 cm, 10 - 20 cm and 20 - 40 cm soil depth in two samples per plot in two years, 2009 and 2010. Samples were always collected at flowering maize (phenological stage R1).

The procedure to remove a sample of soil with roots began with the choice of the sampling area must be homogeneous with the crop of maize, excluding areas affected by pests and diseases, plantsuneven, nests, holes, etc. The auger was stuck into the ground so that it is close to the stems of maize, sectioning different desired depths. A maize plant was removed with the aid of a knife severing its stem near the ground, to facilitate removal of soil sample roots.

Samples destructive roots with soil were stored in plastic bags with proper identification. Plastic bags used possessed great strength to hold the weight of the soil. The samples were weighed on a precision balance before the separation of the roots in the soil, thus is the weight of the soil to the roots. A small sample was collected 100 g of the sample with destructive to ground roots to determine the water content in soil and deducted from it afterwards. These samples were stored in cold storage for a period of one month with temperatures below −5˚C for subsequent separation of roots and soil. The separation of roots from the soil was carried out in the shortest possible time from the extraction field, avoiding losses of dry mass or dehydration of the roots.

For obtaining the roots requires two steps that were consistent in the use of water to remove soil and other inert materials. The first step separated the roots from the soil with the aid of water. The second stage separated from the roots and other organic materials roots of the plant that are not of interest. In this first step, it was necessary to use a bucket for sample dispersion and deposition of soil in the roots with water. Then passes its contents in a ABNT 35 (500 micron mesh) by applying water to remove soil. To facilitate this, we used a round table made of plastic with holes of the same size sieves. This procedure was repeated four times to remove as much of the soil, avoiding any loss of roots.

After this separation, we collected waste (organic material and roots) retained in the sieve, and they were placed in labeled plastic bags for the process procedure. The waste collected were kept refrigerated in a cold chamber at −5˚C, proceed to the next wash. A second separation of roots occurred in the shortest time possible to avoid the presence of fungi in the roots as a result of moisture.

The washing process of the second sample was used to remove impurities which were as stones, coal, straw and small roots undesirable. These materials could hinder the process of image acquisition thus increasing source of error, especially in root weight. The second washing process was initiated with the deposition of the sample in the plastic bag in a container with water. After this, separate the roots of the impurities. Water helps remove the impurities that are stuck together the roots. We used a white container and shallow for better visualization of impurities. This procedure was repeated twice to obtain a sample without impurities, preventing loss of roots.

The digitization of maize roots separated from the soil were taken with the aid of the glass sheets of A4 size (21 cm × 29.7 cm) with 2 mm thickness without side edges. In this blade, is placed a transparent tape 2 cm long and 2 cm wide reference range for scanning the roots. Separate the roots were placed on paper towel to remove excess water may affect the scanning of the roots. The dried roots were separated and placed on glass slides, arranged in the vertical direction without overlapping, for subsequent scanning. The process of image acquisition roots was done by digitizing the same previously prepared with the use of a scanner table of appropriate size (with ability to scan an entire A4 sheet). The scanner was configured to capture images with a resolution of 300 DPI, with scanning in grayscale. The scan provided images with contrast, the roots black on a white background, for this was placed a sheet of blank paper and a transparency in the wall scanner. The scanner used in this study was the brand Genius model HR8.

The images acquired from maize roots were saved with the file extension type bitmap for further analysis in computer application SIARCS 3.0® [8]. The digitized roots were placed in paper bags identified weighed to obtain fresh weight of the roots. These roots were placed in greenhouses forced ventilation for 72 hours at 60˚C and then weighed to obtain their dry mass. The glass sheet size 21 cm × 29.7 cm, in some cases, the sampled root volume does not contain all of the roots. Thus, subsamples were taken and separated from the roots scanned. The subsamples of roots through the same process of roots scanned to obtain their green mass and dry mass. So, the end of the analysis process area and root length corrections were made based on the subsample to calculate its volume, area and length volume and mass of soil sampled.

