

Nitrogen Mineralisation in Vineyard Soils of the Western Cape as Affected by Soil Management Practices*

P.J. Raath¹ and D. Saayman²

1) Nietvoorbij Institute for Viticulture and Oenology, Agricultural Research Council, Private Bag X5026, 7599 Stellenbosch, South Africa

2) Department of Soil & Agricultural Water Science, University of Stellenbosch, 7600 Stellenbosch, South Africa

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Soil management practices like ridging, liming and irrigation are expected to affect the ability of microorganisms to mineralise plant residues in the soil through their effects on water regime, temperature, pH, organic C and total N contents. Investigations into seasonal changes in the mineral N contents of typical vineyard soils, as affected by these practices, were initiated during 1991 in existing vineyard trials. Soil water, soil temperature and mineral N were measured at regular intervals over two growing seasons. Ridged soil showed higher N release than non-ridged soil during winter, resulting in higher mineral N content at budburst. The effect of liming on microbial activity probably abated after 5 years because no difference in mineral N contents were obtained between soils of different pH. Irrigation showed no effect on N release, probably because of treatment design. Decreases in mineral N content during the growing season in soils from all the trials could not always be attributed to uptake by grapevines or to decreases in potentially mineralisable N contents and microbial activity.

A continuous turn-over of nitrogen (N) occurs in soils through mineralisation and immobilisation processes, usually resulting in a nett release of mineral N available to plants. Despite this, on average more N than any other element is applied to crops in the form of fertilisers. This also applies to grapevines, although the amount of N required by grapevines is less than for most annual crops (Saayman, 1982).

More efficient N fertilisation of vineyards was made possible because information on the N demand of grapevines during different phenological stages has become available in recent years (Conradie, 1980; 1986), and improved irrigation efficiency prevented unnecessary leaching. Nitrogen uptake peaks during the period from a few weeks prior to bloom until veraison, with a second peak during the period from harvest to leaf fall (Conradie, 1980). Nitrogen applications should be timed to optimise levels of mineral N in the root zone. However, any contribution of N, either from irrigation water, crop residues or mineralisation of organic matter, should also be considered when determining N fertiliser requirements at different growth stages (Peacock *et al.*, 1991). The amount of N released from organic matter is determined by many soil factors affecting the rate of mineralisation, presence of mineralisable N and the number of ammonifying and nitrifying organisms (Stevenson, 1986). This makes it difficult to predict plant requirements for N fertiliser in a given situation.

It can be assumed that soil management practices which alter the soil conditions will affect N release. If the effect of soil management practices proves to be great, such practices will have to be taken into account when fertiliser recommendations are made.

Important soil management practices in the Western Cape viticultural regions are ridging, liming and irrigation. It was found that ridging of a clayey hydromorphic soil caused higher soil temperatures and lower soil water contents because of improved internal drainage (Myburgh, 1989). Black (1968) stated that when acid soils are limed, a portion of the soil organic matter becomes more susceptible to mineralisation, but after this portion is decomposed, mineralisation returns to its original level, despite an altered composition of soil microbial populations. Nyborg & Hoyt (1978) also found that the N mineralisation rate of soil increased rapidly when soil pH was increased by liming, but this was only temporary. Irrigation increased ammonia N pools, nitrification potential and the N mineralisation potential of forest soils (White *et al.*, 1988). According to Cortez (1989), continued soil drying and wetting cycles did not significantly affect the mineralisation of bacterial constituents, but increased the size and specific activities of newly formed microbial biomass. Harmsen & Van Schreven (1955) found a decrease in the accumulation of mineral N in irrigated soils because of leaching.

The effect of the above-mentioned soil management practices on N availability in vineyard soils of the Western Cape and the adjustments to be made in N fertilisation are still unknown and need to be qualified and quantified. To this end, three studies were carried out in fully productive experimental vineyards, each representing a different soil management practice commonly applied in the wine-producing areas of the Western Cape.

