Effects of Liming to Near-neutral pH on *Vitis vinifera* L.

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Wine grape vines are sensitive to soil pH and liming. The effects of pre-plant liming at rates sufficient to promote average soil pH levels (1M KCl) of 5.05 (unlimed, treatment L0), 5.64 (L1) and 6.56 (L2) in two wine grape (scion) varieties and four rootstocks five years after planting were investigated over six seasons in a factorial field trial at Stellenbosch. Yields tended to decrease in the sequence: L0 > L1 > L2, and were significantly (P = 0.05) lower in L2 than in L0. Conversely, cane masses increased progressively with lime application rate, with L1 exceeding L0 by 11.0% and L2 exceeding L1 by 13.0%. These increases were significant. Compared to L0, liming decreased the ratio of yield to cane mass by 13.6% in L1 and 28.8% in L2, but increased Ca:Mg ratios in the soil and petioles. Wine quality was significantly better from L0 than L2. Petiole N concentrations were above normal in all treatments. Suppressed yields and wine quality in the limed treatments were attributed to a lime-induced imbalance between vegetative and reproductive growth, possibly exacerbated by increased Ca:Mg ratios and excess nitrogen.

Many soils on the coastal forelands and mountain slopes of the Western Cape are sufficiently acid for vine performance to be affected detrimentally. This acidity is usually considered to have been sufficiently ameliorated when enough lime (finely ground calcium [Ca] and magnesium [Mg] carbonate rock) has been added to the soil during preparation, and as topdressings thereafter, to reduce exchangeable aluminium to 0.2 cmol(+)/kg (Conradie, 1983). Lime application rates are calculated by the method of Eksteen (1969), or as refined by Smuts (2001). If correctly sampled, analysed and calculated, this process results in a soil pH of between 5.0 and 5.5 (1M KCl), and exchangeable Ca and Mg concentrations of around 70 to 80% and 12 to 15%, respectively, of the sum of exchangeable sodium (Na), potassium (K), Ca and Mg. Soils that are naturally rich in carbonates occur in parts of the Breede River Valley, where little leaching has taken place, where the soil parent material contains residual carbonates derived from underlying rock formations, and in low-lying coastal areas where marine carbonates or their transported fragments are present. Compared to soil acidity, the effects on grapevines of soils that have slightly high to near neutral pHs are less well documented, and it is possible that liming to pH 5.0 may be insufficient for certain rootstocks (Conradie, 1983). To gain further information, unpublished data from a lime/scion/rootstock trial done in the 1990s was revisited.

MATERIALS AND METHODS

The trial, which aimed to test the effects of liming and elevated soil pH on grapevines, was carried out on a colluvial, coarse sandy loam to sandy clay loam Avalon (Soil Classification Working Group, 1991) soil of mixed granite and shale derivation. The site was situated on a lower midslope on Nietvoorbij Research Farm, Stellenbosch (33˚55'01.90"S, 18˚51'55.68"E). During soil preparation in autumn 1988, a soil survey was carried out and calcitic lime was applied to designated areas at rates sufficient to establish soil pHs of 5.6 (normal practice, designated treatment L1) and 7.2 (high lime, L2), as measured in 1M KCl. A further treatment (L0) received no lime and had a pH of 4.8. Phosphorus (P), as double superphosphate (20% P), was applied with the lime at 330 kg P/ha. This was sufficient to increase the soil P concentration from eight to an estimated 30 mg/kg (Conradie, 1994). After cross ripping (at 120˚) to 100 cm, 99 Richter (99R), 110 Richter (110R), 140 Ruggeri (140Ru) and SO4 rootstocks, grafted to Pinot noir and Chardonnay, were planted in factorial combination with the lime treatments. Each treatment was replicated at random in five blocks and consisted of a 25 m^2 plot containing 10 adjacent vines. Vine rows containing plots were separated by buffer rows. Plots within the same row were separated by ten buffer vines. Micro-sprinkler irrigation was provided, and the maturing vines were trained to an extended Perold trellising system. With the exception of nitrogen (N) applications, an annual K application in spring at the rate of 3 kg K (as KCl, 50% K)/ha/ton of expected production (Conradie, 1994), pest control sprays and other routine vineyard management practices, no further action was taken until the 1992/1993 season. The soils in each plot were sampled in winter 1993 and in seasons 1992/1993 through 1997/1998. Leaf sampling (40 petioles per sample from basal leaves opposite bunches) was carried out in these seasons at fruit set (late November to early December). The leaf and soil samples were analysed using standard ARC Infruitec-Nietvoorbij methods as described by The Non-Affiliated Soil Analysis Work Committee (1990). Elemental analysis was performed using a Varian inductively coupled plasma atomic emission spectrometer. A Leco Nitrogen Determinator was used to establish leaf N contents.

