

Lime Application to Two Acidic Upland Soils for Soybean Production in Champasak Province, Lao PDR

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ABSTRACT

Low yield of soybean in the Lao People's Democratic Republic (Lao) have been reported, where soil acidity could be one of the limiting factors affecting crop growth. In Champasak province, Lao, the effect of lime application on soybean production was studied on two acid upland soils, which varied in their chemical and physical properties. The NuMaSS software predicted that lime was needed and that the soil at the Bachieng site needed more lime than the Hoythakoune site. The results illustrated that liming had beneficial effects on soybean. The highest grain yields of soybean at the Bachieng and Hoythakoune site were 2,206 and 2,102 kg ha⁻¹ compared with the control treatment, which yielded 1,462 and 962 kg ha⁻¹, respectively. The results of the study indicated that lime had a strong effect on increasing soil pH, from 4.4 to 5.3 and from 4.7 to 6.0 for the Bachieng and Hoythakoune sites, respectively). The appropriate liming rates for soybean production at the Bachieng and Hoythakoune sites were about 1,710 and 550 kg CaCO₃ ha⁻¹, respectively. An economic dominance analysis indicated that the net return from liming was very high for both the Bachieng (\$ 402 ha⁻¹) and Hoythakoune (\$ 503 ha⁻¹) sites.

Key words: lime response, soybean, lime prediction, soil acidity, NuMaSS

INTRODUCTION

Around the world, acidic upland soils have limited crop growth potential. In strongly acid soils, excess soluble or exchangeable Mn and Al cause toxicity in many crops (Jackson *et al.*, 1967). Uexkull and Bosshart (1982) characterized the low fertility of acid soils as due to a combination of Al, Mn, Fe toxicity and P, Ca, Mg, K deficiency. The productivity of many acid soils is also reduced by physical factors related to soil texture that include low water holding capacity (Oxisols, Spodosols) and susceptibility to crusting, erosion and especially compaction (Oxisols, Ultisols).

Andrade *et al.* (2002) found that soil acidity was often accompanied with constraints for plants, including Al and Mn toxicity, Ca and Mg deficiency and low P availability. Borkert and Stredo (1994) reported that acid soil toxicity was not a single factor, but a complex of factors that reduce plant growth. Tropical subsoils are often very acidic and low in Ca content that limit deep soybean root growth.

In Lao, upland soils are strongly acidic, which reduce poor crop growth that results in low crop yields. The acidic upland soils, which belong to the orders Oxisols, Ultisols, and Alfisols, are widespread in the Bachieng and Pathumphone

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districts. In Champasak province, acidic soils with soil pH range from 4.5 to 5.0 occupy more than 78% of the total area (Vonghachack, 2000). Unfortunately, these soils produce little income because of soil acidity limitations on crop selection and crop growth. Soybean (*Glycine max* L) is the third most important crop, after rice and coffee, that farmers cultivate in this area. However, soybean is more sensitive to acidic soil than the peanut. Many farmers attempt to cultivate soybean to increase their income, however low yield of soybean is largely due to the farmers' lack of knowledge on soil nutrient management, and due to low soil pH. Unfortunately, there are no recommendation to assist upland farmers manage acidic upland soils. Lime application may be one option to increase soil pH as well as improve crop yield. Lime can be applied to soybean and the residual effect of liming from the first application can provide adequate available P for the next soybean crop (Anetor and Akinrinde, 2006). Pierce and Warcke (2000) found that the pH change was related to the amount of lime applied. Meng *et al.* (2004) found that liming at the highest rate was favorable for a decline in subsoil acidity and increased grain yield.

The study of lime application rates and N, P, K fertilizers is one alternative that will help farmers use lime and fertilizer economically. Son *et al.* (1994) studied acidic upland soils for crop production in Vietnam and found that liming and fertilization reduced soil acidity and improved soil phosphorus and potassium availability. Lime was important for soybean because it increased the soil pH and decreased the toxicity of Al and Mn (Ranjit *et al.*, 2007), as well as increased the P, K and Ca uptake (Murata *et al.*, 2002).

Managing acidic soils to reduce the adverse effects of acidity on crop growth in Bachieng and Hoythakoune soils is a necessity for soybean cropping. Thus, study to reduce the limitation of acid soil to soybean production was carried out using NuMaSS for lime prediction. The

main objective of the study was to determine the appropriate amount of lime application for soybean production on two acidic soils in Champasak province.

