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Full Length Research Paper

Effective Strategies for Soil Acidity Mitigation Using Specialized Liming Materials

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Soil acidity has been the major limiting factor to farming activities in the tropics and subtropics. The objective of this study was to verify the efficacy of special liming materials, when compared with the dolomitic limestone, regarding the correction of soil acidity with variable charge in controlled conditions. Samples of a Typic Dystrudept and Rhodic Hapludox were collected from a of layer 0-20 cm, and used to carry out two experiments in a completely randomized design of 4 x 4 x 8 factorial design. Four liming materials were studied: dolomitic limestone (DL), granulated micronized calcite (GMC), granulated micronized dolomite (GMD) and carbonated suspension (CS). After they have been characterized, each liming material was added to the soils using doses that aimed to increase the base saturation (V) to 50, 70 and 90% and a control treatment was included. The treated soil samples were incubated at 23 ± 2°C and 60% soil water retention capacity for eight periods (0, 7, 15, 30, 45, 60, 75 and 90 days). The attributes active (pH), potential (H+Al) and exchangeable (Al^{3+}) acidity and V were evaluated. The special liming materials GMC and CS were efficient enough to reduce the active potential and exchangeable acidity, and increase V in soils with variable charge.

Key words: Micronized liming materials, carbonated suspension, soil reaction, Inceptisol, Oxisol.

INTRODUCTION

The need to increase food production has implied the need to improve plant growth in soils with fertility restrictions. In the tropics and subtropics, predominance of soils with variable charge, the major limiting factors to the farming production have been acidity and aluminum (Al) toxicity (Castro and Crusciol, 2013; Vendrame et al., 2013). Correcting the acidity of these soils does not limits only the neutralizing capacity, the exchangeable aluminum (Al^{3+}), but also the pH increase which results in the consumption of protons from the surface functional groups (mainly silanol, aluminol, iron oxide-OH and aluminum oxide-OH radicals, carboxyl and phenolic groups of the soil organic matter), generating negative electrical charge (Sparks, 2003).

After the correction, the soil tends to acidify due to the following factors: (i) rainfall, (ii) basic cations leaching

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Table 1. Characteristics of the two soils (Inceptisol and Oxisol) studied.

Soil	Source material	Geographic coordinates	Altitude (m)	Native vegetation	Management history
Inceptisol[1]	Itararé sandstone3	S 25º24'37.8'' W 49º58'22.8''	900	Araucaria Forest Montana	No-till for 15 years in crops succession between black oat and soybean during 2007/08 to 2011/12
Oxisol[2]	Ponta Grossa Shale3	S 25º0'28.26'' W50º15'09.31''	800	Araucaria Forest Montana	Without cropping

	$pH_{(CaCl_2)}$	H+Al	Al	Ca	Mg	K	CEC[4]
		mmol$_c$ dm^{-3}					
Inceptisol[1]	4.3	103.3	11.3	30.8	9.3	2.3	145.6
Oxisol[2]	3.8	151.6	26.0	6.0	7.0	1.5	166.1
	V[5]	OC[6]	Clay	Silt	Sand	BD[7]	S[7]
	%	g dm^{-3}		g kg^{-1}		g cm^{-3}	cm^{3}cm^{-3}
Inceptisol[1]	29.0	21.0	200.0	255.2	544.8	1.24	1.5
Oxisol[2]	8.7	33.0	736.0	174.2	89.8	0.99	1.0

[1]Typic Distrudept; [2]Rhodic Hapludox; [3]According to Mineropar (2001); [4]CEC: cation exchange capacity; [5]V: base saturation; [6]OC: organic carbon by Walkey-Black method; [7]BD: bulk density, and S: water saturation, according to EMBRAPA (1997). The other soil attributes were performed according to regional procedures (Pavan et al., 1992).

(calcium - Ca^{2+}, magnesium – Mg^{2+}, potassium– K^+ and sodium– Na^+), (iii) uptake and exportation of these cations by the plants, (iv) hydrolysis reactions in the clay-humic plasma, (v) addition of soluble salts and fertilizers (mineral and organic) in the soil-plant system (Nagy and Kónya, 2007; Havlin et al., 2014). Therefore, suitable management and acidity control of soils with variable charge are basic principles of sustainable agriculture (Kirkham et al., 2014) and food safety in underdeveloped countries (Spiertz, 2012; Curtis and Halford, 2014).

Limestone is the most common used liming material to control soil acidity. However, this limestone present low solubility in water (1.4 mg L^{-1}) and needs to be previously applied in advance (around three months), to produce satisfactory agronomic results (Raij, 2011). Therefore, it is important to study special liming materials that present enhanced reactivity in short-term and with the possibility of being used more efficiently in conservationist agriculture systems (in which the soil is not revolved, for example, no-tillage system).

The most important factors to determine the efficacy of liming materials to control soil acidity are: release neutralizing (OH^- or HCO_3^-), particle size and specific surface area, original material crystalline structure and calcium content ($CaCO_3$) (Havlin et al., 2014). In such context, special liming materials are ranked for their particle size, that is, they are finer, than the regular limestones (from particle size of 300 to 840 µm) and larger specific surface, favoring their reactivity in the soil. All these parameters are fundamental to determine their reactivity and efficacy once applied to the soil. This issue is important but there is lack of information on the reactivity and efficacy of special liming materials in soils with variable charge. Moreover, there are few studies on soil acidity control in Inceptisol (mainly in Typic Distrudept) when compared with the number of papers published that emphasize on Oxisols acidity. The Typic Distrudept has distinct characteristics and the representation to grain and forage production in the south of Brazil (EMBRAPA, 2006).

This study compares the efficacy of special liming materials to that of dolomitic limestone, on their correction of soil acidity with variable charge (Typic Distrudept and Rhodic Hapludox) and estimated bases saturation (V) after incubation in controlled conditions for up to 90 days.

MATERIALS AND METHODS

Samples from the 0-20 cm layer of two soils with variable charge (Typic Distrudept and Rhodic Hapludox) were collected in the region of Campos Gerais of Paraná, Brazil, and their characteristics are presented in Table 1. After they have been collected, the samples were dried in oven with air forced circulation at 40°C for 48 h, ground and sieved in a 2.0 mm mesh sieve. Each soil represented one experiment.

The design used, for both experiments, was completely randomized in a 4x4x8 factorial design with four replications. Four liming materials were analyzed: dolomitic limestone (DL), granulated micronized calcite (GMC), granulated micronized dolomite (GMD) and carbonated suspension (CS). The results of physical and chemical characterization (Table 2 and Figure 1) of liming materials were performed according to França and Couto (2007) and MAPA (2007). For each liming materials, there was a

Table 2. Chemical and physical attributes of liming materials (dolomitic limestone – DL, granulated micronized calcite – GMC, granulated micronized dolomite – GMD and carbonated suspension – CS) studied.

Liming materials	CaO[1]	MgO[2]	RE[3]	NP[4]	ECC[5]	CCE[6]
	g kg^{-1}					
DL	265.9	257.6	832.0	1079.7	898.7	1117.3
GMC	462.2	15.5	1000.0	962.7	962.7	861.5
GMD	345.9	121.5	1000.0	1006.5	1006.5	919.4
CS	361.1	8.30	1000.0	770.0	770.0	663.4

[1]CaO: calcium oxide; [2]MgO: magnesium oxide; [3]RE: relative efficiency of the liming materials and [4]NP: neutralizing power: analytical determinations performed according MAPA (2007); [5]ECC: effective calcium carbonate obtained by the equation [(NP*RE)/100]; [6]CCE: Calcium carbonate equivalent which represents the neutralization value of the material compared to pure $CaCO_3$ obtained by the equation [(CaO x 1.79)+(MgO x 2.48)].