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Grapes from each vine in each plot were harvested at *c.* 23 ˚B (Pinot noir) and *c.* 21 ˚B (Chardonnay) (1990's standards, now regarded as low) from February 1993 to 1998, and weighed to determine yield, which was expressed as t/ha The grapes from all 10 vines in each plot were combined before pressing. The unsettled must was analysed soon after pressing, using methods specified by the South African Wine Laboratories Association (undated), after which wines were made under standard conditions in the Nietvoorbij Research Cellar and sensorially assessed by a panel of 12 trained judges using a nine-point scale.

Each winter the masses of cane pruned from each of the ten vines in each plot were individually determined using a top loading balance. Average cane mass per vine was calculated for each plot, and expressed in t/ha.

The leaf, cane mass, must and wine data were tested for normality by the Shapiro-Wilk test (Shapiro & Wilk, 1965), and then subjected to analysis of variance by season using the general linear means procedure of SAS 9.1.3 (SAS Institute Inc., 2003). Student's *t* least significant difference (LSD) values were calculated at the 5% probability level to facilitate comparison between the treatment means. Means that differed at P = 0.05 were considered to be significantly different.

RESULTS AND DISCUSSION

Soil parameters

As determined in 1993 (season five), by which time the vines had settled into a reasonably mature and stable bearing pattern, the average pHs of the soils in L0, L1 and L2 were found to have drifted from the 1988 values to 5.05, 5.64 and 6.56 respectively (Table 1). The 0.25 unit pH increase in the zero lime treatment (L0) was probably due to the movement of lime in the ground water from adjacent limed treatments. Soil P concentrations in the winter of 1993 were below the recommended level of 30 mg/kg for soils containing 30% clay (Conradie, 1994), particularly in L0 and L1. Phosphorus was therefore added to all treatments at 45 kg P/ha. Exchangeable Ca:Mg ratios in the soil in 1993 increased with increasing lime application rate, from 2.2:1 in L0 to 5.3:1 in L1. Grapevines tolerate Ca:Mg ratios over the approximate range of 2:1 to 10:1 (Conradie, 1994). Treatments L0 and L1 fell within this range, but not L2, where the Ca:Mg ratio averaged 22.3:1. To increase the soil Mg content relative to Ca, dolomitic lime was added to L2 in the late winter of 1993 at the rate of two t/ha. No lime was applied to any of the treatments thereafter, and the soils were allowed to slowly reacidify under the prevailing winter rainfall conditions.

Effects of liming on rootstocks and scions

Cane masses from Chardonnay exceeded those from Pinot Noir (by 18.0%). Rootstock masses decreased in the sequence 140Ru > SO4 > 110R. No interaction was observed between liming, scion variety and rootstock. This was in contrast to expectations in view of the finding of Conradie (1983) that 140Ru is relatively more tolerant of acid soils than 99R, 110R and SO4. Data from the two scions and four rootstocks were therefore pooled. Consequently, the results presented in this article concern the main effects of the lime treatments, calculated from the seasonal treatment means for seasons 1992/1993 to 1997/1998.

Vine performance

Grape yields tended to decrease in the sequence L0 > L1 > L2, and were significantly (10.7%) lower in the high lime (L2) than in the unlimed treatment (L0) (Table 2). In contrast, cane masses increased progressively with lime application rate; L1 exceeding L0 by 11.0%, and L2 exceeding L1 by 13.0%. Both increases were significant. Cane mass increases following liming were also reported by Conradie (1983). Compared to L0, liming decreased the ratio of yield to cane mass by 13.6% in L1 and 28.8% in L2. Increasing the lime application rate over the range tested therefore promoted cane mass (indicative of vigour) while depressing fruit yield, thereby contributing to a change in balance between vegetative and reproductive structures.

No chlorosis was observed, even in the treatment with the highest lime. Lime-induced iron deficiency (Lindsay & Schwab, 1982) was therefore not a contributory factor to the results observed in this trial.

