LIMING IN THE CHEMICAL PROPERTIES OF A FERRALITIC SOIL OF ANGOLA

CALAGEM NAS PROPRIEDADES QUÍMICAS DE UM SOLO FERRALÍTICO DE ANGOLA

Jorge Delfim [1*†], Ginhas Manuel [2] and Santos Quizembe [1]
[1]Estação Experimental Agrícola da Chianga (EEAC), Instituto de Investigação Agronómica (IIA), Chianga - Huambo, Angola.
[2]Departamento de Agronomia, Faculdade de Ciências Agrárias (FCA), Universidade José Eduardo dos Santos (UJES), Chianga - Huambo, Angola.
* Corresponding author E-mail: jorgedelfim88@yahoo.com
[†]Actual address: Programa de Pós-graduação em Agronomia da Universidade Estadual de Londrina, PR. Brasil.

ABSTRACT
Liming is one of the most efficient and prevailing practices to correct soil acidity and improve soil fertility. Soil acidity and low native fertility, however, are major constraints for agriculture production of Angola. The objective of this study was to evaluate liming influence on changes in soil chemical properties of a Chianga Ferralitic Soil. The soil was collected from 0 to 20 cm depth at central plateau of Angola. The experimental design applied was completely randomized factorial 6x2 (six lime rates and two soil sampling time) with five replications. The treatments consisted of sex lime rates: 0, 1, 2, 4, 6 and 8 Mg ha^{-1} lime tr-eatments. The soil was incubated for 90 days at 60% water-holding capacity, sampling soil at 60 and 90 days after incubation for chemical analysis. The liming had significant interactions effect between the treatments and the soil sampling time (P = 0.1 and 0.001), and the different rate of lime increase pH, Ca^{2+}, BS, ECEC and reduce Al^{3+} toxicity and Al^{3+} saturation in soil. The results of this study show that the rate of lime between 4 and 8 Mg ha^{-1} reduce soil acidity and improve its fertility.
Keywords: Soil acidity, liming, Ferratic soil of Angola.

RESUMO
A calagem é uma das praticas, mas eficientes e predominante para corrigir a acidez do solo e melhorar a sua fertilidade. Portanto, a acidez do solo associado a baixa fertilidade, são importantes limitantes para a produção agrícola em Angola. O objetivo deste trabalho foi de avaliar a influencia da calagem nas propriedades químicas de um solo ferralítico (Oxisol) da Chianga. A amostragem do solo foi realizada na camada de 0 – 20 cm de profundidade no planalto central de Angola. O desenho experimental utilizado foi o completamente casualisado com um arranjo fatorial 6x2 (seis doses de calcário e duas épocas de amostragem do solo) e 5 repetições. Os tratamentos foram constituídos por seis doses: 0, 1, 2, 4, 6 e 8 Mg ha^{-1} de calcário. O solo foi incubado durante 90 dias a 60% da capacidade de campo, e se realizou amostragem de solo aos 60 e 90 dias depois da incubação para a analise química. A calagem teve efeito significativo na interação entre os tratamentos e as épocas de amostragem do solo (P = 0.1 e 0.001), e as diferentes doses de calcário incrementaram significativamente o pH, Ca^{2+}, SB, CTC efetiva e reduziu a toxidade do Al^{3+} a saturação por Al do solo. Os

resultados deste trabalho mostraram que as doses de calcário entre 4 e 8 Mg ha^{-1} reduz a acidez do solo e melhora a sua fertilidade.
Palavra chave: acidez do solo, calagem, solos ferralíticos de Angola.

INTRODUCTION

Land degradation due to soil acidity is one of the most important limitations for optimal use of land resources for higher crop production worldwide (Sumner and Noble, 2003). Approximately one third of the soils of the world are acidic (pH < 6.5), and as much as 50% of the world's potentially cropped lands are acidic (Von Uexkull and Mutert, 1995). One of the major constraints on crop production in most soils from tropical regions (e.g., Ferralsols or Oxisols) is greatly associated with the soil acidity. Moreover, tropics and subtropics account for 60% of the acid soils in the world. In Angola, about 85% of the arable land corresponds to Ferralsols or Oxisols (CEP, 1995; Franco and Raposo, 1997), which may have marked consequences on acidity management for agricultural production, because, about 80% of the surface of Angola is occupied by soils of acid reaction (Dias, 1973). Theoretically, soil acidity is measured by determining hydrogen (H+) and aluminum (Al3+) ions in soil solution. However, for crop production, soil acidity is a complex issue involving availability of many essential plant nutrients and toxicity of some elements. The problem of soil acidity affects soil production across Asia, America, Europe and Africa as well as imposes heavy costs on farmers in Europe and North America. The production of staple food crops, is negatively impacted by soil acidity (Sumner and Noble, 2003).