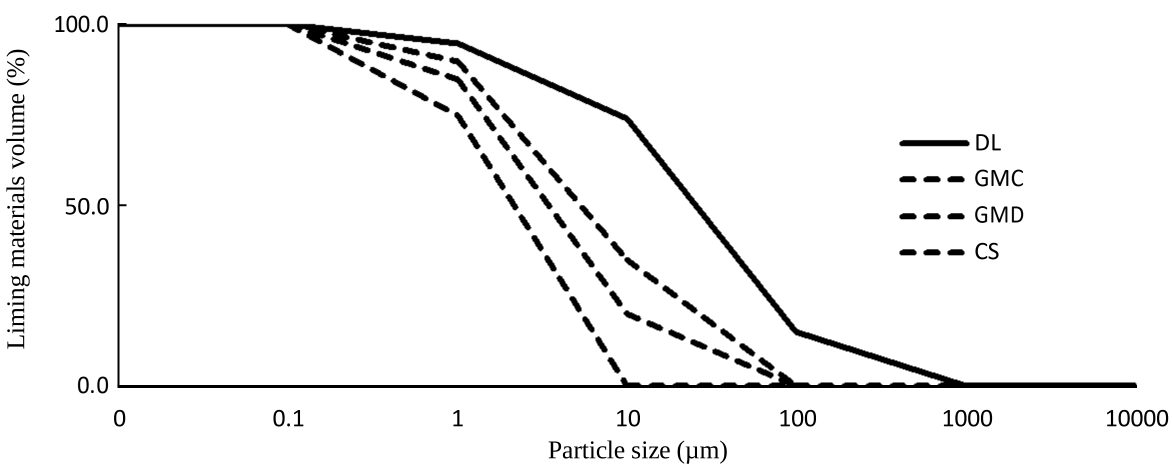

Figure 1. Particle size of the liming materials under study: dolomitic limestone (DL), granulated micronized calcite (GMC), granulated micronized dolomite (GMD) and carbonated suspension (CS). The liming materials attribute was obtained according to procedures of França and Couto (2007).

control treatment. Also, three doses were studied aiming to increase V to 50, 70 and 90%. The liming materials were duly homogenized in the soil and incubated for 0, 7, 15, 30, 45, 60, 75 and 90 days, at constant temperature of 23 ± 2°C and soil humidity conditions aiming at 60% of soil water retention capacity [169.4 and 112.0 ml of deionized water (average electrical conductivity: 0.5 µS cm^{-1}) was added to the Typic Distrudept and Rhodic Hapludox, respectively]. Each experimental unit consisted of 500 g soil. The lime requirement (LR) was obtained with the equation according to Raij et al. (1996):

$$LR = [CEC (V_2 – V_1)]/(10 x ECC) \quad (1)$$

LR: lime requirement (Mg ha^{-1}) for layer 0-20 cm; *CEC*: cation exchange capacity (mmol$_c$ dm^{-3}); V_1: base saturation (%) obtained; and V_2: base saturation (%) aimed.
The ECC was estimated with the equation according to Raij (1977):

$$ECC = (NP \times RE)/100 \quad (2)$$

ECC: effective calcium carbonate – %; *NP*: neutralizing power – calculated with the equation [CaO (%) x 1.79 + MgO (%) x 2.48] and *RE*: relative efficiency of the liming.

For the special liming materials, 100% RE was adopted, due to the fact that they present very fine particle size (mean particle size < 10 µm) when compared with a limestone which is considered to have fine particles (mean particle size < 300 µm) (Figure 1). The doses estimated to increase V to 50, 70 and 90% are presented in Table 3.

After each incubation period is finished (0, 7, 15, 30, 45, 60, 75 and 90 days), the experimental units of both soils were removed from the incubation room, taken to the laboratory, dried in oven at 40°C with air forced circulation, they were then ground and sieved in a 2.0 mm mesh sieve. In the sequence the following attributes were determined: active (pH), potential (H+Al) and exchangeable (Al^{3+}) acidity employing the methods suggested by Pavan et al. (1992). The concentrations of exchangeable cations (calcium– Ca, magnesium– Mg and potassium– K) were used to estimate the V values.

Data were submitted for statistical analysis employing the computer program SAS Version 9.1.2 (SAS, 2004). The program suggested transformations to the square root of the potential acidity (H+Al) and V attributes for both soils under study. Three factors were considered in the statistical model: (i) four soil acidity liming

Table 3. Doses of each liming material applied [dolomitic limestone (DL); granulated micronized calcite (GMC); granulated micronized dolomite (GMD) and carbonated suspension (CS)] to increase the soil base saturation (V) to 50, 70 and 90%.

Doses	Liming materials							
	DL	GMC	GMD	CS	DL	GMC	GMD	CS
	g of liming material per kg of soil				dose of liming materials (Mg) corresponding per hectare			
Typic Distrudept								
50%*	1.38	1.28	1.23	1.60	3.41	3.18	3.05	3.98
70%*	2.68	3.72	2.39	4.65	6.65	6.21	5.94	7.76
90%*	3.99	3.72	3.56	4.65	9.89	9.23	8.83	11.54
Rhodic Hapludox								
50%*	3.83	3.57	3.42	4.47	7.63	7.13	6.82	8.91
70%*	5.68	5.30	5.07	6.63	11.33	10.58	10.12	13.22
90%*	7.54	7.03	6.73	8.80	15.03	14.03	13.42	17.54

The quantities of each liming material to estimate the need for liming were obtained with the equation (according to Raij et al., 1996): LR = [CEC(V2 – V1)/10*ECC], where: LR: lime requirement (Mg ha^{-1}) for layer 0-20 cm; CEC: cation exchange capacity ($mmol_c$ dm^{-3}); V1: base saturation (%) obtained; and V2: base saturation (%) aimed. The ECC was estimated through the equation (according to Raij, 1977): ECC = (NP x RE)/ 100, where: ECC: effective calcium carbonate – %; NP: neutralizing power – calculated through the equation [CaO (%) x 1.79 + MgO (%) x 2.48] and RE: relative efficiency of the liming.

materials: (DL, GMC, GMD and SC), (ii) four doses of each liming material applied (to increase V to 50, 70 and 90% besides the control treatment) and (iii) eight incubation periods were studied (0, 7, 15, 30, 45, 60, 75 and 90 days). The effect of predictive variables (doses of liming materials) was adjusted to the response variables (soil attributes) in each incubation period, using the regression models (linear or quadratic). Besides that, the profile analysis was used to compare the effects of each dose of soil acidity liming materials employed in the incubation periods.

RESULTS

Interactions between the liming materials and doses applied (F = 55.69 to pH, F = 122.32 to H+Al, F = 87.21 to Al and F = 154.56 to V; P < 0.0001); liming materials and incubation periods (F = 4.22 to pH, F = 8.60 to H+Al, F = 35.08 to Al and F = 15.25 to V; P < 0.0001); doses applied and incubation periods (F = 7.39 to pH, F = 13.02 to H+Al, F = 35.19 to Al and F = 38.41 to V; P < 0.0001); and liming materials, doses applied and incubation periods (F = 3.10 to pH, F = 7.69 to H+Al, F = 13.58 to Al and F = 11.28 to V; P < 0.0001) were observed in Typic Distrudept.

Also observed were interactions in Rhodic Hapludox between the liming materials and doses applied: (F = 192.39 to pH, F = 205.92 to H+Al, F = 43.34 to Al and F = 368.53 to V; P < 0.0001); liming materials and incubation periods (F = 25.27 to pH, F = 48.59 to H+Al, F = 32.29 to Al and F = 85.24 to V; P < 0.0001); doses applied and incubation periods (F = 15.03 to pH, F = 118.50 to H+Al, F = 467.62 to Al and F = 95.08 to V; P < 0.0001); and liming materials, doses applied and incubation periods (F = 15.39 to pH, F = 22.40 to H+Al, F = 8.81 to Al and F = 37.77 to V; P < 0.0001).

In typic distrudept

All the special liming materials reduced active (pH) and potential H+Al (Figure 2) and exchangeable Al^{+3} acidity (Figure 3), in all the doses under study when the incubation period increased. This fact may be ascribed to the interaction between periods of incubation, liming materials and doses.

The GMC reduced active acidity (pH) (Figure 4) after 0, 30, 60 and 90 days and the potential acidity (H+Al) (Figure 5) after 15 and 30 days of incubation, in doses to increase V to 70 and 90% respectively. However, CS was more efficient in the reduction of potential acidity (H+Al) (Figure 5) when applied in the dose aiming to increase V to 90%. The exchangeable acidity (Al^{+3}) (Figure 6) was neutralized after the application of the special liming materials GMC and CS in doses to increase V to 70 and 90%. GMD was the only liming material under study that was inefficient to reduce exchangeable acidity (Al^{3+}) on 7, 15, 30, 45, 60 and 90 days after being applied (Figure 6). The exchangeable acidity (Al^{3+}) was kept low with the application of GMC doses to increase V to 70 and 90% during the 90 days of incubation. This fact was not observed with the special liming materials GMD (Figure6). Therefore, special liming materials (GMC and CS) presented higher efficacy, in short-term (90 days), when compared with the DL.