The data area, length and root mass of maize were used to generate the following attributes depending on the root volume and mass of dry soil sampled: The root area due to the volume of soil sampled (ARV), the root area due the mass of soil sampled (ARM), root length due to the volume of soil sampled (CRV), root length depending on the weight of the sampled soil (CRM), the root mass as a function of the volume of soil sampled (MRV) the root mass as a function of the mass of soil sampled (MRS), root length as a function of root mass by the mass of soil sampled (CREM). The CREM refers to the diameter of the roots in the soil, the larger the relative length of the root mass, the smaller the diameter of these roots.

The nutrition of the plants was assessed from samples collected from maize leaves every season done. Leaf sampling was carried out in the maize when 50% to 75% of the crop had the female inflorescence, collecting below and opposite to the first spike, discarding the midrib, ten plants per plot. At the laboratory samples obtained were analyzed for the determination of macronutrients (Ca and Mg) and micronutrients (Cu, Fe, Mn and Zn) using the methodology described by [9].

The plots were harvested inside a useful plot of 20 m^2 on 15/04/2009 and on 25/04/2010 representing maize production in 2009 and 2010 respectively. These plots were threshed grain and maize were weighed correcting the grain moisture to 13%. The grain yield of maize extrapolated to megagram per hectare.

The data were statistically analyzed using the computer application [10]. Data were analyzed by applying the F test in analysis of variance and means were compared by Tukey test (α = 0.05). We performed the correlation of root attributes maize with chemical soil with foliar and production of this crop.

To evaluate the attributes of maize root area and length as two samples were collected per plot. Thus, considering the number of repetitions of 24 samples of maize roots per treatment were used. The results of root attributes of maize this study were submitted to the normality. When this data was not normal applied the methodology proposed by [11] to classify the coefficient of variation (C.V.) of these attributes. The classification of C.V. has shown how the study methodology was efficient to root.

3. Results and Discussion

The use of limestone in different particle size distribution did not change the root of the maize plant at 0 - 20 cm soil in 2009. In that year, the maize had bigger CREM using limestone to a particle size of 2.00 mm to 0.82 mm (**Table 3**). The residual effect of limestone in larger than 0.30 mm was also observed by [7,12,13].

The effectiveness of corrective materials soil acidity is measured only by the relative power of total neutralization (PRNT) according to the current legislation for limestone in the Brazil [14]. However, the residual effect of lime and root growth promoted by it not should be considered to measure its efficiency in Brazil. Thus, this information should be used to evaluate soil acidity corrective. Furthermore, the effectiveness of these correctives should consider the residual power of these limestones and crop response and not only the PRNT [15]. Else, in this work, the use of limestone in different particle sizes was effective on root development of maize plants.

Root attribute maize influenced by liming with differ-

Table 3. **Average values of attributes root of maize with application the lime in different particle size, in three soil depths (0 - 10 cm, 10 - 20 cm and 20 - 30 cm). Year 2009.**