MATERIALS AND METHODS

Experimental site and soil properties

Two field experiments were carried out in the wet season of 2006, at Champasak province in the southern part of the Lao at an elevation of 204 m. One site was located at the Horticulture Research Station in Bachieng district, about 24 km east from Pakse city. The other site was located at the Hoythakoune Seed Multiplication Station in Pathumphone district, about 70 km south of Pakse city. The distance between the two sites was about 90 km. The Bachieng soil (Bc) was classified as an Ultisol, while the soil at the Hoythakoune (Hk) was classified as an Ultisol, a typic Kandiodult. These two upland soils were selected for study because they had been extensively used by farmers for upland crops. The majority of the land in this area was fallow. However, new land use systems in these areas were upland rice, coffee plantation, and soybean, peanut and other crops.

Crop management, liming and fertilizer rates

The soybean variety planted at both sites was Chiang Mai 60 at a seeding rate of 18 kg ha⁻¹. Before planting, soybean seeds were mixed with *Rhizobium* at the ratio of 4000g seed to 200g of *Rhizobium*. In the wet season of 2006, on 1 July 2006, planting at the Hoythakoune site occurred followed by the Bachieng site on 10 July 2006. The growth period of soybean was 90 d after emergence. Weeds were controlled by hand weeding at 15 and 35 d after soybean emergence. The soybean was harvested on 10 October and 2 November 2006 at Bachieng and Hoythakoune site, respectively.

The amount of lime predicted by the Nutrient Management Support System (NuMaSS)

software (Version 2.0) was 1,600 kg $\text{CaCO}_3 \text{ ha}^{-1}$ and 1,000 kg $\text{CaCO}_3 \text{ ha}^{-1}$ for the Bachieng and Hoythakouane sites, respectively. Phosphorus and potassium were simulated by the PDSS (Phosphorus Decision Support System) software. P and K fertilizer was applied at 19 kg P_2O_5 and 74 kg $\text{K}_2\text{O} \text{ ha}^{-1}$ at Bachieng and 13 kg P_2O_5 and 60 kg $\text{K}_2\text{O} \text{ ha}^{-1}$ at Hoythakouane.

Experimental design

The experiments were conducted using a randomized complete block design, with five treatments (L0, L1, L2, L3 and L4; Table 2) and four replications. The individual plot size was 5 × 8 m with a harvested area of 4.5 × 4 m. The plant spacing was 50 cm between rows and 20 cm between plants. Each plot consisted of 10 rows.

Soil sampling and analysis and plant data collection

At both sites, soil samples were taken from each plot in the soil depth zone from 0 to 20-cm, before planting and after harvest. The samples were air-dried and crushed to pass through a 2-mm sieve and thoroughly mixed. Soils were analyzed for pH, organic matter, total N and extractable P, K, Ca, Mg, Mn and Al in the laboratory at the Department of Soil Science, Faculty of Agriculture, Kasetsart University. Soybean was collected from the sampled plots using a randomized collection procedure and prepared for plant nutrient analysis. Soybean was harvested from the eight middle rows, which

equated to a plot area of 18 m². At the same time, all remaining plant material above the soil surface was harvested and the fresh weight was recorded. A sample of 20 soybean plants was randomly collected from each plot for analysis. Grain yield was adjusted to 15% moisture content. The grain yield, fresh weight and dry weight were recorded for analysis.

Statistical and economic analysis

The SigmaPlot program was used to fit a linear plateau curve to quantify the effect of lime on soybean grain yield at both sites. An economic dominance analysis using the methods of CIMMYT (Harrington, 1998) was also performed.

RESULTS AND DISCUSSION

Soil analytical results

The soil at Bachieng was acidic (pH 4.3), with a reddish soil color, clay content of 407 g kg^{-1} , and 43 g kg^{-1} organic matter (Table 1). The Bray 2 extractable soil P was 0.75 mg kg^{-1} , the NH_4OAc extractable K was 61 mg kg^{-1} and the DTPA extractable Mn was 111 mg kg^{-1} . The soil at Hoythakouane was grayish in color with clay content of 203 g kg^{-1} , a soil pH of 4.7 and 12.7 g kg^{-1} organic matter. The Bray 2 extractable soil P and NH_4OAc extractable K were 0.4, and 93 mg kg^{-1} , respectively, and the DTPA extractable Mn was 86 mg kg^{-1} . Both soils had high concentration of KCl extractable Al. High concentrations of Mn and Al have been considered to inhibit root growth

Table 1 Some physical and chemical properties of soils at the selected sites.