All liming materials under study increased the base saturation of Typic Distrudept (initial V: 29.0%). However, only GMC, applied in the dose to increase V to 70% (Figure 3) resulted in a value close to the aim (V: 70%) in the first 30 days of incubation (Figure 7). After 60 days of incubation, GMC and CS, used in doses to increase V to

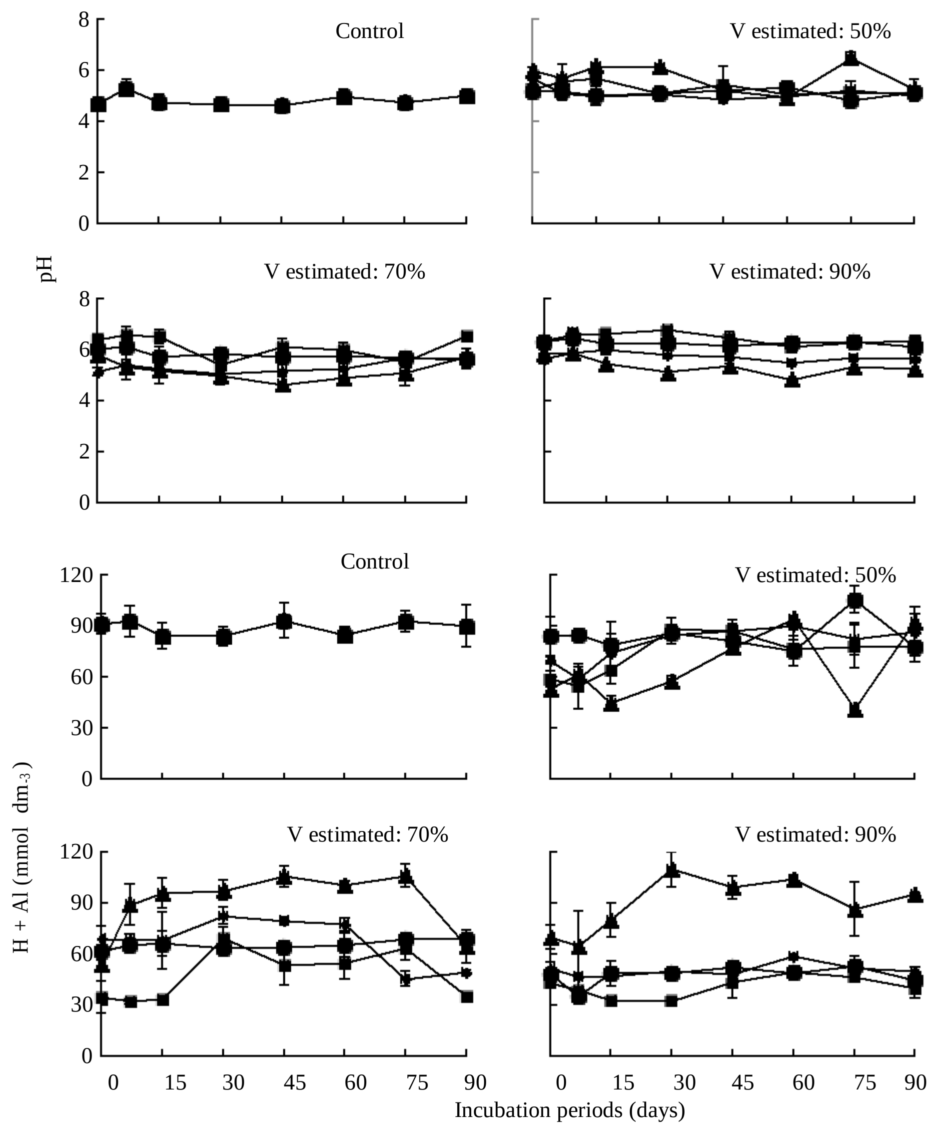

Figure 2. Active (pH) and potential (H + Al) acidity values on a Typic Distrudept (n = 4 ± standard deviation) during 90 days of incubation for the control treatment and after application of the liming materials aiming base saturation (V) to 50, 70 and 90%. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Coefficient of variation: 4.8 and 5.0 % to pH and H+Al, respectively.

70 and 90%, reacted similarly, keeping the average values very close. The special liming materials, GMC and CS are more efficient to increase V to the estimated values. GMD showed data discrepancy of all attributes under study.

In Rhodic Hapludox

All liming materials, doses and periods under study reduced the active (pH) and potential (H+Al) (Figure 8) and exchangeable Al^{3+} (Figure 9) acidity. The GMC and the CS applied in doses to increase V to 70 and 90%, after 7, 15, 30, 45 and 90 days of incubation, resulted in active acidity reduction (Figure 8 and 10). When CS was applied in the dose to increase V to 90% (Figure 8) on 45, 60 and 75 days, it was observed to be the most efficient to reduce acidity (H+Al) (Figure 11). The exchangeable acidity (Al^{3+}) was neutralized by the dose used to increase V to 50% with GMC (Figure 9) in the early days (0, 7 and 15 days) of incubation (Figure 12) and this was constant with the other doses studied. The CS, when applied in doses to increase V to 70 and 90%(Figure 9) showed efficacy (Figure 13).

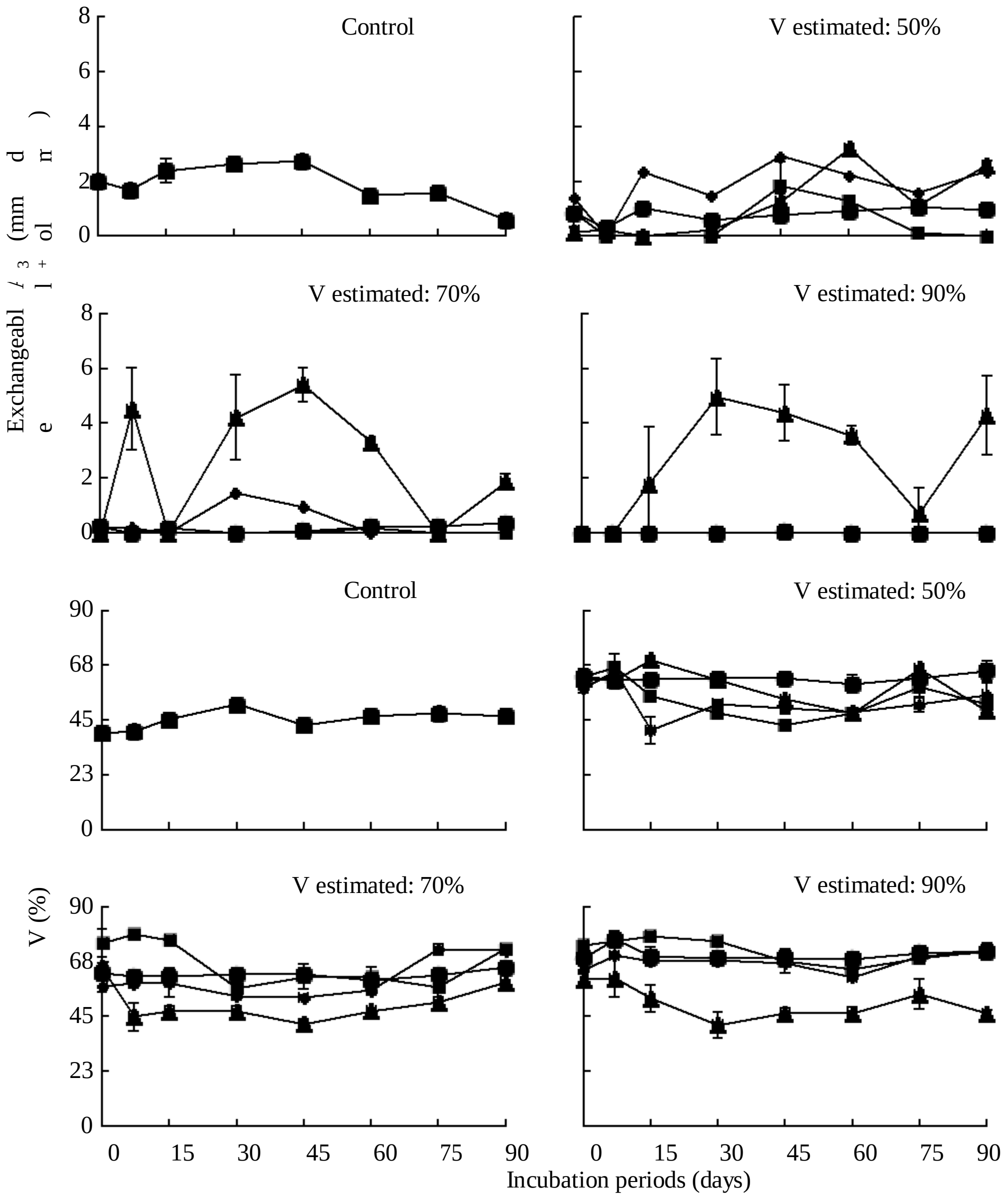

Figure 3. Exchangeable acidity (Al^{3+}) values and base saturation (V) values on a Typic Distrudept (n = 4 ± standard deviation) during 90 days of incubation for the control treatment and after application of the liming materials aiming base saturation (V) to 50, 70 and 90%. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Coefficient of variation: 35.2 and 2.3% to Al^{3+} and V, respectively.