Particles size (mm)	ARV[1] $cm^2 \cdot dm^{-3}$		ARM $cm^2 \cdot kg^{-1}$		CRV $cm \cdot dm^{-3}$		CRM $cm \cdot kg^{-1}$		MRV $g \cdot dm^{-3}$		MRS $g \cdot kg^{-1}$		CREM $cm \cdot g^{-1} \cdot kg^{-1}$	
							---------- 0 - 10 cm ----------							
Control	125.59	a[2]	92.77	a	1554.73	a	861.28	a	3.02	a	2.23	a	527.36	a
2.00 - 0.82	129.97	a	111.45	a	1701.41	a	1094.25	a	2.95	a	2.53	a	579.26	a
0.82 - 0.56	223.55	a	157.95	a	2301.11	a	1219.34	a	3.78	a	2.67	a	651.86	a
0.56 - 0.30	267.14	a	227.47	a	1922.03	a	1227.50	a	3.88	a	3.30	a	466.91	a
0.30 - 0.20	170.94	a	132.07	a	1825.56	a	1057.80	a	3.17	a	2.45	a	571.14	a
Average	183.44		144.34		1860.97		1092.03		3.36		2.64		559.31	
CV (%)	85.87		43.96		58.39		29.55		42.63		42.16		43.40	
CV ranks	Medium		Medium		Low		Low		High		High		Low	
							---------- 10 - 20 cm ----------							
Control	39.74	a	27.75	a	482.52	a	252.75	a	1.07	a	0.74	a	341.05	a
2.00 - 0.82	35.91	a	23.75	a	516.54	a	256.25	a	1.13	a	0.75	a	329.97	a
0.82 - 0.56	59.92	a	43.82	a	632.52	a	346.98	a	1.42	a	1.04	a	366.51	a
0.56 - 0.30	26.74	a	20.43	a	382.24	a	219.06	a	1.17	a	0.89	a	247.58	a
0.30 - 0.20	53.06	a	36.43	a	554.67	a	285.63	a	1.25	a	0.86	a	332.94	a
Average	43.07		30.44		513.70		272.14		1.21		0.86		323.61	
CV (%)	30.76		28.91		31.17		26.56		24.89		24.78		39.62	
CV ranks	Medium		Medium		Low		Low		High		High		Low	
							---------- 20 - 40 cm ----------							
Control	10.99	a	8.14	a	175.46	a	195.89	a	0.42	a	0.31	a	668.86	b
2.00 - 0.82	12.79	a	9.10	a	208.63	a	223.91	a	0.39	a	0.28	a	809.55	a
0.82 - 0.56	20.22	a	14.69	a	277.52	a	304.05	a	0.68	a	0.49	a	630.02	c
0.56 - 0.30	9.87	a	7.90	a	177.47	a	214.24	a	0.44	a	0.35	a	668.93	bc
0.30 - 0.20	17.17	a	12.80	a	252.35	a	503.01	a	0.45	a	0.34	a	758.53	ab
Average	14.21		10.53		218.29		288.22		0.48		0.35		707.18	
CV (%)[3]	61.08		36.77		50.52		21.76		27.46		27.11		19.58	
CV ranks[4]	High		High		Low		Low		High		High		Low	

[1]ARV: root area based on the volume of soil sampled; ARM: root area based on soil mass sampled; CRV: root length based on the volume of soil sampled; CRM: root length based on mass sampled soil; MRV: root mass based on the volume of soil sampled; MRS: dry root mass-based soil sampled; CREM: root length per root mass based on the mass of the sampled soil; [2]Values followed by lower case letters in the same column do not differ (Tukey test, $P < 0.05$); [3]CV (%): Coefficient of variation; [4]CV ranks: Coefficient of variation classification proposed by [11].

ent particle sizes, in all soil depth, presented probability distribution that deviated from normal in the two years of study. Thus, the classification of CV proposed by [11] was utilized to verify the efficiency of this variability data.

The CV values were average for ARV and ARM maize in the 0 - 10 cm and 10 - 20 cm depth, and high in the 20 - 40 cm soil depth. The average results from CRM, CREM CRV and had low CV values in all soil depths. The average results of MRV and MRS at high CV values in all soil depths, in 2009. Given these data, it can be said that the method was efficient auger to describe the characteristics of maize root development with the use of lime in the soil for the parameters involving root length.

Have to root mass, the auger method showed high CV values which may not reflect the reality of the root growth of maize through the use of limestone, due to the large variability in the data. However, it was essential that all parameters of roots were observed to generate the CREM attribute, which found that the use of limestone incorporated into the soil with a particle size bigger than 0.30 mm favored root development of maize in the 20 - 40 cm depth soil.

The limestone with a particle size between 0.56 mm to 0.30 mm provided bigger root mass of maize per soil volume (MRV), and particle size 0.30 mm to 0.20 mm caused bigger root mass per mass of maize soil (MRS) in the 0 - 10 cm soil depth in 2010 (**Table 4**). Already on

Table 4. Average values of attributes root of maize with application the lime in different particle size. in three soil depths (0 - 10 cm, 10 - 20 cm and 20 - 30 cm). Year 2010.