Soil	Texture	pH	Sand	Silt	Clay	OM ¹	Total ² N	P ³	K ⁴	Ca ⁵	Mg ⁶	Mn ⁷	Al ⁸
			----- g kg^{-1} -----							----- mg kg^{-1} -----			
Bachieng	clay	4.3	290	253	407	43.0	0.8	0.75	61	131	31	111	98
Hoythakouane	sandy loam	4.7	594	203	203	12.7	0.4	4.0	93	109	36	86	58

Note: ¹ Walkley and Black (1934)

³ Bray 2 (Bray and Kurtz, 1945).

⁷ Extractable Mn by DTPA method (Jones, 2001)

⁸ Extractable Al by KCl (Barnhisel and Bertsch, 1982)

² Kjeldahl methods (1883)

⁴⁻⁵⁻⁶ 1 M Ammonium acetate, pH 7 (Rhoades, 1982)

in sensitive crops (Uexkull and Bosshart, 1982). The Ultisols with their slowly permeable, argillic horizons might pose physical barriers to root growth as well. The annual rainfall at Champasak province during the past 10 years (1990-2000) averaged about 2,000 mm and the mean temperature was 28 °C

Effect of lime on soybean yield in 2006

Bachieng site

The increases in grain and haulm yields were highly significant with increasing liming rates. Grain yields of L1, L2, L3 and L4 were 1,688, 1,699, 2,182 and 2,206 kg ha⁻¹, respectively, while the control treatment was 1,462 kg ha⁻¹ (Table 2). The increasing yields of L1 and L2 were not significantly different compared with the control treatment, as in the case of L3 and L4. Grain yield responded to lime up to 1,710 CaCO₃ kg ha⁻¹ with a yield of about 2,200 kg ha⁻¹ (Figure 1). High liming rates had positive effect on soybean yield, doubling the yield (L3). Soil data indicated that the pH increased with higher liming rates, but there were no significant differences among various liming treatments (Table 3). The lack of significance may have been due to the short duration for the lime incorporation into the soils. Wortmann *et al.* (2005) reported that it could take one to two years for the full effect of lime application to be effective. Bray 2 extractable soil

P content slightly increased with liming treatments from 1.8 to 2.8 mg P kg⁻¹. The concentration of Ca and Mg also increased (from 154 to 314 mg Ca kg⁻¹ and from 66 to 93 mg kg⁻¹) due to liming. Caires *et al.* (2006) studied the effect of liming on Oxisols and found that liming resulted in a significant increase in pH and exchangeable Ca²⁺ and Mg²⁺ contents for as long as 58 months after application. According to the current study, the Al content in the soil decreased from 58.3 mg kg⁻¹ to 23.5 mg Al kg⁻¹ in the highest liming treatment. Higher Ca and Mg uptake by plants in the high liming rate treatments were observed (Table 4).

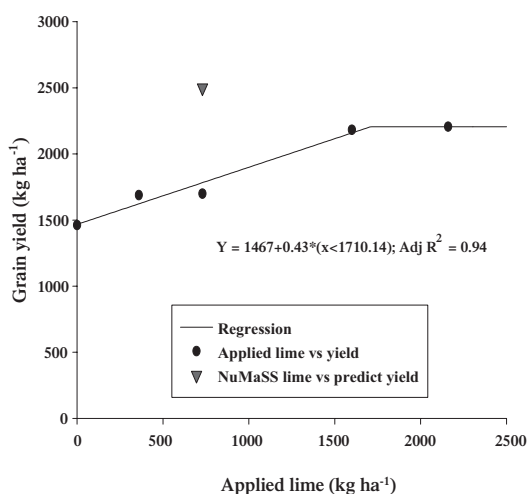


Figure 1 Soybean grain yield response to lime application at the Bachieng site.

Table 2 Grain and haulm yield of soybean grown on soils at Bachieng & Hoythakoune sites with different liming rates.