Acid soils in the plateau of southern Angola are because parent materials that are initially law in basic cations, law effective cation exchange capacity (ECEC), agriculture practices, and high rainfall areas wherein heavy precipitation leads to leaching of appreciable amounts of exchangeable basic ions like Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} from surface soil and causes colloidal exchange sites to be dominated by H+, Al3+ ions and high aluminum saturation (CEP, 1995; Asanzi et al., 2006; Madeira et al., 2015). Dominance of H^{+} and Al^{3+} ions in colloidal exchange sites is toxic for plants (Behera and Shukla, 2014). Most of the acid soils had more of the problems including low base saturation percentage and low concentrations of exchangeable Ca^{2+}, Mg^{2+} and K^{+}. Detrimental effects of soil acidity on plant growth are related to Al3+ (which causes stunted root development) and the availability of soil nutrients, which may increase with decrease in pH (Fe, Mn, Cu, Zn and Co), decrease with increase in pH (Ca^{2+}, Mg^{2+}, and K^{+}) or be restricted to pH intervals (P, B and N) because of different processes (Chintala, 2012).

Chemical characterization of soil properties is required for effective management of acid soils, for more efficient crop production, including lime application for amelioration which is an established practice. Liming has shown a synergistic interaction with applied nutrients (through fertilizers) and increased the nutrient uptake by plants by suitably changing soil chemical and physical properties (Chintala, 2012). With the neutralization of part of the soil total acidity by lime application, negative charges of the soil exchange complex are released and then occupied by Ca^{2+}, Mg^{2+} and K^{+} improving the soil fertility and the conditions for agricultural production (Kamprath, 1984). Uniform rate of liming by the farmers without considering the variability of soil properties in an area leads to sub-optimal use of inputs and unsustainable crop production. Therefore, information about soil pH and other properties like soil organic carbon content and status of exchangeable basic cations like $Ca^{2+,}$ Mg^{2+} and K^{+} are required for effective assessment of lime requirement and adoption of other management

options in a particular area for efficient and sustainable crop production (Oates and Kamprath, 1983). Soil pH is an important property of soils determining the availability and toxicity of nutrients. Variation in pH across fields will undoubtedly affect the level of soil acidity and availability of nutrients if applied as fertilizer in uniform quantities.
The correction of soil acidity in Angola soils (e.g., Ferralsols or Oxisols) is essential to improve the soil fertility and increases in yields, which have been widely represented in the Angolan territory (CEP, 1995), especially in the old plateau, occurring in somewhat differentiated climatic conditions and evolving on very different originating materials. These soils are also the most representative in vast areas of Angola considered of great importance for the development of the agricultural sector (Asanzi et al, 2006). The general characteristics of Ferralitic Soils are; horizon B, show the null or weak "alterable mineral reserve" in the sandy fraction, a direct cation exchange capacity at pH 7 (ammonium acetate method) of the "colloidal fraction (with a SiO_2/Al_2O_3 ratio of less than 2) generally below 15 $cmol_c\ kg^{-1}$, strongly to moderately acid soil reaction and generally less than 50% base saturation and low ECEC. However, Ferralitic Soils present a certain diversity, evidenced by the characteristics of the respective suborders CEP, 1995). Many soils in Angola are naturally very acid and unfertile to great depths in the profile. Cultivation of such soils without inputs results in very low yields. Which has maintained the farming population in poverty. Thus, the solution to the problem of soil acidity in developing does not require more research but the aggressive extension program to promote the use of lime, gypsum in quantity necessary for correction soil acidity and other inputs. Whose benefits have been amply demonstrated in other soils. The quantity of lime required depends on the soil type, quality of liming material, costs and crop species or cultivars (Fageria, 2008a). Information on appropriate liming rates for acid soils in Angola is limited or not exist. Knowledge the problem in this soil the aims of this study was to evaluate liming influence on changes in soil chemical properties of a Chianga Ferralitic Soil (Oxisols).