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MATERIALS AND METHODS

Trials

Ridging trial: In this randomised block trial with five blocks as replicates, on a gleyed, medium-textured Katspruit soil (Soil Classification Working Group, 1991) at Nietvoorbij, Stellenbosch, three treatments were evaluated (Table 1). Plots consisting of 30 vines each were divided into three sub-plots, to which three soil sampling times (budburst, bloom and post-harvest) were randomly allocated. These sampling times represented the onset and most important periods of N uptake by grapevines. For further details regarding the layout of treatments, refer to Myburgh & Moolman (1991). No N fertilisation was applied during the course of the trial. A weekly irrigation according to evaporation from a standard American class A pan was applied. Irrigation systems used are shown in Table 1.

Liming trial: This trial was laid out five years before the onset of this research on a yellow-brown, well drained, medium-textured Clovelly soil (Soil Classification Working Group, 1991) at Nietvoorbij, Stellenbosch. In each of the three, non-replicated treatments (Table 1) five plots (3 rows with 6 vines in each row) were randomly selected and each divided into three randomly allocated soil sampling time sub-plots, as above. Over the full course of the trial this vineyard received no N fertilisation. Two supplementary irrigations were applied in December and January through a micro irrigation system.

Soil depth/irrigation trial: Four treatments were evaluated (Table 1) in a randomised design with three replicates on a shallow, granitic Glenrosa soil (Soil Classification Working Group, 1991) at Nietvoorbij, Stellenbosch. Each treatment plot contained 15 experimental vines, which were divided into three sub-plots to which the three soil sampling times were randomly allocated. Post-harvest fertilisation (20 kg N ha⁻¹) was applied in 1992 in the form of limestone ammonium nitrate. Plastic sheets were installed as artificial depth restrictions at the relevant depths only in the case of irrigated plots. For further information regarding the detailed layout of treatments, refer to Conradie, Myburgh & Van Zyl (1995). A weekly irrigation according to evaporation from a standard American class A pan was applied, using micro irrigation systems.

Soil samples

Sampling: For the 1991/92 and 1992/93 seasons soil samples were collected at budburst, bloom and post-harvest. For each treatment and sampling time, composite soil samples were obtained by combining and thoroughly mixing two 70 mm diameter soil auger cores taken one meter apart in the inter-row space and 300 mm from the vine row. The depths of sampling were 0-150 mm; 150-300 mm; 300-600 mm and 600-900 mm. These samples were immediately air-dried at room temperature, passed through a 2 mm sieve and store in plastic bags. Samples collected at bloom during the 1991/92 season were erroneously left in a moist condition in plastic bags for two months.

TABLE 1
Trials, treatments and soils used for sampling.

Location and trial	Cultivar/ Rootstock	Soil Form	Texture (0-300 mm)			Treatments	pH (KCl)	Organic C (%)	Total N (mg kg ⁻¹)	C:N
			Sand (%)	Silt (%)	Clay (%)					
1) Stellenbosch; Ridging*	Chenin blanc/ 99 R	Katspruit	59	22	19	1) Micro irrigated; non-ridged soil	5,98a	0,703a	543a	12,9a
						2) Drip irrigated; non-ridged soil	6,14a	0,710a	504a	14,1a
						3) Micro irrigated; 400 mm high ridge	6,29a	1,148b	828b	13,9a
2) Stellenbosch; Liming	Pinot noir/99 R	Clovelly	70	8	22	1) 0 t ha ⁻¹ lime (pH = 4,9)	4,94 ± 0,20**	0,552 ± 0,121	304 ± 40	18,6 ± 1,2
						2) 7,1 t ha ⁻¹ lime (pH = 5,6)	5,77 ± 0,15	0,512 ± 0,073	285 ± 38	18,2 ± 1,1
						3) 108 t ha ⁻¹ lime (pH = 7,3)	7,30 ± 0,35	0,479 ± 0,085	295 ± 15	16,5 ± 1,4
3) Stellenbosch; Soil depth/ irrigation	Pinot noir/99 R	Glenrosa	52	20	28	1) 400 mm deep; non-irrigated	5,69a	0,715a	508a	14,1a
						2) 400 mm deep; irrigated	6,13b	0,714a	510a	14,0a
						3) 1200 mm deep; non-irrigated	6,47b	0,767a	589b	13,0a
						4) 1200 mm deep; irrigated	6,58b	0,665b	500a	13,3a

* The topsoil was heaped up with an articulated grader to form a ridge. It was then trimmed by hand to obtain a 1,5 m wide flat crest to accommodate two vine rows.