Bachieng site			Hoythakoune site		
Lime rate (kg CaCO ₃ ha ⁻¹)	Grain kg ha ⁻¹	haulm kg ha ⁻¹	Lime rate (kg CaCO ₃ ha ⁻¹)	Grain kg ha ⁻¹	haulm kg ha ⁻¹
L0 (0)	1462 b	1508 c	L0 (0)	962 d	1607 c
L1 (360)	1688 b	2168 b	L1 (330)	1562 c	2165 b
L2 (730)	1699 b	2192 b	L2 (670)	1769 b	2422 b
L3 (1600)	2182 a	2196 b	L3 (1000)	2019 a	2480 b
L4 (2160)	2206 a	2726 a	L4 (1300)	2102 a	2689 a
F- test	**	**		**	*
CV (%)	15.7	12.2		6.8	13.1

Table 3 Properties of the two soils at Bachieng and Hoythakoune sites after harvest.

Treatment	pH	Bachieng site					Treatment	pH	Hoythakoune site						
		P ¹	K ²	Ca ³	Mg ⁴	Mn ⁵			Al ⁶	P ¹	K ²	Ca ³	Mg ⁴	Mn ⁵	Al ⁶
lime		-----	-----	-----	-----	-----	lime		-----	-----	-----	-----	-----	-----	-----
kg CaCO ₃ ha ⁻¹		mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	kg CaCO ₃ ha ⁻¹		mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹
L0	4.4	1.8	82	154	66	63	58.3	L0 (0)	4.7	4.2	82	94	28	38	52.8
L1 (360)	5.1	2.5	82	156	68	58	45.9	L1 (330)	5.3	5.0	82	100	29	32	30.9
L2 (730)	5.1	2.7	81	231	81	55	29.9	L2 (670)	5.7	5.1	82	109	44	32	21.9
L3 (1600)	5.2	2.8	82	273	87	55	29.5	L3 (1000)	5.7	5.6	81	117	74	31	18.6
L4 (2160)	5.3	2.8	82	314	93	53	23.5	L4 (1300)	6.0	5.7	83	124	87	29	13.1

^{*1} Bray - 2 extraction (Bray and Kurtz, 1945); ^{2,3,4,5} 1 M Ammonium acetate, pH 7; ⁶ Al by 1M KCl extraction (Pratt and Bair, 1961)

Table 4 Effect of lime on P, K, Ca, Mg, Mn and Al uptake by grain and haulm of soybean grown on the soil at Bachieng site.

Treatment	Grain						Haulm					
lime	P ¹	K ²	Ca ³	Mg ⁴	Mn ⁵	Al ⁶	P ¹	K ²	Ca ³	Mg ⁴	Mn ⁵	Al ⁶
kg CaCO ₃ ha ⁻¹	----- kg ha ⁻¹ -----						----- kg ha ⁻¹ -----					
L0	5.6 c	34c	3.2b	1.9b	4.3b	0.07	0.9 d	10c	6.1b	4.3c	5.5b	0.4c
L1 (360)	5.8c	38bc	3.2b	2.3b	5.5a	0.07	1.3c	15b	8.3a	6.0b	7.5b	0.4bc
L2 (730)	6.6bc	46ab	4.2ab	2.3b	5.4a	0.06	1.5bc	15b	8.1a	6.0b	7.1b	0.5ab
L3 (1600)	7.8ab	52a	4.7ab	3.5a	5.3a	0.08	1.6ab	16b	9.0a	6.2b	9.8a	0.5ab
L4 (2160)	10a	52a	5.5a	3.6a	5.4a	0.08	1.9a	18a	9.0a	8.2a	11.5a	0.6a
F- test	***	**	*	**	*	ns	***	***	**	***	***	**
CV (%)	11.1	13.3	23.4	24.8	7.0	36.8	12.4	7.4	13.1	12.8	17	14.7

* Significant at the 0.05 level; ** Significant at the 0.01 level; *** Significant at the 0.001 level; ns = not significant.

Means followed by the same letter in the column were not significantly different at a = 0.05 by Duncan's multiple range test (DMRT)

Randall *et al.* (2006) and Franzen and Gerwing (1997) found that Ca and Mg uptake in grain were lower than those in haulm, with values of calcium in grain and haulm of 12.1 and 27.4 kg ha⁻¹, respectively, and Mg in grain and haulm of 8.3 and 22.6 kg ha⁻¹, respectively. The P and K uptake by grain and haulm were higher in the higher liming rate (2,160 kg CaCO₃ ha⁻¹). This was probably because grain and haulm yield increased (Table 2 and 4).