MATERIALS AND METHODS

Soil

The Ferralitic soil was collected in 2014 from 0 to 20 cm depth at Chianga Agricultural Experiment Station about (2,550 ha) in the province of Huambo, situated at central plateau of Angola, which lies between 12º 14' and 12º 16'latitude and between 15º 48' and 15º 52' longitude. This site lies at elevation 1700 m above sea level. Mean annual precipitation 1400 mm, and mean annual temperature 19 ºC. According to the Köppen classification, the study area has a tropical savanna climate, which has monthly mean temperature above 18°C. The soil was dried at ambient temperature and passed through a 2 mm sieve. The properties of the soil are as follows: depth (0 – 20 cm) prior to treatment (Table 1).

Table 1. The properties of the soil prior to establishment of the experiment (depth 0 - 20 cm)

Sandy	Silt	Clay	pH		$cmol_c\ Kg^{-1}$							(%)
	%		H_2O	$CaCl_2$	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	BS	ECEC	Al Sat.
57,5	14,75	27,75	4,1	3,8	0,10	0,05	0,23	0,00	1,25	0,39	1,64	76,35

BS = bases sum, ECEC= effective cations exchange capacity, Al Sat= aluminum saturation.

Experimental design

The experimental design applied was completely randomized factorial 6x2 (six lime rates and two soil sampling time) with five replications. The treatments consisted of four lime rates: 0, 1, 2, 4, 6 and 8 Mg ha^{-1} lime treatments. The soil was incubated for 90 days using 1kg-1 of soil in plastic bags at 60% of field capacity using distilled water. Irrigation was applied manually. was incubated in the laboratory of soil and plant analysis at Chianga Agricultural Experiment Station, realizing sampling soil at 60 and 90 days after incubation for chemical determinations. Liming material had neutralizing power 80% was used and classified as limes of calcitic type.

Chemical determinations

Soil pH was measured pH in a 2:2.5 soil – water suspension and $CaCl_2$ 0,01 mol L^{-1} suspension. Cation exchange K^+, Ca^{2+}, Mg^{2+} and Na^+, was determined using 5 g soil with 100 mL of 1 mol L^{-1} ammonium acetate (NH_4OAc) buffered at pH 7,0, Ca^{2+} and Mg^{2+} by (atomic absorption spectrophotometer model PG-990, PG instruments Ltd, UK) K^+ and Na^+ by (Flame spectrophotometer, Chicago, USA), Al^{3+} was extracted with 1 mol L^{-1} potassium chloride (KCl), and was determined by titration with sodium hydroxide (NaOH). Soil analysis methods used in this study are described in a soil analysis manual published by (Embrapa, 1997; Camargo, 2007). The effective cation exchange capacity (ECEC), base sum (BS), and Al^{3+} saturations were calculated.

$$ECEC\ (cmol_c\ Kg^{-1}) = \Sigma(K^+, Ca^{2+}, Mg^{2+}, Na^+, Al^{3+})$$

$$BS\ (cmol_c\ Kg^{-1}) = \Sigma(K^+, Ca^{2+}, Mg^{2+}, Na^+)$$

$$Al^{3+}\ saturation\ (\%) = [Al^{3+}/ECEC] \times 100$$

Statistical analysis

Data were analysed by GLM method (treatments, soil sampling time and treatments x soil sampling time) for two sampling time, and regression analysis was used to evaluate the relationship between pH, Ca^{2+}, Al^{3+}, BS, Al saturation and treatments (lime rates) with (SPSS 23 Inc., Chicago IL, USA).

RESULTS

Ferralitic Soil (Oxisols) of the plateau of southern Angola had significant interactions effect between the treatments and soil sampling time, the lime reaction in the soil significantly affected many parameters measured (P = 0.1 and 0.001 Table 2). However, had not significant interactions on the exchangeable Mg^{2+}, K^+ and Na^+ content of the soil at any treatments and soil sampling time. Al^{3+} had significant effect, solely in the Treatment x soil sampling time had not significant interaction (P = 0.1 and 0.001 Table 2). The significant effect interaction of treatments (lime rates of $CaCO_3$) x soil sampling times (incubation 60 and 90 days) is also another indication to this different behavior rates, the time after lime application and the quantity of lime in soil.