Particle size	ARV		ARM		CRV		CRM		MRV		MRS		CREM	
(mm)	$cm^2 \cdot dm^{-3}$		$cm^2 \cdot kg^{-1}$		$cm \cdot dm^{-3}$		$cm \cdot kg^{-1}$		$g \cdot dm^{-3}$		$g \cdot kg^{-1}$		$cm \cdot g^{-1} \cdot kg^{-1}$	
---------- 0 - 10 cm ----------														
Control	292.17	a	265.01	a	3186.12	a	2389.59	a	5.93	b	5.48	ab	350.17	a
2.00 - 0.82	243.27	a	181.56	a	2366.33	a	1774.75	a	6.05	ab	5.25	ab	383.80	a
0.82 - 0.56	292.80	a	233.86	a	2869.82	a	2152.36	a	6.32	ab	5.18	b	444.97	a
0.56 - 0.30	112.28	a	77.77	a	1102.83	a	827.13	a	7.29	a	4.17	b	136.35	a
0.30 - 0.20	329.80	a	228.96	a	3340.97	a	2505.73	a	7.03	ab	5.57	a	520.73	a
Average	254.06		197.43		2573.21		1929.91		6.53		5.13		367.21	
CV (%)	66.27		58.83		63.96		56.27		9.18		18.84		58.31	
CV Ranks	High		High		Medium		Medium		High		High		Medium	
---------- 10 - 20 cm ----------														
Control	65.02	a	49.14	c	708.08	a	531.06	b	5.41	a	4.40	ab	112.63	c
2.00 - 0.82	120.83	a	95.73	b	1037.28	a	777.96	b	5.25	a	4.19	ab	194.44	ab
0.82 - 0.56	245.47	a	218.01	a	2103.57	a	1577.68	a	6.70	a	6.25	a	271.40	ab
0.56 - 0.30	114.45	a	88.85	bc	1122.77	a	842.08	b	5.37	a	2.97	b	175.00	bc
0.30 - 0.20	199.38	a	168.98	ab	1901.48	a	1426.11	ab	4.31	a	3.60	ab	290.28	a
Average	149.03		124.14		1374.64		1030.98		5.41		4.28		208.75	
CV (%)	50.16		53.37		37.67		42.79		14.24		19.68		37.61	
CV ranks	High		High		Low		Low		High		High		High	
---------- 20 - 40 cm ----------														
Control	47.75	a	45.50	a	596.85	a	900.05	a	3.28	a	3.03	a	284.20	b
2.00 - 0.82	65.60	a	59.53	a	721.01	a	1087.29	a	2.88	a	2.85	a	426.22	ab
0.82 - 0.56	69.30	a	59.52	a	793.00	a	1195.84	a	2.79	a	2.49	a	484.14	a
0.56 - 0.30	46.99	a	40.92	a	461.80	a	696.40	a	3.18	a	2.19	a	255.50	b
0.30 - 0.20	74.65	a	65.67	a	747.36	a	1127.03	a	2.55	a	2.33	a	389.91	ab
Average	60.86		54.23		664.01		1001.32		2.94		2.58		367.99	
CV (%)	37.59		41.50		29.09		32.09		10.28		20.62		33.64	
CV ranks	High		High		Low		Low		High		High		High	

[1]ARV: root area based on the volume of soil sampled; ARM: root area based on soil mass sampled; CRV: root length based on the volume of soil sampled; CRM: root length based on mass sampled soil; MRV: root mass based on the volume of soil sampled; MRS: dry root mass-based soil sampled; CREM: root length per root mass based on the mass of the sampled soil; [2]Values followed by lower case letters in the same column do not differ (Tukey test, $P < 0.05$); [3]CV (%): Coefficient of variation; [4]CV ranks: Coefficient of variation classification proposed by [11].

depth 10 - 20 cm depth, the use of limestone with a particle size between 2.00 mm and 0.82 mm promoted larger area (MRA) and root length (CRM) maize. This same effect was found with particle size 0.30 to 0.20 mm for ARM in this work.