DISCUSSION

Soil initial conditions and description of the liming materials studied

The soils

Typic Distrudept and Rhodic Hapludox were selected for this study because they exhibit high acidity and low base saturation (Table 1). The predominant mineralogy of the clay fraction was gibbsite and quartz for the Typic Distrudept, and kaolinite, goethite, hematite and quartz for the Rhodic Hapludox. Most of the special liming material volume have particle size of 1.91-6.58 µm (Figure 1), which is finer than the dolomitic limestone (high quality product in the market used as reference in this study). The specific surface area of the liming materials: DL, GMC, GMD and CS were 306.6; 1055.0;

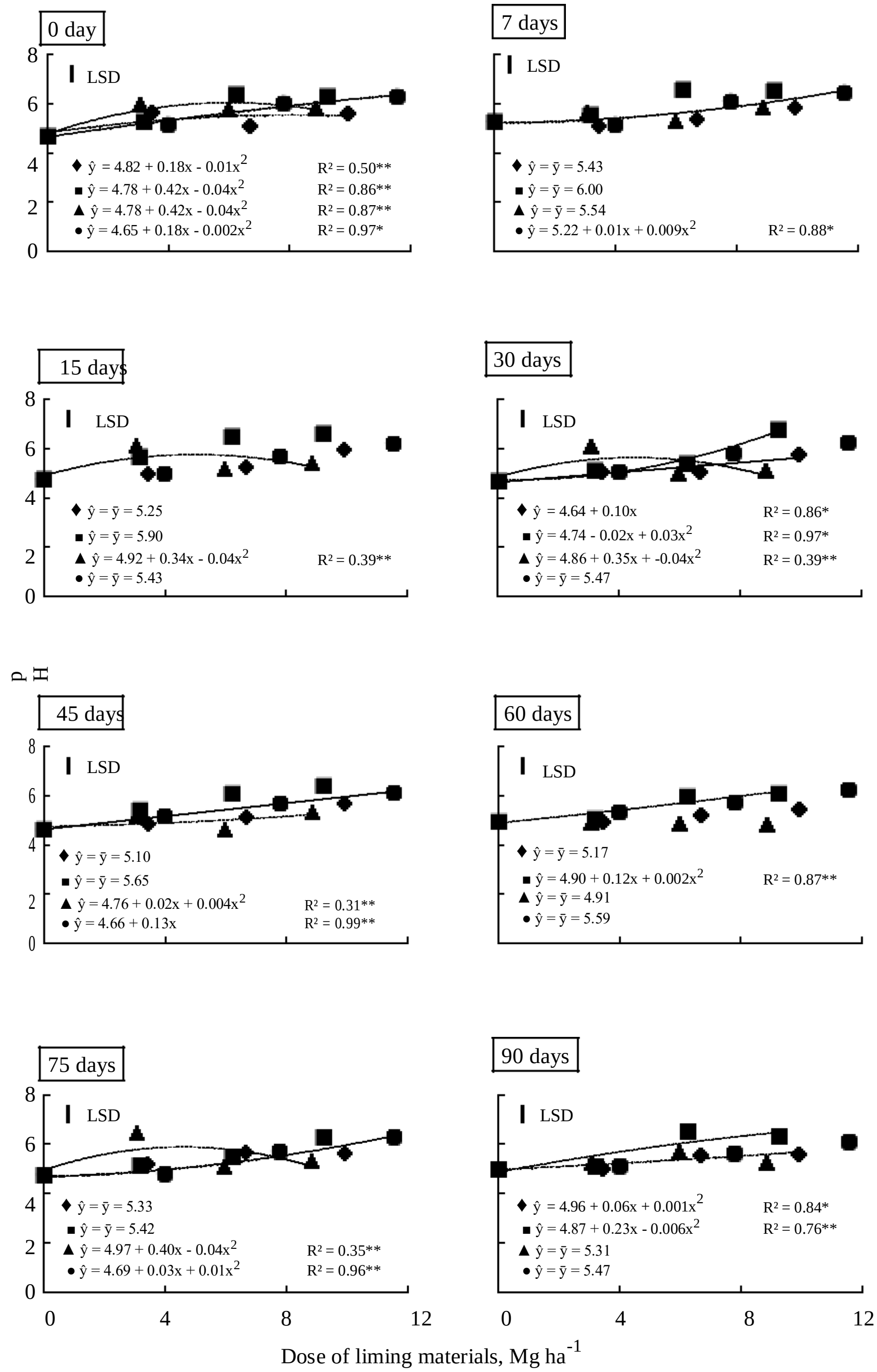

Figure 4. Active acidity (pH) values on a Typic Distrudept ($n = 4$) during eight periods of incubation in the control treatment and in doses to increase the soil base saturation (V) to 50, 70 and 90% of each of the liming materials studied. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Vertical bars indicate the least significant difference (LSD). *: P < 0.05. **: P < 0.01.

1099.0 and 1559 m^2 kg^{-1}, respectively. This provides evidence of the special liming materials (GMC, GMD and CS) and their reactivity potential as compared to DL.

Changes on acidity of Typic Distrudept

The special liming materials reduced active (pH) (Figure

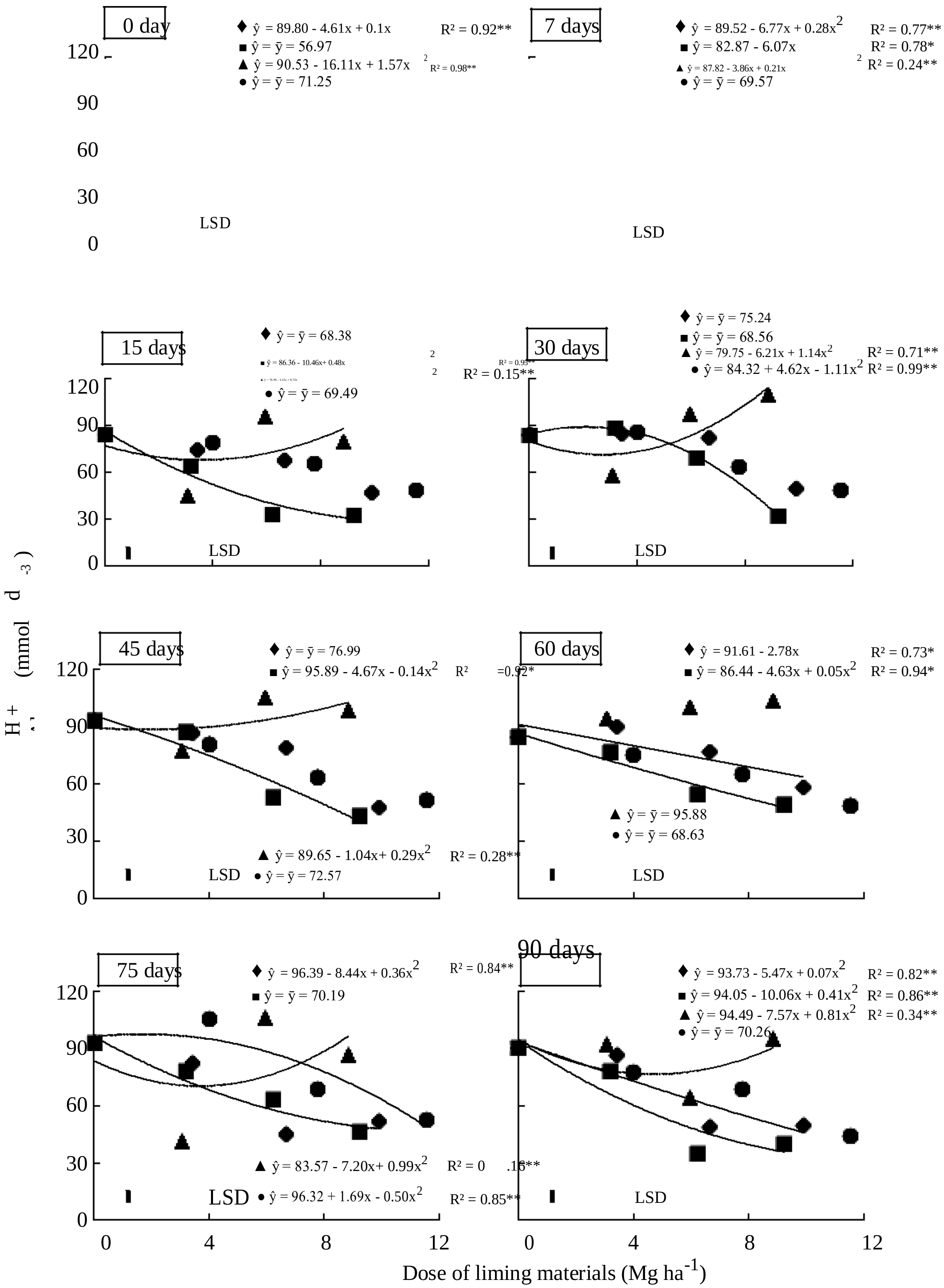

Figure 5. Potential acidity (H +Al) values on a Typic Distrudept (n = 4) during eight periods of incubation in the control treatment and in doses to increase the soil base saturation (V) to 50, 70 and 90% of each of the liming materials studied. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Vertical bars indicate the least significant difference (LSD). *: $P < 0.05$. **: $P < 0.01$.