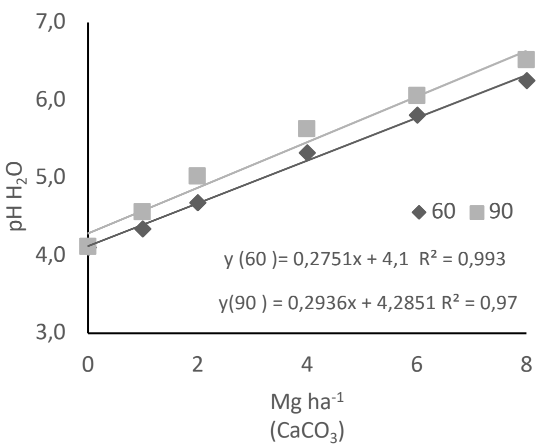
Table 2. The effects of the liming in the soil chemical proprieties

GLM Model	pH		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	ECEC	BS	Al^{3+} Sat.
	H_2O	$CaCl_2$	$cmol_c\ kg^{-1}$							%
Treatments	***	***	***	ns	ns	Ns	***	***	***	***
SST	***	***	***	ns	ns	Ns	*	***	***	***
Traet x SST	***	***	***	ns	ns	Ns	ns	***	***	***

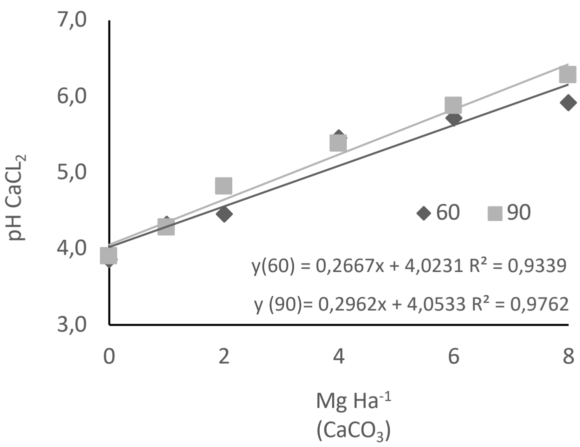
ns: not significant, * and ***: significant at P = 0.1, and 0.001, respectively. SST= soil sampling time, treat= treatments, ECEC = effective cations exchange capacity, BS= base sum, Al^{3+} Sat= Aluminum saturation.

The different rate of lime ($CaCO_3$) 0 - 20 cm depth in a Feralitic soil in 60 and 90 days of soil sampling time was having significant linear response in relation to pH-H_2O and $CaCl_2$ (Figure 1a and b), Ca^{2+}, ECEC and BS (Figure 1c, e and g), in case of the Al^{3+} and Al saturation having significant exponential response, the values were quite in the sampling time (60 and 90) and variable depending the lime rates and constant in the height doses of lime (Figure 1d and f).

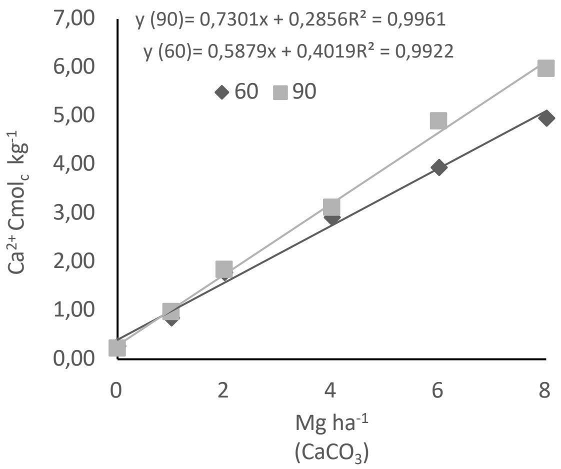
(a)