In 2010, the CV values were high for ARV and ARM maize in all soil depths. The average results of CRM and CRV and CREM had mean CV in the 0 - 10 cm depth and low in the 10 - 20 cm and 20 - 40 cm soil depth. The average results of MRV and MRS at high CV values in all soil depths. The CREM had average CV values in the 0 - 10 cm depth, and high in the 10 - 20 cm and 20 - 40 cm soil depth. However, the root length of maize was effectively described by the auger method.

The development of roots in the soil is prone to large variability because soils are very heterogeneous, even in experimental field condition, where it seeks to standardize the treatments increasing the number of samples per plot, this is hardly achieved. However, following the proposal of [11], the CV values are proportional data obtained when the data do not show normality. Therefore, the maize root parameters were influenced by the use of different particle sizes even with large limestone data variability.

The effective depth of the root system of maize is between 0.40 m to 0.46 m regardless of the system used, no-tillage or tillage [16]. Therefore, the limestone with different particle sizes provided that the roots of maize reached their effective depth in the soil. Since the particle size of 2.00 mm to 0.82 mm, promoted bigger volume of fine roots of maize that depth. Thus, resulted in a bigger use of land and nutrient absorption by the plant.

[17] also observed that the incorporation of lime and gypsum did not favor the growth of maize root system under NT. Already, [18] reported that maize root growth is affected by the concentration of Al in the soil. Like this, the limestone with large particle sizes in the soil promoted the precipitation of Al in the depth 20 at 40 cm, and this favored root growth of maize plants in the first and second year.

The thinner maize had roots in the amount of CREM depth 20 to 40 cm from the ground with the use of limestone of different particle size. Pursuant to, limes were effective to promote rooting of plants. Furthermore, [19] reported that the incorporation of lime dose of 6.8 $t \cdot ha^{-1}$ in a sandy loam, promoted root growth of maize to 0.45 m depth in the soil, compared to liming.

The values of root length density (CRV) and (CRM) in the first year were higher than those found by [16]. These authors reported that the roots of maize in two cropping system, direct and conventional, were with root length density around 1.0 cm^{-3} cm to 1.5 $cm \cdot cm^{-3}$ while using different particle sizes limestone this value was about 0.02 $cm \cdot cm^{-3}$ to 2.30 $cm \cdot cm^{-3}$ depending on the soil depth. In this sense, it shows that the root development of maize is related to the use of lime and soil depth in which this limestone corrects soil acidity.

The application and incorporation of particle size of 0.56 mm to 0.30 mm limestone soils decreased the concentration of Ca and Fe in maize leaves in the second year (**Tables 5** and **6**). Thus, the particle sizes of limestone thicker and higher dose provided equivalent levels of Ca, Mg, Cu, Fe, Mn and Zn in the leaves of maize compared to finer particle sizes , with the exception of particle size of 0.56 mm to 0.30 mm. In this sense, the application of lime to lower reactivity and higher volume did not impair the nutrition of the maize plant during the two years of cultivation.

The expected result in foliar nutrition of maize with the use of limestone in different particle sizes was that foliar Ca and Mg is increased as found by [6]. This author describes the application of lime increased the Ca

Table 5. Average values of nutrients in leaves of maize with application different particle size of limestone. Year 2009.