** Standard errors.

a, b, c Groups of means for each trial and in the same column followed by the same letter(s) do not differ significantly ($p \leq 0,05$).

To determine the extent of N mineralisation taking place in the bags in the moist condition, a laboratory experiment was conducted. Four soil samples were kept in plastic bags at room temperature (20-25°C). After each consecutive 10-day period \pm 200 g soil was removed from the bags, air-dried and stored for mineral N analysis.

Physical and chemical analyses: Soil pH was measured in 1M KCl using a soil:solution ratio of 1:2.5. Organic carbon (C) was determined by the Walkley-Black method as described by The Non-Affiliated Soil Analysis Work Committee (1990), and extractable cations by standard Nietvoorbij methods, using 1M NH_4Ac (pH 7) as extractant and atomic absorption spectrophotometry. Total N content was determined using a Perkin Elmer 2410N Nitrogen Analyzer. Mineral N was determined as $\text{NH}_4^+\text{-N}$ and $\text{NH}_3^+\text{-N}$ according to the method described by The Non-Affiliated Soil Analysis Work Committee (1990), but using 10 g soil samples and 60 m^3 1M KCl extracting solution. The particle size distribution of the soils was determined using standard Nietvoorbij sieve and hydrometer methods.

Soil water content of the ridging trial was measured fortnightly at 150 mm, 300 mm, 600 mm and 900 mm depths, using the neutron moisture probes (NEA Nuclear Tronics, Denmark), while the soil water content of the soil depth/irrigation trial was measured at the same depths with the same technique, using a Troxler 3330 neutron moisture probe. Soil temperature of the ridging and soil depth/irrigation trials was measured weekly between 14:00 and 15:00 at 150 mm, 300 mm and 450 mm depths, using copper-constantan thermocouples and a digital thermometer. Because of soil damping effects, these depths, however, soon proved to be too deep and were changed in mid-January 1992 to 30 mm, 80 mm, 220 mm and 370 mm.

Data processing: For the ridging and soil depth/irrigation trials, analyses of variance were done on all soil water content, soil temperature and soil analyses data as well as on the soil mineral N data after conversion of concentration values to mass of mineral N per hectare, assuming a soil bulk density of 1500 kg m^{-3} . A Genstat software package and Tukey's test for significance of difference between means of treatments and sampling times were used.

Since there was no replication of treatments in the liming trial, standard error calculations were used to evaluate the effects of main treatments.

RESULTS AND DISCUSSION

A peak in N release during 1991/92 bloom time was traced back to the fact that these samples were erroneously kept in plastic bags for more than two months before air drying and grinding. This created incubation conditions, resulting in N mineralisation taking place in the bags (Fig. 1). These data were therefore discarded as they were not representative of actual field conditions.

Ridging trial: The higher organic C and total N content found for the ridged soil (Table 1) can be ascribed to the fact that ridging is a technique where adjacent topsoil (generally with higher organic material contents) is heaped onto the topsoil of the vine row. The original A horizon being less than 300 mm, a 0-300 mm sampling depth for non-ridged soil caused dilution of the organic C content of the samples by the underlying hydromorphic G horizon,

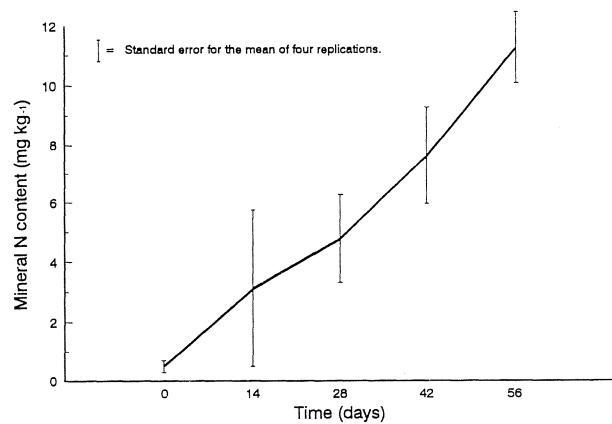


FIGURE 1

Change in mineral N content of ridging trial soil sampled at field capacity and stored in plastic bags for different periods before air drying and grinding.

whereas in the case of the ridged soil, only topsoil was sampled. The significantly higher mineral N content of the ridged soil compared to that of non-ridged soil at budburst (Fig. 2) is in accordance with the organic C and total N content of the topsoil (Table 1).