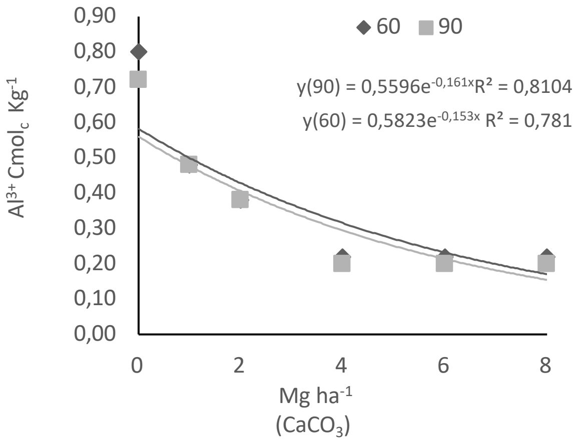
(b)



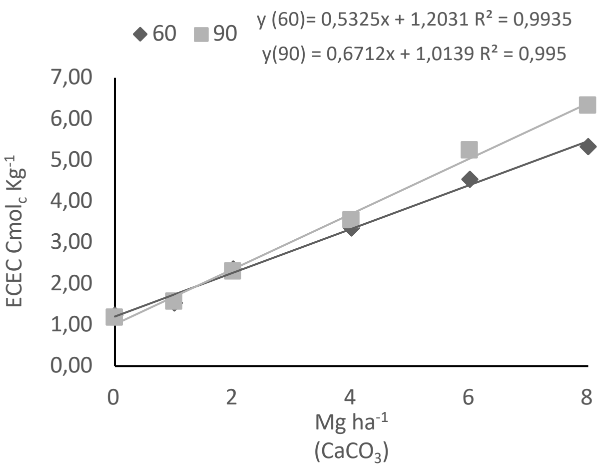
(c)


y (90)= 0,7301x + 0,2856R² = 0,9961
y (60)= 0,5879x + 0,4019R² = 0,9922
60 90
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
0 2 4 6 8
Ca^{2+} $Cmol_c$ kg^{-1}
Mg ha^{-1}
($CaCO_3$)

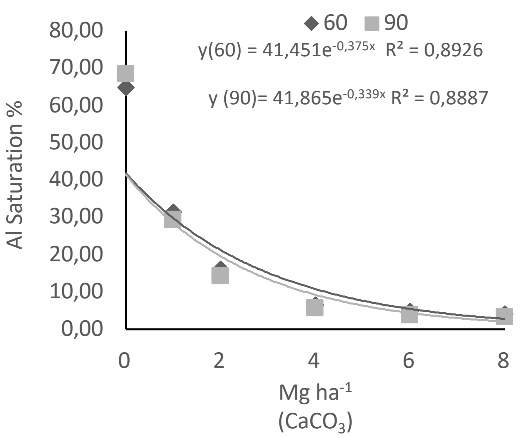
(d)


60 90
y(90) = $0,5596e^{-0,161x}$R² = 0,8104
y(60) = $0,5823e^{-0,153x}$ R² = 0,781
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
0 2 4 6 8
Al^{3+} $Cmol_c$ Kg^{-1}
Mg ha^{-1}
($CaCO_3$)

(e)


60 90
y (60)= 0,5325x + 1,2031 R² = 0,9935
y(90) = 0,6712x + 1,0139 R² = 0,995
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
0 2 4 6 8
ECEC $Cmol_c$ Kg^{-1}
Mg ha^{-1}
($CaCO_3$)

(f)


60 90
y(60) = $41,451e^{-0,375x}$ R² = 0,8926
y (90)= $41,865e^{-0,339x}$ R² = 0,8887
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
0 2 4 6 8
Al Saturation %
Mg ha^{-1}
($CaCO_3$)

(g)

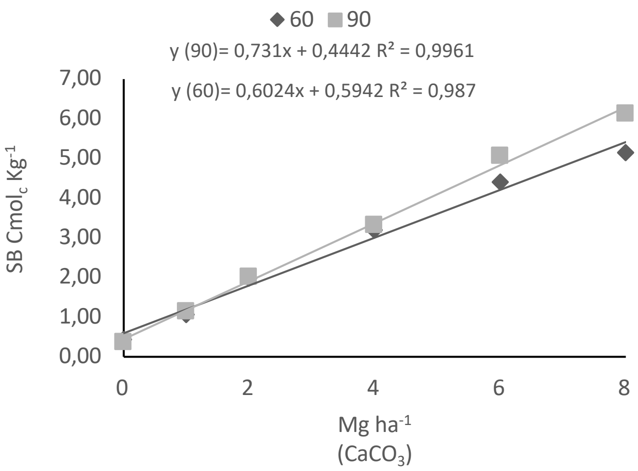

60 90
y (90)= 0,731x + 0,4442 R² = 0,9961
y (60)= 0,6024x + 0,5942 R² = 0,987
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
0 2 4 6 8
SB $Cmol_c$ Kg^{-1}
Mg ha^{-1}
($CaCO_3$)