Particle size	Ca		Mg		Cu		Fe		Mn		Zn	
(mm)	-----$g \cdot kg^{-1}$-------				-----------------$mg \cdot kg^{-1}$-------------------							
Control	3.25	a[1]	1.00	a	12.00	a	223.75	a	62.50	a	18.80	a
2.00 - 0.82	4.50	a	2.00	a	11.25	a	213.50	a	57.00	a	19.65	a
0.82 - 0.56	4.25	a	2.25	a	12.25	a	220.25	a	57.00	a	20.08	a
0.56 - 0.30	4.00	a	2.00	a	10.75	a	215.50	a	52.25	a	19.35	a
0.30 - 0.20	4.75	a	2.25	a	11.25	a	221.25	a	58.50	a	19.30	a
Average	4.15		1.90		11.50		218.85		57.45		19.44	
CV (%)[2]	23.27		15.67		10.04		5.08		5.72		9.05	

[1]Values followed by lower case letters in the same column do not differ (Tukey test, $P < 0.05$); [2]CV: Coefficient of variation.

Table 6. Average values of nutrients in leaves of maize with application different particle size of limestone. Year 2010.

Particle size	Ca		Mg		Cu		Fe		Mn		Zn	
(mm)	------ $g \cdot kg^{-1}$-----				--------------- $mg \cdot kg^{-1}$---------------							
Control	2.33	b[1]	0.90	a	19.75	a	164.25	ab	52.00	a	18.00	a
2.00 - 0.82	3.45	a	1.33	a	18.75	a	152.00	ab	49.50	a	17.50	a
0.82 - 0.56	3.47	a	1.35	a	19.25	a	169.75	ab	45.75	a	18.75	a
0.56 - 0.30	2.96	b	1.27	a	19.00	a	144.33	b	51.00	a	19.67	a
0.30 - 0.20	3.62	a	1.45	a	20.25	a	177.75	a	51.75	a	19.50	a
Average	3.41		1.36		19.40		161.62		50.00		18.68	
CV (%)[2]	5.29		7.30		5.84		7.40		13.93		9.05	

[1]Values followed by lower case letters in the same column do not differ (Tukey test, $P < 0.05$); [2]CV: Coefficient of variation.

and Mg and reduced the concentration of K in the leaves of maize, while the Re-liming did not significantly alter the nutrient content. In fact, this has not occurred in this study due to the supply of Ca and Mg in soil with the use of limestone with particle size bigger than 0.2 mm and suitable to be slow, causing no chemical imbalance in the supply of nutrients for the plants maize which resulted in their nutrition.

According to [20], the application and incorporation of lime promotes significant reduction in the concentrations of Zn, Fe and Mn in leaves of maize in three of the four years studied, and Cu concentrations were not affected by the addition of lime. However, [17] found no influence of lime incorporation levels of macronutrients in maize leaves. Therefore, the present study agree with the work of [20] due to the fact that the limestone with a particle size of 0.56 mm to 0.30 mm decreased the concentration of Fe in leaves of maize in the second year. Trought, [17] showing that reactivity of lime with that grain size decreased the concentration of Ca.

The Ca and Mn in leaves of maize not showed significant correlation in 2009. Thus, attributes ARV, ARM, CRV, CRM and CREM maize significantly correlated with foliar Cu. Furthermore, ARV values correlated significantly with the ARM, CRV, CRM and CREM. Besides, the Ca in maize values correlated significantly with the Mn in leaves of maize (Table 7). Therefore, root development interfered with foliar nutrients and this reflected in the productivity of maize.

In 2010 there was also a significant correlation between MRV and yield of maize and values ARM ARV, CRV, CRM and CREM, and MRV with MRS significantly correlated with each other (Table 8). Even with these correlations, the root development of maize provided by the use of limestone with different particle size did not result in increased levels of nutrients in maize leaf and grain yield of maize.

Most maize grain yield was found with the use of limestone particle size 2.00 mm to 0.82 mm in the first year (Table 9). That same particle size was found to further development of fine roots (CREM) in the depth 20 - 40 cm soil depth. Even so, there was no correlation between this particle and maize production.

The distribution and activity of roots determine the amount of water and nutrients absorbed [21]. Thus, the use of limestone with large particle sizes (2.00 mm to 0.82 mm) improved root distribution in the soil and this allowed the correlation between the absorption of nutrients like Ca and Mg in the case and also in the production of grain maize in the second year. But this influence root development did not reflect a significant difference between the use of limestone in different particle sizes for the production of maize in the second year.