These results implied that the N release in the ridged soil was higher during winter and spring than it was in the non-ridged soils. The decrease of mineral N during summer and increase from autumn 1992 toward the following spring (Fig. 2) is in accordance with results obtained by Bonde & Rosswall (1987), who found that the amount of potentially mineralisable N follows the same pattern. The increase in the mineral N content of the soil from autumn to spring supports the recommendation of Conradie (1980) that N fertiliser should not be applied before or at budburst. The decrease in mineral N over the period of a year (Table 2) indicates the need for post-harvest N fertilisation. It needs to be investigated whether the mineral N present in the soil at harvest can supply a part of the N needed during post-harvest or whether there is a minimum threshold value of N in the soil solution below which mineral N will not be available to the grapevine. The ridged soil was expected to have better internal drainage,

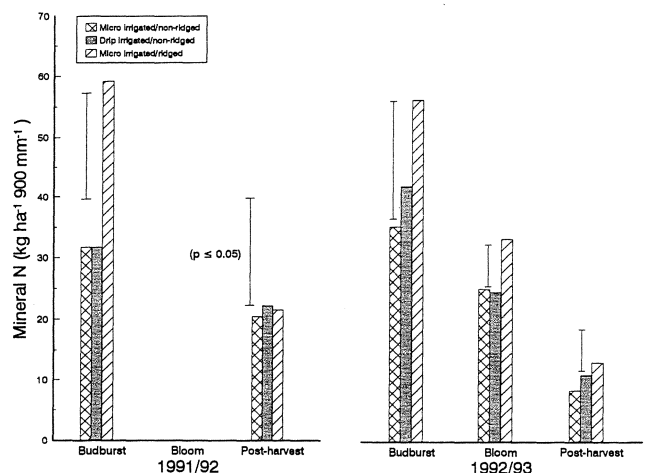


FIGURE 2

Mean seasonal changes in mineral N content of a Katspruit soil as affected by ridging and irrigation system: Nietvoorbij, Stellenbosch.

* 1991/92 Bloom results discarded because of erroneous procedures.

leading to larger amounts of N being leached out of the soil. This probably explains the apparent lack of difference obtained between the amount of N mineralised in the ridged soil compared to the non-ridged soil (Table 2).

TABLE 2
Annual balance sheet for nitrogen, as measured in the different trials.

Trials and treatments	Estimated uptake by vines* (kg ha ⁻¹)	Decrease in mineral soil N** (kg ha ⁻¹)	N mineralised over a year# (kg ha ⁻¹)
Ridging trial			
Micro irrigated/non-ridged	74	12	62
Drip irrigated/non-ridged	83	11	72
Micro irrigated/ridged	73	8	65
Liming trial			
0 t ha ⁻¹ lime (pH 4,9)	40	16	24
7 t ha ⁻¹ lime (pH 5,6)	37	10	27
108 t ha ⁻¹ lime (pH 7,3)	41	10	31
Soil depth/irrigation trial##			
400 mm deep; non-irrigated	50	19	31
400 mm deep; irrigated	36	1	35
1200 mm deep; non-irrigated	57	4	53
1200 mm deep; irrigated	56	14	42

* Calculated according to Conradie (1986).

** Difference between the amount of mineral N measured post-harvest 1991/92 and post-harvest 1992/93.

Calculated by subtracting the decrease in mineral soil N from the estimated N uptake by the vines, assuming no leaching or volatilisation losses and constant N mineralisation over seasons.

Only irrigated vs non-irrigated soil can be compared since N was utilised over 1 200 mm in the case of the deeper soil preparation treatment while the decrease of mineral N was only determined in the top 400 mm of both soil depths treatments.

Soil water measurements taken during the 1991/92 season (data not shown) were suspect, probably due to a defective neutron probe, because they produced results contradictory to those of Myburgh & Moolman (1991), who found that ridged soil had a lower water content than non-ridged soil. The following season, water content could only be measured until mid-December when the neutron probe again became defective.