Figure 1. Effects of the liming in the Ferralitic soil chemical proprieties in different soil sampling time, they should be listed as: (a) pH-H_2O, (b) pH-$CaCl_2$, (c) Ca^{2+}, (d) Al^{3+}. (e) ECEC, (f) Al saturation and (g) BS. 60 and 90 = soil sampling time (days of incubation).

Soil pH changes over 60 and 90 soil sampling time (days of incubation) of lime applications increase significantly 2.2 and 2.4 (pH-H_2O) and 2.0 and 2.4 (pH-$CaCl_2$) units in treatment (8 Mg ha^{-1}) compared to the control (0 Mg ha^{-1}) (Figure 1a and b). Exchangeable Ca^{2+} increased at all lime rate compared with the control, particularly in the (8 Mg ha^{-1}), where it increased 4.70 and 5.76 cmol$_c$ kg^{-1} (60 and 90 days of incubation) compared to the control 0 Mg ha^{-1} (Figure 1c). The lime used in this study had an increase BS content of 4.31 and 5.75 cmol$_c$ kg^{-1} (60 and 90) soil sampling time, ECEC content in soil increase 4.90 and 5,16 cmol$_c$ kg^{-1}, 8 Mg ha^{-1} compared to the control 0 Mg ha^{-1}; therefore, the input of BS, ECEC to the soil increased linearly in proportion to the rate of lime applied (Figure1e and g). Al^{3+} and Al^{3+} saturation significantly decreased with rate of lime past 60 and 90 soil sampling time (0.58 and 0.52 cmol$_c$ kg^{-1}; 60.70 and 65.56 %), rate 8 Mg ha^{-1} compared to the 0 Mg ha^{-1} (Figure 1d and f).
The relationship was determined between treatment and pH in water in two sampling time using simple linear regression (Table 3).

Table 3. Regression equations showing relationship treatments and pH-H_2O in different soil sampling time.

Treatment (X) vs pH-H_2O values (Y)	Regression equation	R^2
60	Y= 4.122 + 0.275X	0,993[a]
90	Y= 4.285 + 0.294X	0.976[a]

[a] Significant at the 1% probability level. SST = soil sampling time, 60 and 90= days after incubation.

DISCUSSION
The present study incubated the Ferralitic Soil with different rates lime 0, 1, 2, 4, 6 and 8 Mg ha^{-1} ($CaCO_3$). The results showed that the liming had significant interactions effect between the treatments and the soil sampling time (P = 0.1 and 0.001, Table 2), This positive effect was observed by (Fageria and Baligar, 2008b; Hirzel et al., 2016). Mg^{2+} was not affected by treatment, soil sampling time and interaction by two factors, this negative effect was caused by lime type. This lime had low percent of MgO and correspond a calcitic limestone. therefore, when using this lime type, it is necessary to correct magnesium deficiency with synthetic or organic fertilizers or others material if necessary.
The lime was positive effect in the many chemical properties of soil (pH, Ca^{2+}, Al^{3+}, ECEC, Al^{3+} saturation and BS, Figure 1a,b,c,d,e,f, and g), the changes observed in these parameters are similarly reported by Campanharo et al., (2007). The soil pH at an optimum value for some crops was obtained between the rates 6 and 8 Mg ha^{-1} of lime, the lowest pH values corresponded to the control 0 Mg ha^{-1}. Soil pH plays a key role in soil fertility. Maintaining the soil pH at the optimum level will increase the microbiological activity of the soil, and

result in better soil nutrient recycling and release. Soil pH is also critical for maximizing the availability of nutrients (N, P and K) applied in organic and chemical fertilizers (Culleton et al., 1997). It has been reported by Foy (1992) that soil pH is an important factor in determining the kinds, numbers, and activities of microorganisms involved in organic-matter transformations. The effect of lime in soil pH depend the buffering capacity of the soil and organic matter.