Petiole and must composition

Averaged over all the years, petiole P, Ca, Mg and K concentrations were within the adequate ranges put forward by Conradie (1994) (Table 3). The once-off P application in 1993, and the annual applications of K in the spring, were therefore sufficient to maintain the vines throughout the trial period, despite the initially (1993) low soil P and K concentrations. Petiole N concentrations exceeded both the range of Conradie (1994), and the somewhat higher (0.8 to 1.10%) range of Robinson *et al.* (1997). Likewise, the must Ca, Mg, P and K concentrations fell within broad ranges derived from the results of Conradie (2001). The lime treatments had no significant effects on must sugar content or on pH, although the acidity of the must in L1 (8.89 g/L) and L2 (9.02 g/L) was significantly higher than that in L0 (8.68 g/L). The N and K contents of the petioles and the must, both of which fertiliser elements were supplied to the vines in all treatments at the same rates, were also unaffected by liming. Compared with L0, liming of L1 and L2 increased petiole P by 18.8% and 31.3% respectively. These differences in petiole P, which were significant, may have been due to progressive, lime-induced reductions in both Al toxicity and fixation of P by Al and

TABLE 1

Effect of liming and P applications during soil preparation in 1988 on average soil pH, P and cation concentrations in November 1993.

Lime treatment	pH (1M KCl)	Bray II P (mg/kg)	Bray II K (mg/kg)	Exch. Na (cmol(+)/ kg)	Exch. Ca (cmol(+)/ kg)	Exch. Mg (cmol(+)/ kg)	Ca:Mg ratio
L0	5.05a	7.24b	48.18a	0.063a	1.27c	0.59a	2.15
L1	5.64b	6.89b	46.56a	0.054ab	2.28b	0.43b	5.30
L2	6.56c	9.97a	44.88a	0.049b	8.47a	0.38c	22.3

Means in the same column that are followed by the same letter do not differ at P = 0.05.

Fe. Liming had no significant effect on must P. The ratio of Ca to Mg in the must tended to increase with increasing Ca:Mg ratio in the petiole. Petiole Ca concentrations were adequate, even in L0, where no lime was applied in 1988 or thereafter. Averaged over all years, L1 and L2 increased petiole Ca, relative to L0, by 23.6% and 35.0% respectively. Must Ca concentrations in L1 and L2 were both around 11.8% greater than in L0. These increases were significant. Also significant were the 30.4% and 33.9% reductions in petiole Mg brought about by L1 and L2 respectively, compared with L0. The pattern for Ca to increase and Mg to decrease with liming accords with the concept of antagonism between Ca and Mg during root uptake (Conradie, 2001), but may also reflect high soil Ca:Mg ratios. That the ratios of yield to cane mass tended to decrease with increasing Ca:Mg ratios (Table 4) in both the petiole and stem implies that small decreases in Mg availability, relative to Ca, have greater effects on yield than on vegetative growth as indicated by cane mass. Petiole Na concentrations were too low to constitute a hazard (data not shown), and will not be considered further.

Sensory characteristics

Overall quality, as indicated by the sensorial data averaged for the wines produced from all scions and rootstocks between 1994 and 1998, tended to decline with increasing lime application rate (L0: 5.39, L1: 5.28, L2: 5.11). Quality in L0 was significantly greater than in L2. This finding (data not shown) was consistent with the conclusion of Hepner *et al*. (1985) that wine quality correlates negatively with pruning weight (*i.e.* cane mass), which, in the present trial, increased with rate of liming. Neither quality nor aroma showed significant scion x lime, or scion x rootstock interactions.

TABLE 2

Effect of liming on cane mass, yield and yield:cane mass ratio in *Vitis vinifera* L. Data are averages for the seasons 1992/1993 to 1997/1998.

Lime treatment	Yield (t/ha)	Cane mass (t/ha)	Ratio of yield to cane mass
L0	14.19a	2.36c	6.01:1a
L1	13.59ab	2.62b	5.19:1b
L2	12.67b	2.96a	4.28:1c

Means in the same column that are followed by the same letter do not differ at P = 0.05.