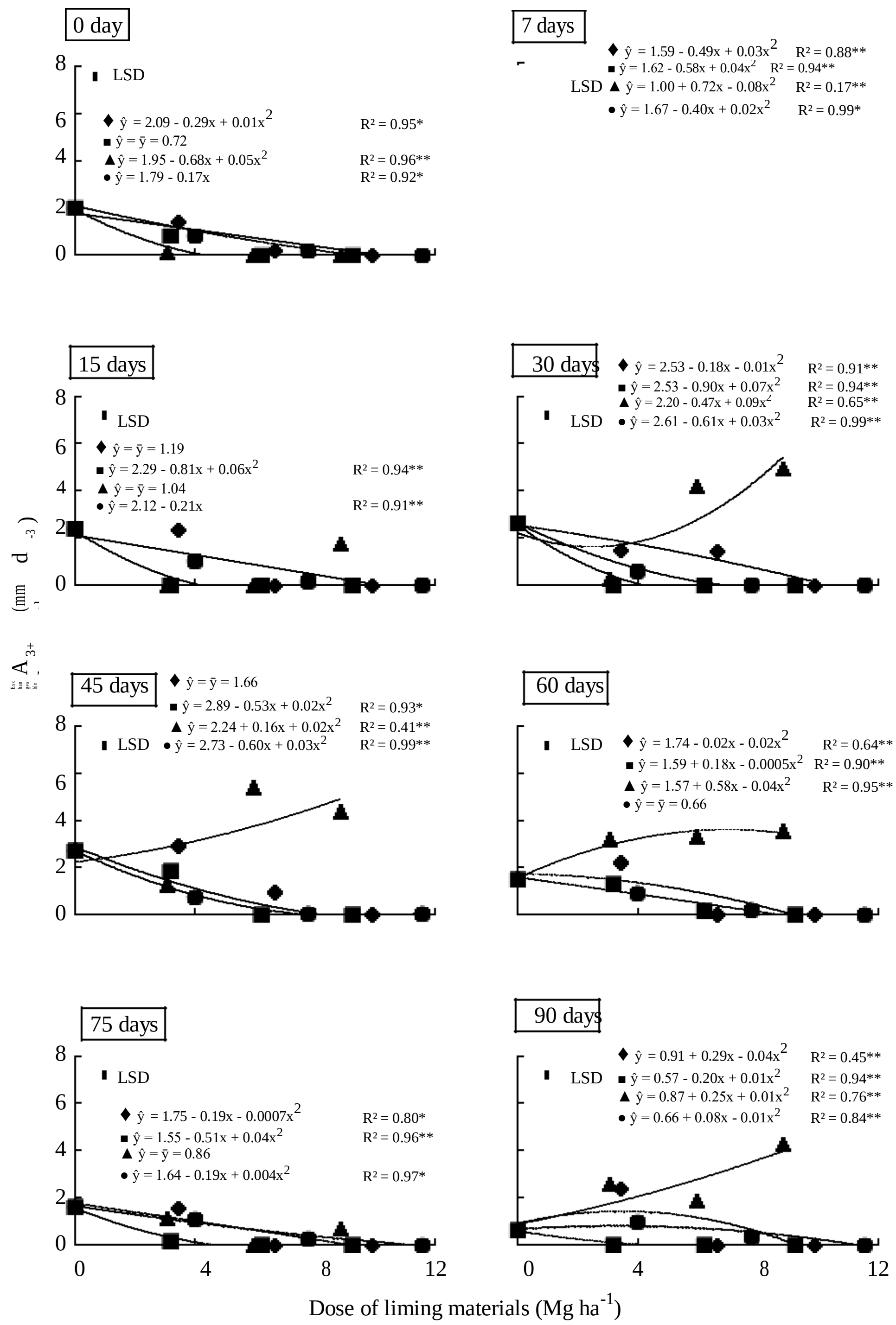

Figure 6. Exchangeable acidity (Al^{3+}) values on a Typic Distrudept (n = 4) during eight periods of incubation in the control treatment and in doses to increase the soil base saturation (V) to 50, 70 and 90% of each of the liming materials studied. (♦) Dolomitic limestone; (■) Granulated micronized calcite; (▲) Granulated micronized dolomite; (●) Carbonated suspension. Vertical bars indicate the least significant difference (LSD).*: P < 0.05. **: P < 0.01.

2 and 4), potential (H+Al) (Figures 2 and 5) and exchangeable (Al^{+3}) acidity (Figure 3 and 6) and increased base saturation (Figure 3 and 7), in all doses under study when the incubation period increased. This

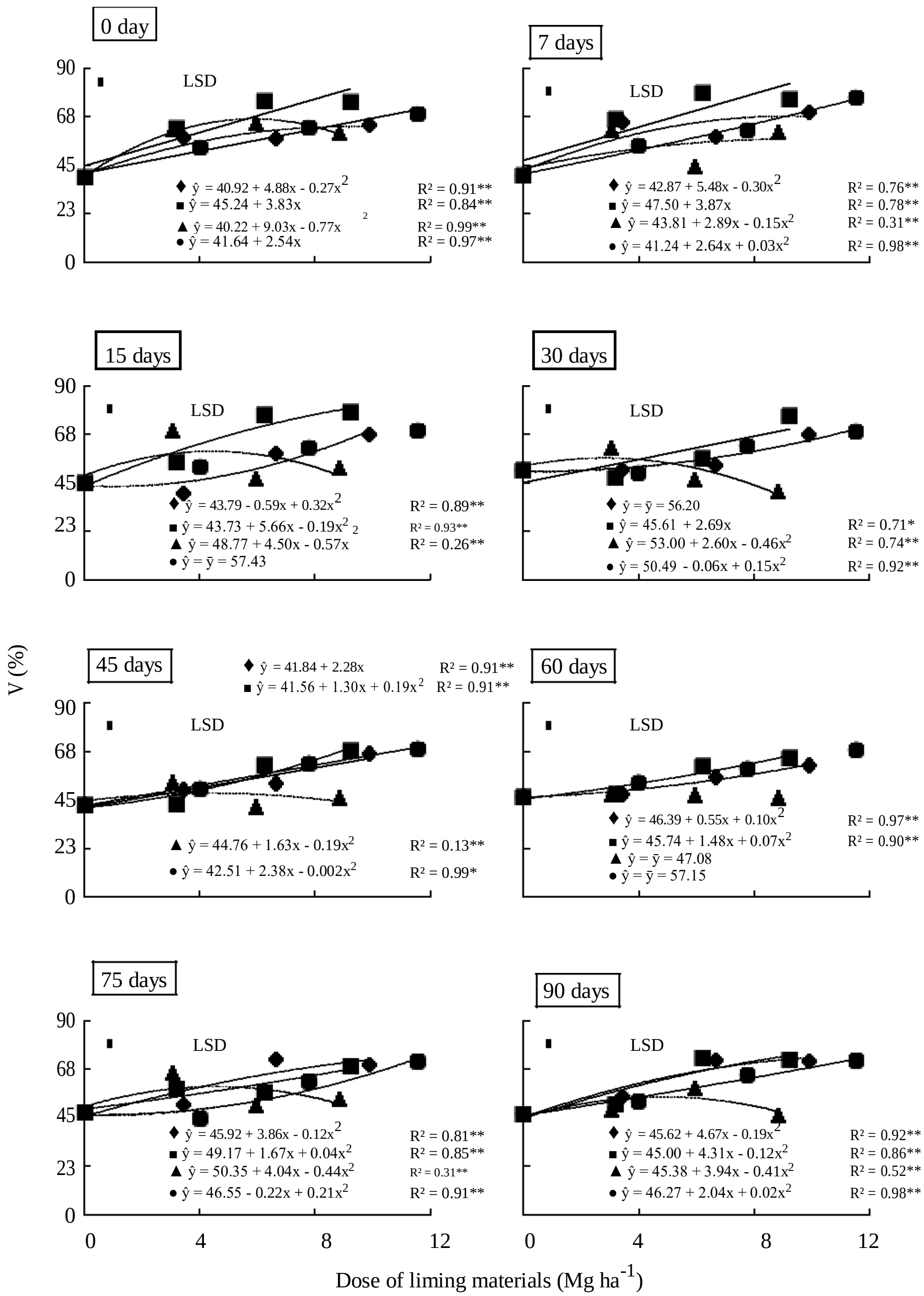

Figure 7. Bases saturation (V) values on a Typic Distrudept (n = 4) during eight periods of incubation in the control treatment and in doses to increase the soil base saturation (V) to 50, 70 and 90% of each of the liming materials studied. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Vertical bars indicate the least significant difference (LSD). *: $P < 0.05$. **: $P < 0.01$.

fact may be ascribed to the interaction between periods of incubation, liming materials and doses. All liming materials reached the pH value ($CaCl_2$) 5.5, which has been considered ideal for most crops. Thus, materials