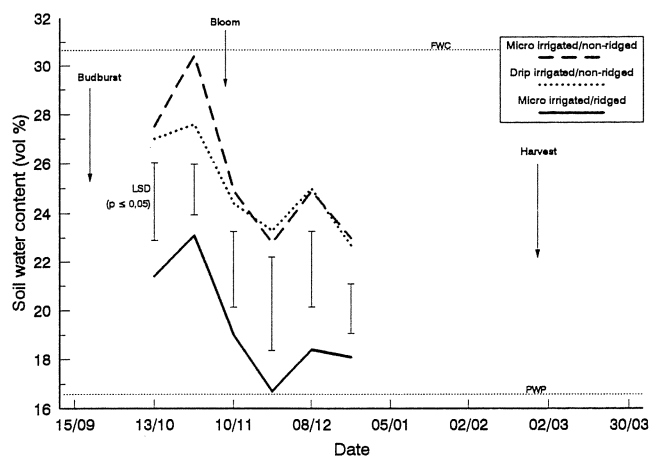


FIGURE 3

Mean soil water content as affected by ridging and irrigation system: Nietvoorbij, Stellenbosch, 1992/93.

The higher water content of non-ridged soils during spring probably reflected the soil water conditions that prevailed during winter. Due to the hydromorphic nature of the soil excessive water probably inhibited N mineralisation or caused leaching of NO₃ and/or denitrification in the non-ridged soil during winter, resulting in lower mineral N contents at budburst (Fig. 2).

The effect of soil water content, together with total N and organic C contents, inducing differences in spring N release between treatments, seemed to decrease as the non-ridged soils dried out during the season and ridged soil probably became too dry. Although the temperature of the ridged soil tended to be higher than that of non-ridged soils, these differences were not significant (data not shown). It was therefore assumed that soil temperature had little effect on the differences in mineral N obtained between treatments.

Although the relative magnitude of the contribution of soil water, soil temperature and total N to a higher mineral N content build-up during winter in the case of ridged soil could not be calculated, it would appear that drier soil conditions during winter and as measured during spring (Fig. 3) had a major effect. Since Myburgh & Moolman (1991) found that the soil water content was comparable at harvest, the non-significant difference in mineral N at harvest (Fig. 2) can partly be explained; the tendency for the ridged soil to have a higher mineral N content, was probably the result of its higher total N content (Table 1).

No difference in the mineral N content of the soil was obtained between the different types of irrigation systems (Fig. 2). It can therefore be assumed that the water supply and the effect it had on soil aeration and N mineralisation were similar for both irrigation systems.

Liming trial: No significant or consistent effect of pH on the mineral N content of the soils was obtained during the consecutive seasons (Fig. 4). This absence of liming effects on N mineralisation probably resulted from the fact that soil sampling was done five years after lime was applied, the effect of the lime on microbial activity having already diminished or ceased. Nyborg & Hoyt (1978) found that the increased N mineralisation caused by liming abated after 3-5 years. However, the calculated N release throughout the year from post-harvest in 1992 to post-harvest in 1993 indicates an apparent positive pH effect (Table 2).

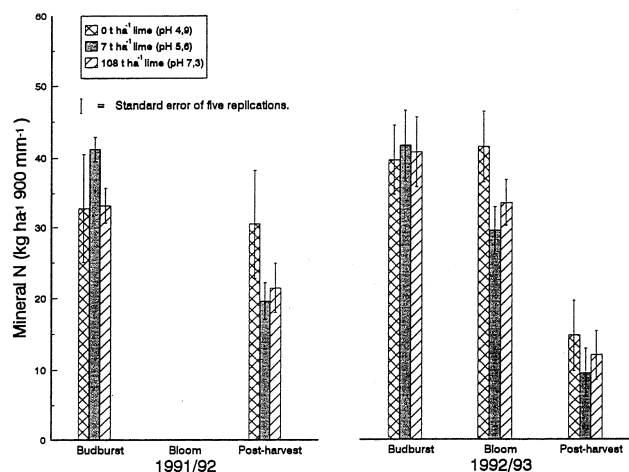


FIGURE 4

Mean seasonal changes in mineral N content of a Clovelly soil as affected by liming.