Implications

The reduced yield and yield:cane mass ratios observed in L1 and L2, relative to L0, occurred in vines in which the concentrations of the main nutrient elements were, and in all treatments remained, within (or, in the case of petiole N, above) acceptable limits (Conradie, 1994). This observation probably indicates that the supply of nutrient elements other than Ca and Mg was not a limiting factor in this trial. Had these elements been deficient, the observed lime-induced increases in vegetative growth (vigour), as indicated by cane mass, would not have occurred. Neither would these cane mass increases have occurred had the lime applications not been beneficial to the vines. Since the petiole Ca concentrations were

TABLE 3

Effect of liming on petiole element composition at fruit set, and in unsettled must of *Vitis vinifera L*, averaged over the seasons 1992/1993 to 1997/1998.

Element	Lime treatment	Petiole (%)		Must (mg/L)	
		Range*	Observed	Range**	Observed
	L0	Min: 0.60	1.32a	Min: 450	386a
Nitrogen	L1	Max: 0.98	1.31a	Max: 600	373a
	L2		1.34a		415a
	L0	Min: 0.13	0.16b	Min: 90	100a
Phosphorus	L1	Max: 0.62	0.19ab	Max: 150	101a
	L2		0.21a		104a
	L0	Min: 0.60	1.40b	Min: 35	37.8b
Calcium	L1	Max: 1.40	1.73a	Max: 55	42.3a
	L2		1.89a		42.2a
	L0	Min: 0.25	0.56a	Min: 50	78.8a
Magnesium	L1	Max: 0.80	0.39b	Max: 90	68.7b
	L2		0.37b		61.3c
	L0	Min: 1.00	1.79a	Min: 1000	1558a
Potassium	L1	Max: 2.90	1.78a	Max: 2000	1563a
	L2		1.92a		1572a

*Adequate range for petioles (Conradie, 1994).
**Possible adequate range for must, based on results of Conradie (2001).
Means in the same column and for the same element that are followed by the same letter do not differ at P = 0.05.

TABLE 4

Effect of liming on ratios of Ca to Mg in the petioles and must of *Vitis vinifera L*, averaged over the seasons 1992/1993 to 1997/1998.

	L0	L1	L2
Petiole	2.50	4.44	5.11
Must	0.48	0.62	0.69

within the adequate range, it is more likely that the greater vigour in the limed treatments was due to improved, less acid soil conditions than to the increased supply of Ca. This agrees with the finding of Conradie (1983) that improvements in root mass due to liming promote disproportionately large increases in vegetative growth.

That yields decreased relative to cane mass (Table 2) as the ratio of Ca to Mg increased in the soil (Table 1), petioles and must (Table 4), suggests that, under the prevailing trial conditions, the balance between reproductive growth (yield) and vegetative growth (cane mass) was influenced by the Ca:Mg ratios in the soil. According to Conradie (1994), the ideal ratio of Ca to Mg in vineyards is 4:1. In relation to this value, the exchangeable Ca:Mg ratio in L1 was slightly high, whilst that in L2 was excessive. These results confirm that, as recommended by Conradie (1994), a Ca:Mg ratio of around 4:1 is probably close to ideal for promoting a desirable yield:cane mass balance in the scion/rootstock combinations used as test crops. Nevertheless, the lime-induced yield suppression observed in this trial seems excessive in the light of the comment by Conradie (1994) that the Ca:Mg ratio is not critical from the viewpoint of vine nutrition, and that Ca:Mg ratios in vineyard soils may vary from 2:1 to 10:1. It may therefore be pertinent that the petiole N concentrations were around 35% greater than the maximum of the range quoted by Conradie (1994), signifying that over-fertilisation with N had taken place. In view of the common vineyard experience that N affects the balance between vegetative and reproductive growth by stimulating excess vegetative growth, it is likely that the yield:cane mass ratios in treatments L1 and L2 would have been greater if N had been applied in the postharvest period only, and at much reduced rates. Although reducing the N supply may reasonably have been expected to reduce vegetative growth, insufficient data is available to predict whether applying less N would have increased or decreased yield. This requires elucidation. Measures to control excess vegetative growth are likely to become increasingly necessary as lime rates increase, probably to a greater extent in lime-responsive than in acid-tolerant rootstocks (Conradie, 1983).