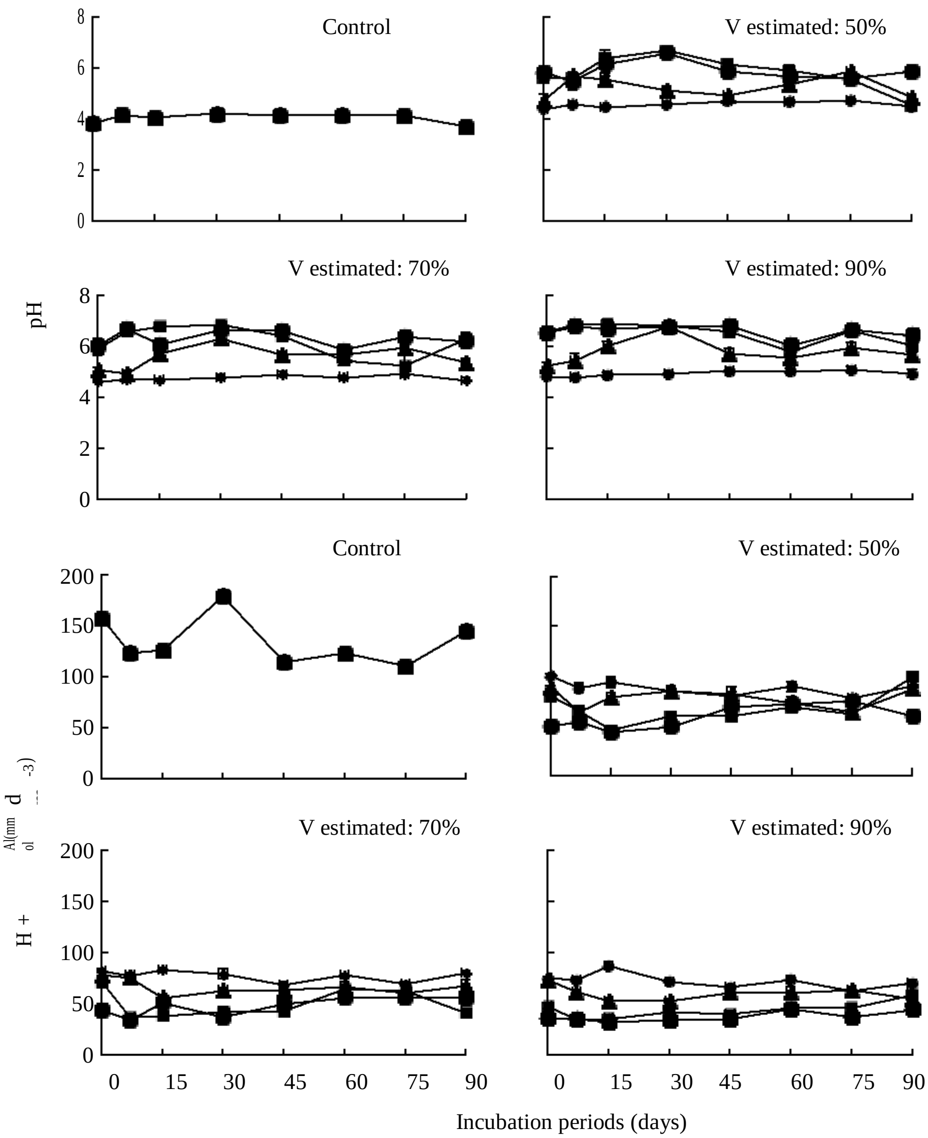

Figure 8. Active (pH) and potential (H + Al) acidity values on a Rhodic Hapludox (*n* = 4 ± standard deviation) during 90 days of incubation for the control treatment and after application of the liming materials aiming base saturation (V) to 50, 70 and 90%. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Coefficient of variation: 2.7 and 2.5% to pH and H+Al, respectively.

classified as special liming materials increase pH values (Oliveira et al., 2014) due to the release of OH^- and HCO_3^- and Ca content in the soil (Havlin et al., 2014) in accordance with the information in the current literature (Basak and Biswas, 2016).

The GMC reduced active (pH) and potential (H+Al) acidity. This show that the special liming material GMC reacted faster and neutralized the soil acidity. However, CS was more efficient to reduce potential acidity (H+Al) when applied in the dose aiming to increase V to 90%. Therefore, CS was efficient when applied in higher doses. Therefore, special liming materials (GMC and CS) presented higher efficacy, in short-term (90 days), when compared with the DL. This is a relevant fact, since studies on liming material incubation take into consideration the 90 days period (Alcarde, 2005) and, in this period, GMC and CS reacted much faster than DL.

Changes on acidity of Rhodic Hapludox

All liming materials, in their applied doses and in the periods used under this study reduced the active (pH) (Figure 8 and 10), potential (H+Al) (Figure 8 and 11) and

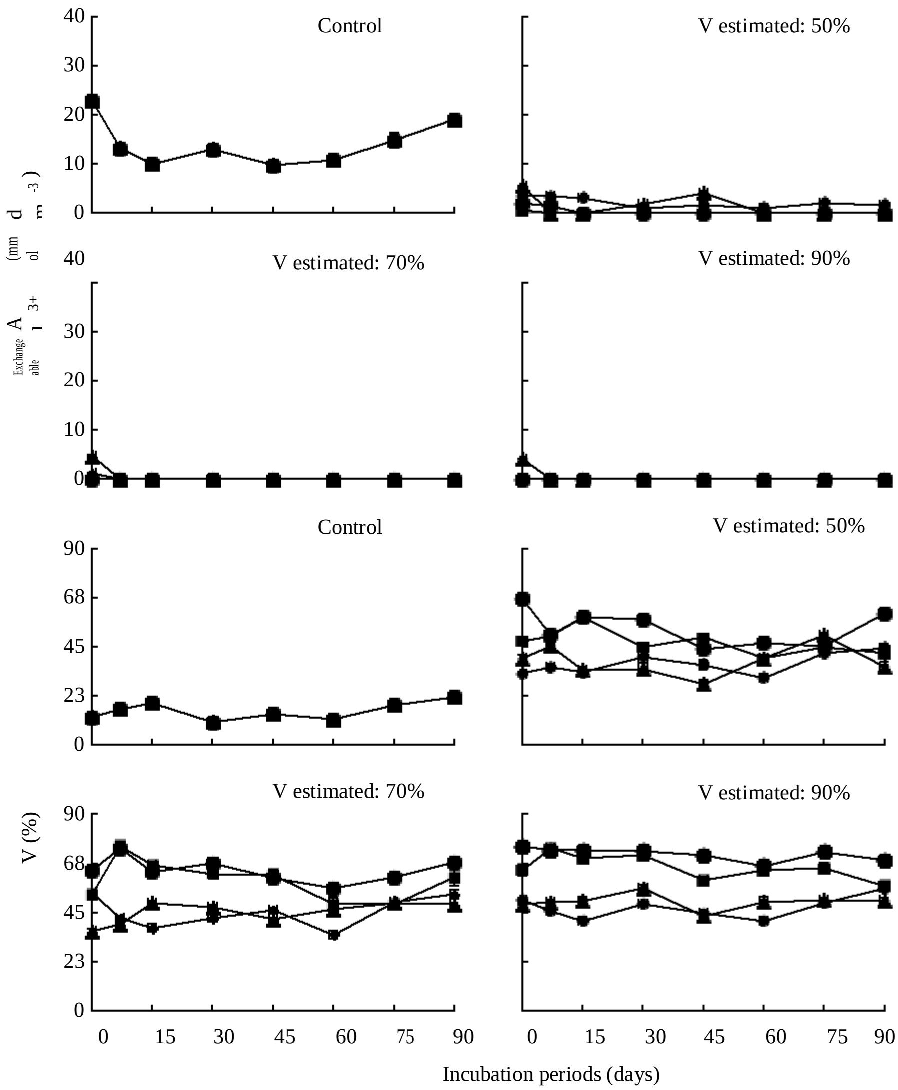

Figure 9. Exchangeable acidity (Al^{3+}) and base saturation (V) values on a Rhodic Hapludox (*n* = 4 ± standard deviation) during 90 days of incubation for the control treatment and after application of the liming materials aiming base saturation (V) to 50, 70 and 90%. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Coefficient of variation: 10.0 and 1.6% to Al^{3+} and V, respectively.

exchangeable Al^{3+} (Figures 9 and 12) acidity and increased V (Figure 9 and 13). This is because special liming materials are more reactive, presenting finer particles (Figure 1) and higher specific surface area, which provides better contact with the soil particles and consequently faster reaction (< 30 days), as compared to DL. Therefore, the use of GMC and CS in doses of 70 and 90% respectively, presented the highest efficacy to reduce active, potential and exchangeable acidity and increase V in the Rhodic Hapludox. The application of DL in Rhodic Hapludox, usually resulted in reduction in the active, potential and exchangeable acidity and increase in V (Caires et al., 2000, 2004; Fidalski and Tormena, 2005; Corrêa et al., 2007). However, DL presented lower efficacy in reducing active (pH), potential (H+Al) and exchangeable Al^{3+} acidity as compared to the special liming materials, GMC and CS throughout the periods observed in this study. GMD presented data discrepancy of all attributes under study in the Rhodic Hapludox. Therefore, the acidity control of soils with variable charge (Typic Distrudept and Rhodic Hapludox) and special liming materials can result in major soil quality and consequently, higher grain, meat and wood yield for the growing global population (Spiertz, 2012; Vendrame et