The method of the monolith adapted from [1] to study

Table 7. Pearson correlation between Ca, Mg, Cu, Fe, Mn and Zn in leaves of maize, root attributes and grain yield of maize with application different particle sizes of limestone. Year 2009.

Variables	Ca	Mg	Cu	Fe	Mn	Zn	ARV(1)	ARM	CRV	CRM	MRV	MRS	CREM	Grain yield
Ca	1	0.24	0.08	−0.11	0.47**	−0.03	-0.17	−0.21	−0.18	−0.24	0.08	−0.03	−0.31	0.21
Mg	0.24	1	−0.16	0.04	0.14	0.24	0.26	0.15	0.30	0.18	−0.05	0.17	0.15	−0.05
Cu	0.08	−0.16	1	0.20	−0.01	0.14	−0.57**	−0.60**	−0.46**	−0.48**	−0.12	0.00	−0.54**	0.28
Fe	−0.11	0.04	0.20	1	−0.05	−0.23	−0.22	−0.18	−0.25	−0.21	0.16	0.04	−0.22	0.02
Mn	0.47**	0.14	−0.01	−0.05	1	0.03	−0.20	−0.29	−0.25	−0.34	−0.12	−0.07	−0.34	0.27
Zn	−0.03	0.24	0.14	−0.23	0.03	1	−0.05	−0.11	−0.02	−0.09	−0.01	0.21	−0.10	−0.13
ARV	−0.17	0.26	−0.57**	−0.22	−0.20	−0.05	1	0.98**	0.96**	0.93**	0.16	0.38	0.94**	−0.10
ARM	−0.21	0.15	−0.60**	−0.18	−0.29	−0.11	−0.98**	1	0.92**	0.95**	0.21	0.32	0.97**	−0.16
CRV	−0.18	0.30	−0.46**	−0.25	−0.25	−0.02	−0.98**	0.92	1	0.97**	0.22	0.47**	0.94**	−0.15
CRM	−0.24	0.18	−0.48**	−0.21	−0.34	−0.09	−0.98**	0.95	0.97	1	0.26	0.41	0.98**	−0.22
MRV	0.08	−0.05	−0.12	0.16	−0.12	−0.01	0.16	0.21	0.22	0.26	1	0.67**	0.19	0.00
MRS	−0.03	0.17	0.00	0.04	−0.07	0.21	0.38	0.32	−0.98**	0.41	−0.98**	1	0.29	−0.06
CREM	−0.31	0.15	−0.54**	−0.22	−0.34	−0.10	0.94**	0.97**	0.94**	0.98**	0.19	0.29	1	−0.19
Grain yield	0.21	−0.05	0.28	0.02	0.27	−0.13	−0.10	−0.16	−0.15	−0.22	0.00	−0.06	−0.19	1

*Significant at 1% for test F; **Significant at the 5% for test F; (1)ARV: root area based on the volume of soil sampled; ARM: root area based on soil mass sampled; CRV: root length based on the volume of soil sampled; CRM: root length based on soil mass sampled; MRV: root mass based on the volume of soil sampled; MRS: dry root mass-based soil sampled; CREM: root length per root mass based on the mass of the sampled soil.

Table 8. **Pearson correlation between Ca, Mg, Cu, Fe, Mn and Zn in leaves of maize, root attributes and grain yield of maize with application different particle sizes of lime. Year 2010.**