Hoythakouane site

Grain and haulm yields of soybean at higher liming rates were increased (Table 2). Grain yield of L3 was 2,019 kg ha⁻¹ which was the highest yield compared with the control treatment (962 kg ha⁻¹). Lime application at the rate of 1,000 kg CaCO₃ ha⁻¹ had a significant positive effect. Lime applications on sandy soils may be as high as 2 to 4 tons ha⁻¹ (Martin and Douglas, 1967; Jackson *et al.*, 1967; Lim and Shen, 1978). The SigmaPlot program indicated that soybean responded up to 550 kg CaCO₃ ha⁻¹ (Figure 2) while the predicted amount was at 670 kg CaCO₃ ha⁻¹ by NuMaSS. The lime increased soybean growth and grain yield due to the higher soil pH (Table 3). Extractable P increased from 4.2 to 5.7 mg kg⁻¹, at the highest liming rate. Friesen *et al.* (1980) also reported that P increased when soils were limed to pH 6.0 or higher. The calcium and magnesium content in this soil increased with liming from 94 to 124 mg Ca kg⁻¹ and from 28 to 87 mg Mg kg⁻¹. This case was similar to Ciful *et al.* (2004) who found that lime application to the soil increased exchangeable Ca and Mg. Extractable Al and Mn decreased with increasing liming rates (Table 3). The aluminum content in L0 was 52.8 mg Al kg⁻¹ in contrast with 13.1 mg Al kg⁻¹ at the liming rate of 1,300 kg CaCO₃ ha⁻¹ (L4). The highest benefits of liming application on acid soil were the reduction of Al and Mn in the solution. Both Al and Mn are toxic to most plant (Tisdale *et al.*, 1985). Higher Ca and Mg

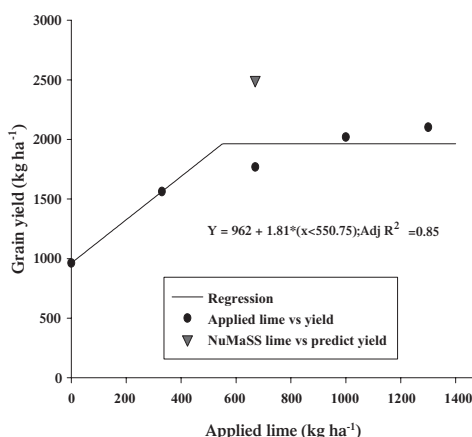


Figure 2 Soybean grain yield response to lime application at the Hoythakouane site.

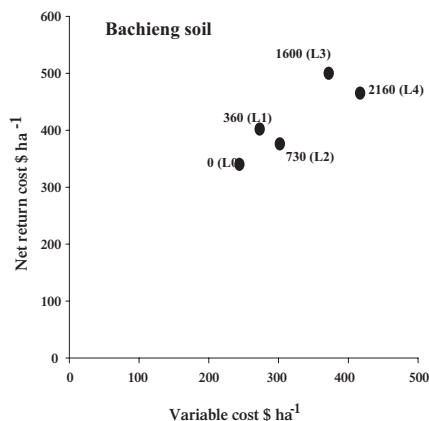


Figure 3 Relationship of costs and net return, Bachieng site.

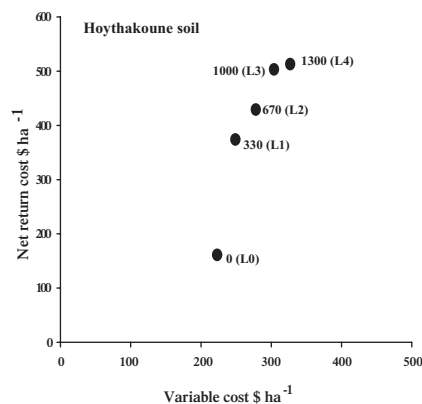


Figure 4 Relationship of costs and net return, Hoythakouane site.

uptake by plants was observed in treatments with a high liming rate (Table 5). The uptake of P, K, Mn and Al uptake by grain and haulm was higher at the highest liming rates (1,300 kg CaCO₃ ha⁻¹). This was probably because the grain and haulm yield increased (Table 2 and 5).