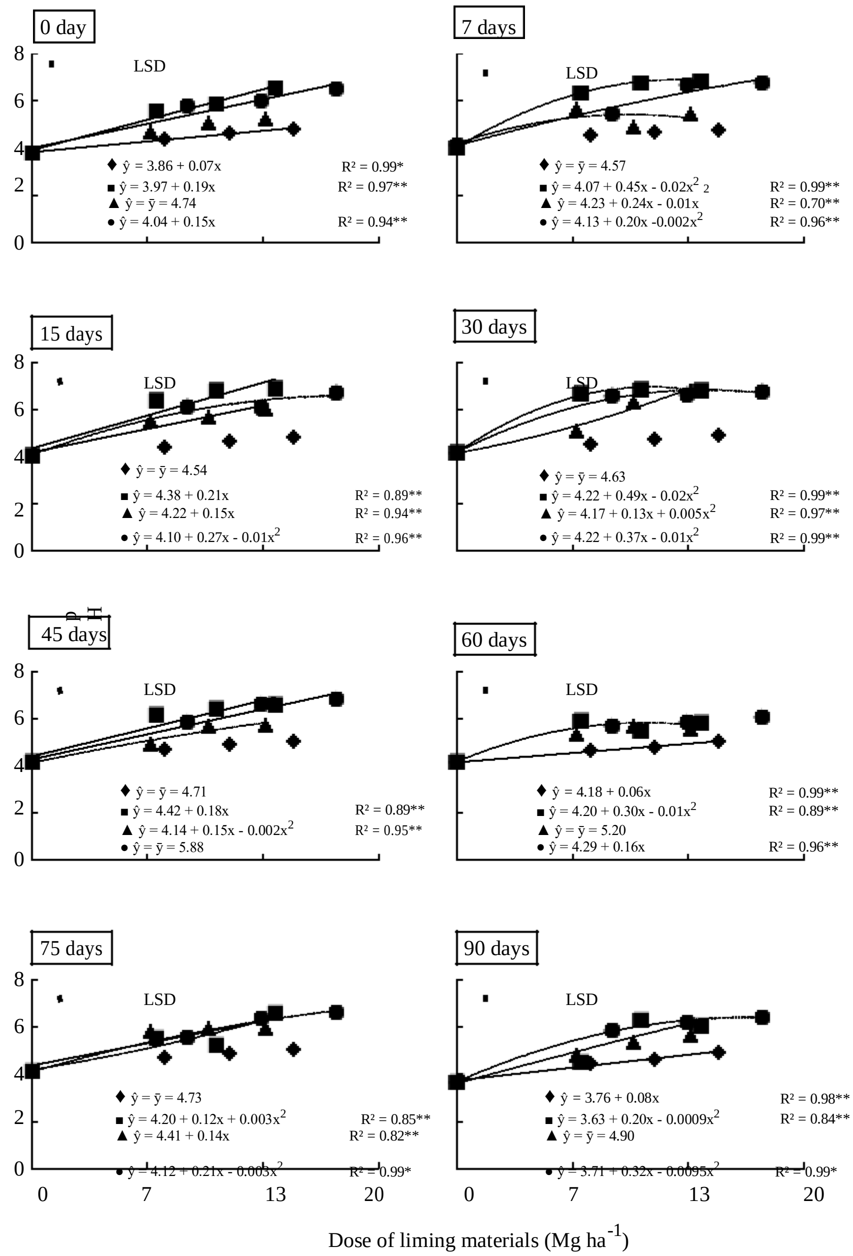

Figure 10. Active acidity (pH) values on a Rhodic Hapludox (*n* = 4) during eight periods of incubation in the control treatment and in doses to increase the soil base saturation (V) to 50, 70 and 90% of each of the liming materials studied. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Vertical bars indicate the least significant difference (LSD).*: $P < 0.05$. **: $P < 0.01$.

al., 2013; Lasso et al., 2013; Curtis and Halford, 2014). However, field studies should be carried out to verify the residual effects of these special liming materials, as well as their effects on other soil fertility attributes; nutritional aspects and crop yield, particularly in conservationist management systems (with minimum soil revolving).

Conclusions

1) The special liming materials which were granulated micronized calcite and carbonated suspension were efficient to reduce active, potential and exchangeable acidity and increase base saturation in soils with variable

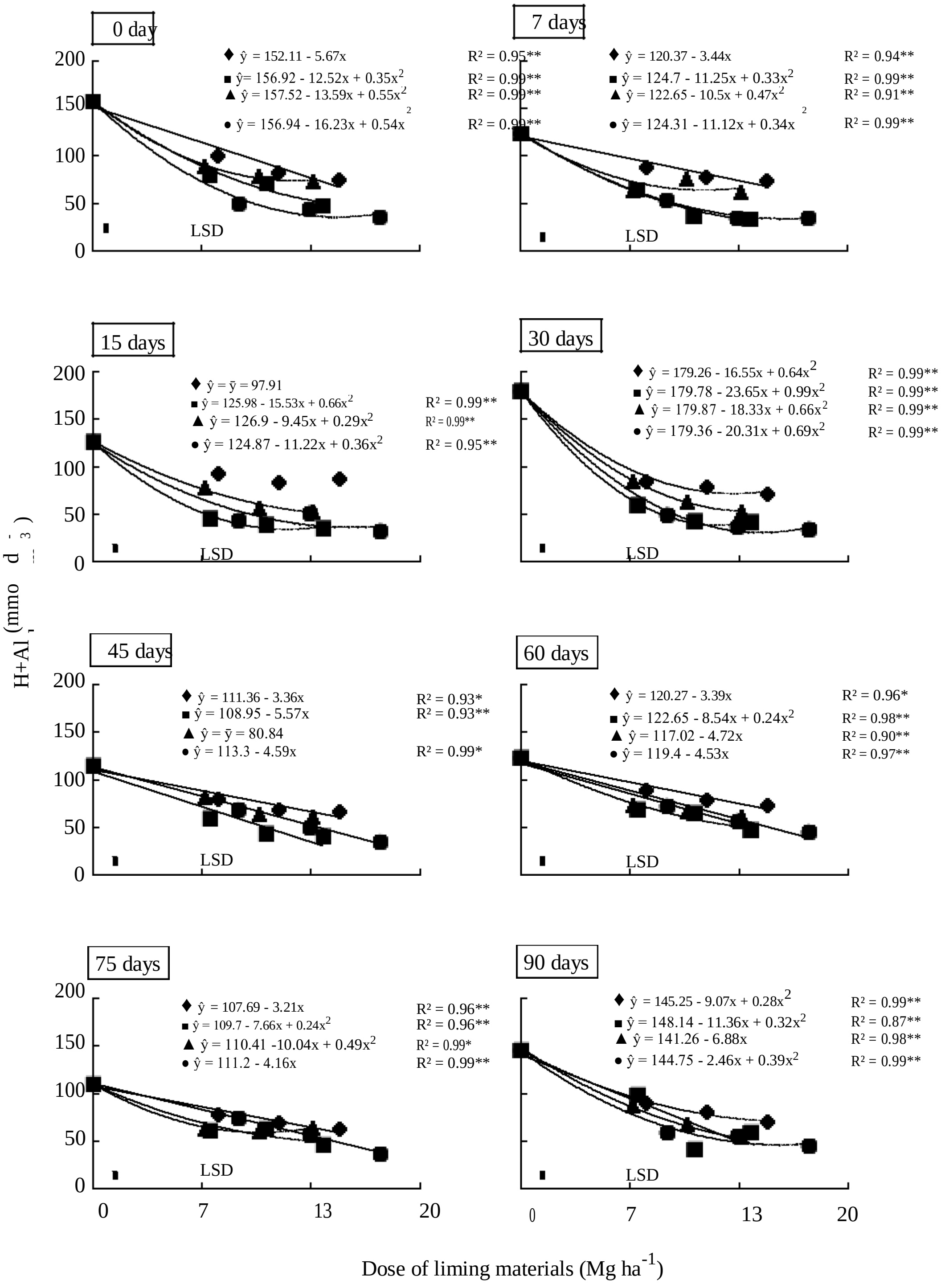

Figure 11. Potential acidity (H + Al) values on a Rhodic Hapludox (*n* = 4) during eight periods of incubation in the control treatment and in doses to increase the soil base saturation (V) to 50, 70 and 90% of each of the liming materials studied. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Vertical bars indicate the least significant difference (LSD). *: P < 0.05. **: P < 0.01.

charge (Typic Distrudept and Rhodic Hapludox).
2) The application of granulated micronized calcite in a dose to increase base saturation to 70% in the Typic Distrudept and the carbonated suspension material in