Variables	Ca	Mg	Cu	Fe	Mn	Zn	ARV(1)	ARM	CRV	CRM	MRV	MRS	CREM	Grain yield
Ca	1	0.34	0.20	0.67**	−0.55**	0.31	0.01	−0.04	−0.02	0.07	−0.06	0.04	−0.06	−0.44
Mg	0.34	1	−0.26	0.05	−0.24	0.04	0.17	0.10	0.23	0.24	0.17	0.01	0.06	−0.57
Cu	0.20	-0.26	1	0.35	0.23	0.21	0.02	0.03	−0.14	−0.40	−0.12	−0.30	−0.12	0.10
Fe	0.67**	0.05	0.35	1	−0.21	0.18	0.16	0.17	0.08	0.12	0.08	0.24	0.10	0.14
Mn	−0.55**	−0.24	0.23	−0.21	1	−0.10	0.00	0.01	−0.04	−0.08	−0.03	−0.13	−0.15	0.56
Zn	0.31	0.04	0.21	0.18	−0.10	1	−0.10	−0.13	−0.16	−0.02	−0.18	−0.11	−0.20	−0.01
ARV	0.01	0.17	0.02	0.16	0.00	−0.10	1	0.98**	0.97**	0.62**	0.96**	0.72**	0.89**	−0.08
ARM	−0.04	0.10	0.03	0.17	0.01	−0.13	0.98**	1	0.94**	0.56**	0.96**	0.72**	0.92**	0.00
CRV	−0.02	0.23	−0.14	0.08	−0.04	−0.16	0.97**	0.94**	1	0.66**	0.98**	0.70**	0.89**	−0.13
CRM	0.07	0.24	−0.40	0.12	−0.08	−0.02	0.62**	0.56**	0.66**	1	0.61**	0.87**	0.59**	−0.22
MRV	−0.06	0.17	−0.12	0.08	−0.03	−0.18	0.96**	0.96**	0.98**	0.61**	1	0.71**	0.94**	−0.07
MRS	0.04	0.01	−0.30	0.24	−0.13	−0.11	0.72**	0.72**	0.70**	0.87**	0.71**	1	0.74	0.03
CREM	−0.06	0.06	−0.12	0.10	−0.15	−0.20	0.89**	0.92**	0.89**	0.59**	0.94**	0.74**	1	−0.09
Grain yield	−0.44	−0.57	0.10	0.14	0.56	−0.01	−0.08	0.00	−0.13	−0.22	−0.07	0.03	−0.09	1

*Significant at 1% for test F; **Significant at the 5% for test F; (1)ARV: root area based on the volume of soil sampled; ARM: root area based on soil mass sampled; CRV: root length based on the volume of soil sampled; CRM: root length based on soil mass sampled; MRV: root mass based on the volume of soil sampled; MRS: dry root mass-based soil sampled; CREM: root length per root mass based on the mass of the sampled soil.

Table 9. **Grain yield of maize ($mg \cdot ha^{-1}$) with application different particle size of lime, in two year (2009 and 2010).**

Particle size (mm)	Grain yield of maize --------$mg \cdot ha^{-1}$----------						Average	CV (%)
	2009			2010				
Control	4.89	b[1]	A	5.31	b	A	5.10	28.38
2.00 - 0.82	9.89	a	A	7.01	a	B	8.44	10.89
0.82 - 0.56	7.77	ab	A	7.51	a	B	7.65	23.65
0.56 - 0.30	7.02	b	B	7.85	a	A	7.43	26.06
0.30 - 0.20	5.48	b	B	7.09	a	A	6.28	9.81
Average	7.41		A	6.95		A		
CV(%)[2]	15.57			12.61				

[1]Means followed by the same letter in lowercase in columns and uppercase in the row do not differ by Tukey test ($P < 0.05$); [2]CV: Coefficient of variation.

the maize root development with the use of lime and applied superficially embedded in dystrophic Argisol [18]. This method requires the opening of a trench to observe root development. Thus, the auger method is more practical because of no need of opening a trench in the study of maize roots and shows the possibility of study parameters between root area, length and weight of maize roots.

4. Conclusion

The further development of fine roots of maize (CREM) is found with the use of lime particle size of 2.00 mm to 0.82 mm in the first year. The root development of maize influences the absorption of Ca, Mn and Cu, as well as in the production of maize. The methodology auger associated with the processing of images of roots is efficient to check the response of maize to soil acidity corrective.

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