Within the parameters of this trial, liming did not significantly affect overall wine quality from L0 to L1. Although quality tended to decrease with liming, this was probably a secondary effect brought about by the positive effect of liming on cane mass. Moderate liming can therefore be carried out without risk to the product. The finding that liming to near neutral pH (L1) had no significant negative effect on wine quality agrees with international experience that excellent wines may be produced from high-pH, carbonate-rich soils. Examples of these are the Kimmeridgian chalky marls and overlying Portland limestone of the south eastern rim of the Paris Basin, which support many vineyards beneath the cap rock (Wilson, 1998), and the calcareous brown soils on crinoidal limestone and oyster marl of the Côte d'Or (White, 2003).

CONCLUSIONS

The results from this field trial confirm the desirability of liming vineyard soils to their full effective depth with sufficient calcitic and/or dolomitic lime before planting, to eliminate exchangeable acidity and promote exchangeable Ca and Mg saturations in a ratio of 4:1 and a pH of 5.0 to 5.5. However, relative to unlimed soils, or soils that are underlimed for that particular rootstock, liming may result in increased vegetative growth and reduced yields. The possibility of such an imbalance is nevertheless not a valid reason for underliming, which merely leaves the root system under conditions of avoidable stress. Rather, liming should be carried out to the point where the vigour of the scion/rootstock combination in question just ceases to show further benefit. This may require a pH in excess of 5.0, and the elimination of all exchangeable acidity. Any tendency to excess vigour and imbalance that may result from this liming, should be controlled by canopy management practices, such as reduced N applications and irrigation scheduling.

LITERATURE CITED

Conradie, W.J., 1983. Liming and choice of rootstocks as cultural techniques for vines in acid soils. S. Afr. J. Enol. Vitic. 4(2), 39-44.

Conradie, W.J., 1994. Vineyard nutrition. Proceedings of a workshop on vineyard nutrition, held at Nietvoorbij on 30 September. ARC-Infruitec-Nietvoorbij, Private Bag X5026, Stellenbosch, South Africa.

Conradie, W.J., 2001. Timing of nitrogen fertilisation and the effect of poultry manure on the performance of grapevines on sandy soil. II. Leaf analysis, juice analysis and wine quality. S. Afr. J. Enol. Vitic. 22(2), 60-68.

Eksteen, L.L., 1969. The determination of the lime requirement of soils for various crops in the Winter Rainfall Region. Fertilizer Society of South Africa J. 2, 13-14.

Hepner, Y., Bravdo, B., Loinger, C., Cohen, S. & Tabacman, H., 1985. Effect of drip irrigation schedules on growth, yield, must composition and wine quality in Cabernet sauvignon. Am. J. Enol. Vitic. 36(1), 77-85.

Lindsay, W.L. & Schwab, A.P., 1982. The chemistry of iron in soils and its availability to plants. J. Plant Nutr. 5, 821-840.

Robinson, J.B., Treeby, M.T. & Stephenson, R.A., 1997 (2nd ed). Fruits, vines and nuts. In: Reuter, D.J. & Robinson, J.B. (eds). Plant analysis. An interpretation manual. CSIRO Publishing, Collingwood, Australia. pp. 349 – 382.

SAS Institute, Inc., 2003. Version 9.1.3. SAS Institute, SAS Campus Drive, Cary, North Carolina 27513.

Shapiro, S.S. & Wilk, M.B., 1965. An analysis of variance test for normality (complete samples). Biometrika 52, 591-611.

Smuts, M.N., 2001. Determination of the lime requirement of sandy, organic rich, and structured, high Mg:Ca ratio soils by the Eksteen method. Thesis, Stellenbosch University, Private Bag X1, Matieland 7602 (Stellenbosch), South Africa.

Soil Classification Working Group, 1991. Soil classification. A taxonomic system for South Africa. Memoirs of the agricultural natural resources of South Africa no. 15. Department of Agricultural Development, Private Bag X144, Pretoria 0001, South Africa.

South African Wine Laboratories Association, (undated). Methods of analysis for wine laboratories. South African Society for Enology and Viticulture, P.O. Box 2092, Dennesig 7601 (Stellenbosch), South Africa.

The Non-Affiliated Soil Analysis Work Committee, 1990. Handbook of standard soil testing methods for advisory purposes. Soil Science Society of South Africa, P.O. Box 30030, Sunnyside 0132, Pretoria, South Africa.

White, R.E., 2003. Soils for fine wines. Oxford University Press, Oxford.

Wilson, J.E., 1998. Terroir. University of California Press, Berkeley, California.