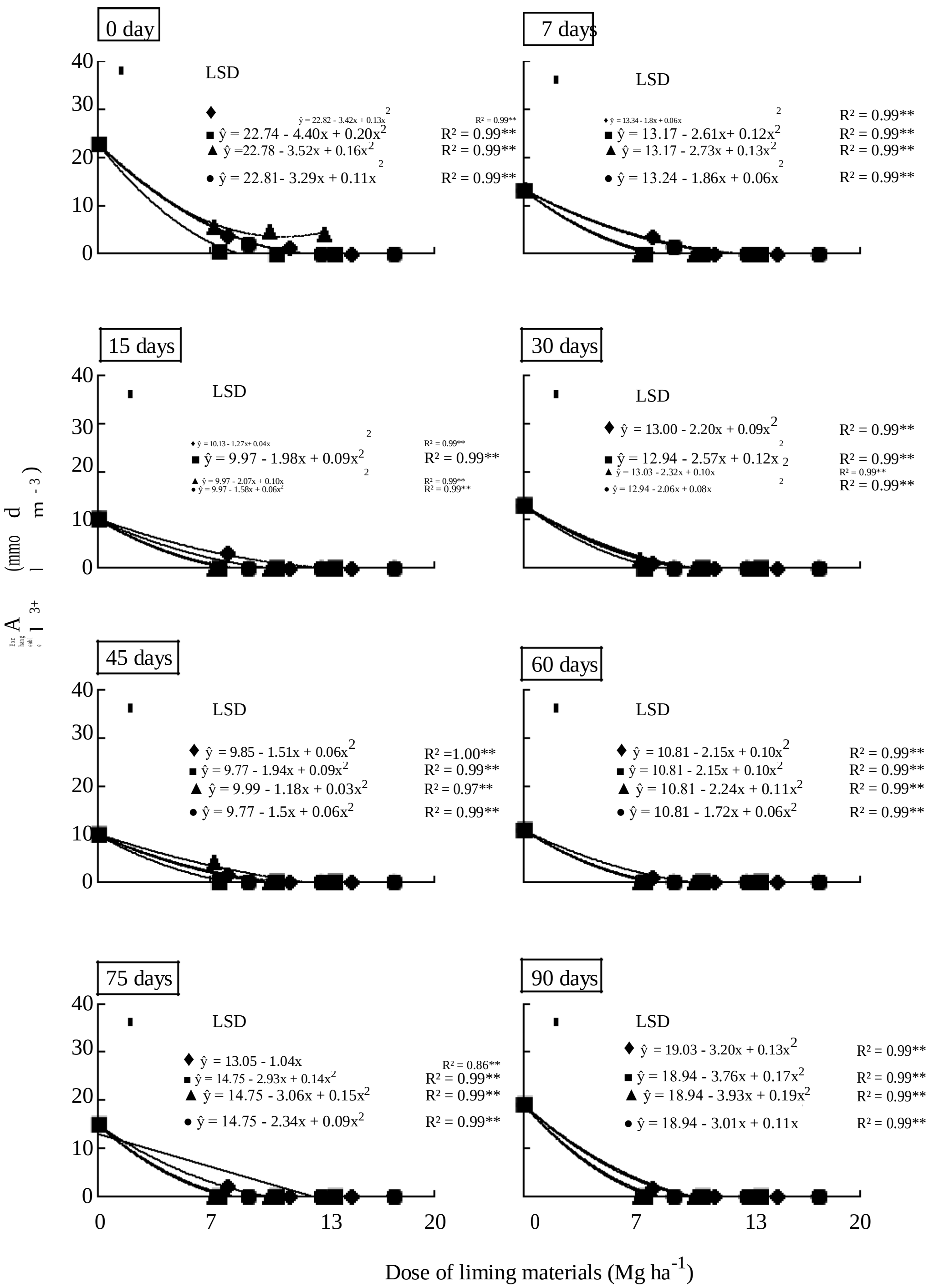

Figure 12. Exchangeable acidity (Al^{3+}) values on a Rhodic Hapludox (*n* = 4) during eight periods of incubation in the control treatment and in doses to increase the soil base saturation (V) to 50, 70 and 90% of each of the liming materials studied. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Vertical bars indicate the least significant difference (LSD).*: $P < 0.05$. **: $P < 0.01$.

the dose to increase base saturation to 90% in the Rhodic Hapludox, were more efficient than the other doses.

3) The special liming materials which are granulated micronized calcite and carbonated suspension were more efficient than dolomitic limestone to control acidity (active, potential and exchangeable) in less than 30 days after

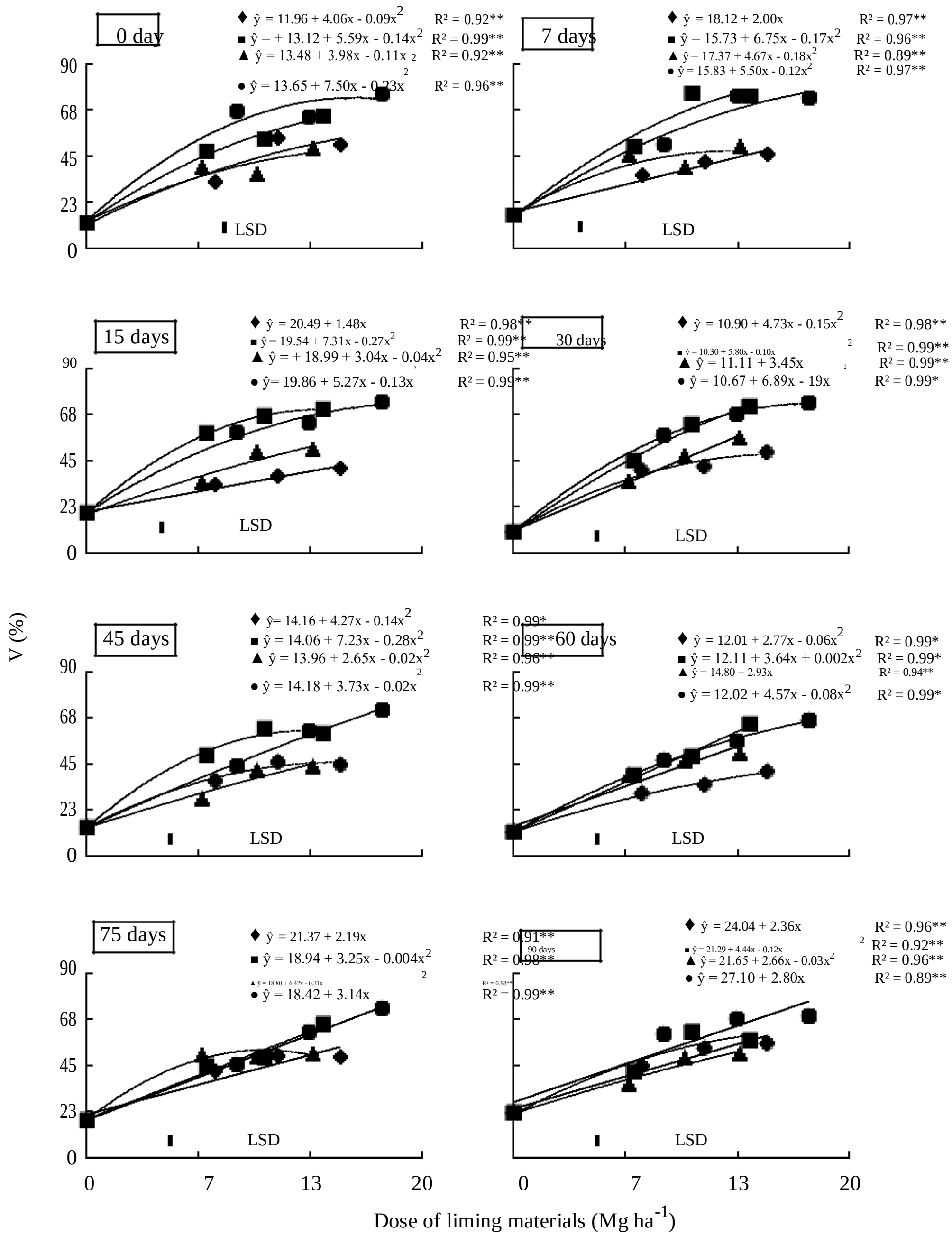

Figure 13. Base saturation (V) values on a Rhodic Hapludox (n = 4) during eight periods of incubation in the control treatment and in doses to increase the soil base saturation (V) to 50, 70 and 90% of each of the liming materials studied. (♦) Dolomitic limestone. (■) Granulated micronized calcite. (▲) Granulated micronized dolomite. (●) Carbonated suspension. Vertical bars indicate the Least Significant Difference (LSD). *: $P < 0.05$. **: $P < 0.01$.

they have been applied to the soil with variable charge.

Conflict of interests

The authors have not declared any conflict of interests.

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