* 1991/92 Bloom results discarded because of erroneous procedures.

Distinguishing between NH_4^+ and NO_3^- contents of the soil, no obvious differences were obtained between treatments for any of the sampling times (Table 3). Except for the 1992/93 post-harvest sampling time, $\text{NH}_4\text{-N}$ content of the soil was lower than $\text{NO}_3\text{-N}$ content at all pH levels. The general decrease in mineral N content from budburst to post-harvest (Fig. 4) can be ascribed mainly to a decrease in $\text{NO}_3\text{-N}$ (Table 3). This does not imply that the activity of the nitrifying bacteria was inhibited, because, if this was the case, an accumulation of NH_4^+ would have taken place (Table 3). Apart from N uptake by the vines, NO_3^- might have been lost through leaching caused by 260 mm rain during autumn 1993 just before sampling, explaining the low $\text{NO}_3\text{-N}$ content of the soil after the 1992/93 harvest.

The sum of estimated N uptake from budburst to bloom and from the post-harvest for the 1992/93 season exceeded the decrease in mineral N content of the respective treatments from post-harvest 1992 to post-harvest 1993 (Table 2), showing that nett N mineralisation took place during this period. It was, however, insufficient to maintain the

mineral N content of the soil, probably due to depletion of potentially mineralisable N, as was the case for the ridging trial.

Soil depth/irrigation trial: Since fairly high soil water contents generally favour microbial activity and mineralisation (Jenkinson & Ayanaba, 1977), it can be expected that the mineral N content of the irrigated soil would have been higher than that of the non-irrigated soil. However, the difference in mineral N content between irrigation treatments was generally not significant and did not show the expected treatment effects (Fig. 5). This is also shown in Table 2. The pattern of N release between treatments apparently differed between the two seasons, but without a consistent or logical relationship to soil water content (Fig. 6). The tendency towards lower soil water contents from budburst to bloom for the irrigated treatments, especially during 1991/92, was probably due to the plastic sheets that were installed as an artificial depth restriction in these plots, preventing capillary rise from the wet subsoil and the fact that irrigation commenced only at bloom, reversing the soil water content situation.

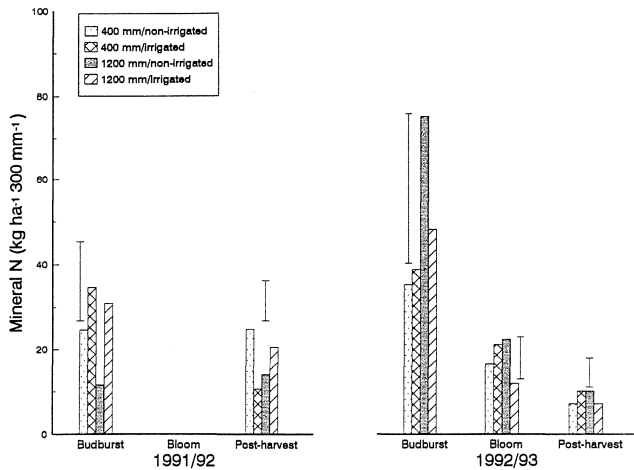


FIGURE 5

Mean seasonal changes in mineral N content of a Glenrosa soil as affected by irrigation and soil depth: Nietvoorbij, Stellenbosch.

* 1991/92 Bloom results discarded because of erroneous procedures.

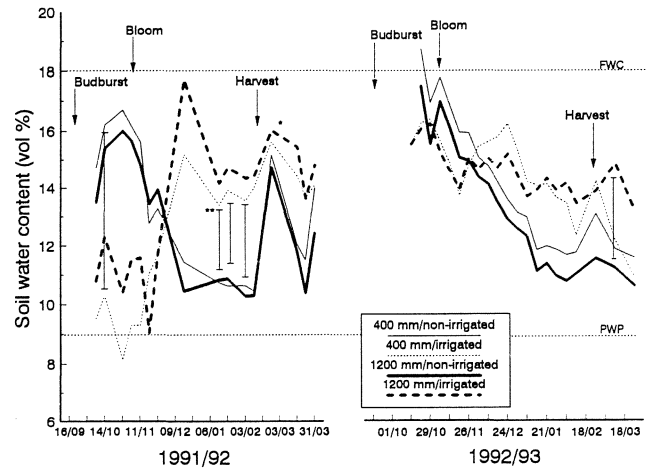


FIGURE 6

Changes in soil water content (0-400 mm) as affected by soil depth and irrigation: Nietvoorbij, Stellenbosch.