Economic dominance analysis

The dominance analysis of the soybean yield at the Bachieng site indicated that the net return of liming the soil for soybean was highest in treatment L3 (about \$500 ha⁻¹), with a benefit/cost ration of 1.3. Lime application of 360 kg ha⁻¹ (L1) gave a net return of \$402, with a benefit / cost ration of 1.4. This suggested that the low investment farmers should apply the L1 treatment with a lower net return. In the case of higher investment farmers, liming at 1,600 kg ha⁻¹ (L3) should be applied to achieve the highest net return. The maximum net return of the soybean on the Hoythakoune site was \$513 ha⁻¹ for 1,000 kg ha⁻¹ of lime application (L3) with a benefit/cost ration of 1.5 (Table 6)

CONCLUSIONS

Soybean responded to lime up to the rates of 1,710 and 550 kg CaCO₃ ha⁻¹ at Bachieng and Hoythakoune sites respectively, which appeared to be a preliminary liming rate for soybean production on these two sites. Liming had beneficial effects on soybean production in these two acid upland soils. At the Bachieng and Hoythakoune sites, the data indicated that soil pH increased from 4.4 to 5.3 and 4.7 to 6.0, respectively. In addition, lime increased the concentration of P, Ca, Mg and decreased Al and Mn in soils at two sites. The dominance analysis of the soybean yields at the Bachieng and Hoythakoune sites indicated very high returns from the addition of lime.

Table 5 Effect of lime on P, Ca, Mg, Mn and Al uptake by grain and haulm of soybean grown on the soil at Hoythakoune site.

Treatment lime, kg ha ⁻¹	Grain						Haulm					
	P ¹	K ²	Ca ³	Mg ⁴	Mn ⁵	Al ⁶	P ¹	K ²	Ca ³	Mg ⁴	Mn ⁵	Al ⁶
	-----kg ha ⁻¹ -----						-----kg ha ⁻¹ -----					
L0	4.1c	16d	3.3b	0.5	3.8c	0.1b	1.5c	13	10	2.7c	4.8	0.6c
L1 (330)	7.7b	31c	3.4b	1.0	5.8b	0.2a	2.1bc	16	13.8	4.3b	4.0	0.8c
L2 (670)	8.3ab	36b	4.5b	1.1	6.2ab	0.2a	2.4ab	17	13	5.2ab	5.0	0.7a
L3 (1000)	8.9ab	41a	5.5ab	1.2	9.2ab	0.2a	2.4ab	18	14	5.5ab	5.6	1.01a
L4 (1300)	9.7a	44a	7.2a	2.8	8.5a	0.2a	2.7a	18	17	5.6a	6.8	1.10a
F- test	**	**	*	ns	**	*	**	ns	ns	**	ns	*
CV (%)	13.0	5.9	31.9	36.3	19.2	24.3	15.8	19.5	22.1	16.7	31.3	24.5

¹⁻⁶Tri acid mixture digestion (HNO₃+H₂SO₄+HClO₄) ; * Significant at the 0.05 level ** Significant at the 0.01 level ns = not significant

Means followed by the same letter in the column were not significantly different at a = 0.05 by Duncan's multiple range test (DMRT)

Table 6 Variable cost and return analysis lime treatments of Bachieng and Hoythakouane sites.

Soil at Bachieng site			Soil at Hoythakouane site		
Lime rate (kg CaCO ₃ ha ⁻¹)	Variable cost ----- US\$ ha ⁻¹ -----	Net return -----	Lime rate (kg CaCO ₃ ha ⁻¹)	Variable cost ----- US\$ ha ⁻¹ -----	Net return -----
L0 (0)	244	340 b	L0 (0)	223	161 c
L1 (360)	273	402 b	L1 (330)	249	374 b
L2 (730)	302	376 b	L2 (670)	278	429 b
L3 (1600)	372	500 a	L3 (1000)	304	503 a
L4 (2160)	417	465 a	L4 (1300)	327	513 a
F- test		*			***
CV (%)		19.4			5.5

* Significant at the 0.05 level ** Significant at the 0.01 level ns = not significant

Means followed by the same letter in the column were not significantly different at $\alpha = 0.05$ by Duncan's multiple range test (DMRT)

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