The increase in soil pH may be associated with improvement in the content of Ca^{2+}, and reduction in the Al^{3+} concentration in soil solution. $Ca^{2+,}$ plays an important role in soil and plant growth. The effectiveness of liming increasing soil pH and mobility of Ca^{2+} and reducing aluminum toxicity has been demonstrated in previous studies (Kamprath, 1983; Campanhero et al. 2007; Fageria et al, 2008a; 2008b; Hirzel et al., 2016). Calcitic limestone is a source of Ca in the presence of water the carbonates dissolve and the OH^- and HCO_3^- ions are released, reducing soil acidity (Halvin et al, 2013). Fageria (2001) also reported significant increase in these soil chemical properties with liming in the Brazilian Oxisols. Soil moisture and temperature and quantity and quality of liming material mainly determine the reaction rate of lime. To get maximum benefits from liming or for improving crop yields, liming materials should be applied in advance of crop sowing and thoroughly mixed into the soil to enhance its reaction with soil exchange acidity. Highly weathered tropical soils such as Oxisols have very low levels of exchangeable Ca, and crops grown on such soils exhibit Ca deficiency when exchangeable Ca^{2+} is < 1 $cmol_c$ kg^{-1} (Fageria, 2001). Application of limestone (calcium carbonate) increases soil-exchangeable, with Ca^{2+} and ECEC, BS respectively. The decrease of Al^{3+} saturation in soil is very important. Because aluminum toxicity interferes with root development, water use, and uptake, transport, and utilization of several essential nutrients (Foy, 1984; 1992).

The linear relationship observed between the treatment and pH (Table 3 and Figure 1a and b). The regression model can indicate the extent to which the dependent variable can be predicted by independent variables. On average, based on R^2, the rate lime treatment and soil sampling time influencing soil pH values. Under tropical conditions, the optimum pH values for much cultivars were observed in rate lime 6 and 8 Mg ha^{-1} (Fageria, 2008a; Culleton et al., 1997), this parameter is very important in these soils.

In the acids Ferralitic soils (Oxisols) of Angola, lime use is significantly below the optimum. However, the low fertility in these soils is one must principal problem and acidity. For maximum production, regular lime applications are essential owing to the pivotal role of soil pH in many soil chemical reactions (Madeira et al., 2015). Lime is an additional purchase for farmers; who will seek a good return for their investment by using a product that is fast acting and has benefits for both crop yield and soil properties of Angola.

Modern agriculture production requires the implementation of efficient, sustainable, and environmentally sound management practices. In this context, liming is an important practice to achieve optimum yields of all crops grown on acid soils. Liming is the most widely used long-term method of soil acidity. Application of lime at an appropriate rate brings several chemical and biological changes in the soil, which are beneficial or helpful in improving crop yields on acid soils. Adequate liming eliminates soil acidity and toxicity of Al^{3+}, Mn, and H; improves soil structure (aeration); improves availabilities of Ca^{2+}, P, Mo, and Mg^{2+}, pH, and N_2 fixation; and reduces the availabilities of Mn, Zn, Cu, and Fe and leaching loss of cations (Fageria and Baligar, 2008b).

Liming raises soil pH, BS, ECEC and Ca^{2+} contents, and reduces aluminum concentration in Oxisols. The changes in these chemical properties with the use of calcitic lime can be explained on the basis (Table 2 and Figure 1a,b,c,d,e and g). Liming improving nutrient use efficiency is becoming increasingly important in modern crop production due to rising costs associated with fertilizer inputs and growing concern about environmental pollution.

CONCLUSIONS

Results of this study show that adequate rate lime reduce soil acidity and increase pH, Ca^{2+}, BS, ECEC, and reduce Al^{3+} and Al^{3+} saturation in soil, can significantly improve soil fertility on Ferralitic Soil (Oxisols). Results further proved that use of an adequate rate of liming could bring profit to the growers on highly weathered unfertile acid soils of Angola. Rate lime quantified in this study for maximum pH can be used as references for liming Oxisols of the plateau of southern Angola. The rate of lime between 4 and 8 Mg ha^{-1} reduce soil acidity and maintain the soil pH at the optimum levels. Therefore, when using this lime type (calcitic) it is necessary to correct magnesium deficiency if necessary.

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