* Increased water contents were caused by 40 mm rainfall which showed more drastic changes in the non-irrigated soil.

** LSD bars shown only where significant differences ($p \leq 0,05$) occurred.

TABLE 3

Seasonal changes in NH_4^+ and NO_3^- contents (mg kg^{-1}) of a Clovelly soil as affected by liming. Standard errors were determined for five replicated samples.

Sampling Time	pH 4,9		pH 5,6		pH 7,3	
	$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$
1991/92						
Budburst	2,20 ± 0,51	0,85 ± 0,35	2,79 ± 0,25	0,66 ± 0,48	2,15 ± 0,48	0,80 ± 0,44
Bloom*						
Post-harvest	1,93 ± 0,45	0,83 ± 0,38	1,31 ± 0,56	0,53 ± 0,34	1,27 ± 0,61	0,66 ± 0,48
1992/93						
Budburst	2,10 ± 0,70	1,41 ± 0,14	2,62 ± 0,39	1,13 ± 0,25	2,58 ± 1,05	0,92 ± 0,62
Bloom	2,79 ± 0,21	0,97 ± 0,35	2,08 ± 0,93	0,69 ± 0,42	2,61 ± 1,30	0,59 ± 0,40
Post-harvest	0,17 ± 0,15	1,08 ± 0,56	0,17 ± 0,20	0,75 ± 0,63	0,48 ± 0,42	0,73 ± 0,65

* 1991/92 Bloom time results discarded because of erroneous procedures.

Although soil temperatures at 30 mm depth (Fig. 7) were lower than the optimum temperature of 30-35°C for microbial activity (Cassman & Munns, 1980), the non-irrigated soil tended to be warmer than the irrigated soil during the 1991/92 season and pre-harvest period of the 1992/93 season. These temperature differences also showed no obvious relationship with N release (Fig. 5).

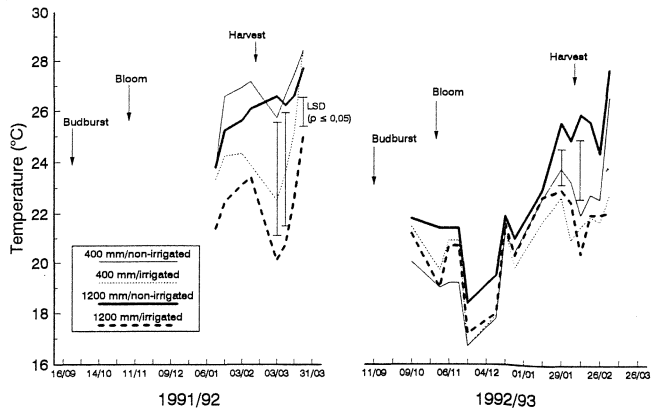


FIGURE 7

Changes in soil temperature at 30 mm depth as affected by soil depth and irrigation: Nietvoorbij, Stellenbosch.

LSD bars shown only where significant differences ($p \leq 0.05$) occurred.

The apparent large difference in spring mineral N content between seasons (Fig. 5) could be traced to the fact that 20 kg ha⁻¹ fertiliser N in the form of limestone ammonium nitrate (LAN) was applied in 1992 after the 1991/92 post-harvest samples were taken. Clay, Clapp & Molina (1990) found that 30% of applied N fertiliser can be incorporated into the biomass, increasing the potential mineralisable N (N₀). The NO₃-N/NH₄-N ratio in the soil changed from 1,9 at post-harvest 1991/92 to 6,5 during budburst 1992/93 and to 4,5 at bloom 1992/93 (data not shown), indicating nitrification of NH₄⁺ present in the applied LAN, Tabatabnai, Fu & Basta (1992) found that NH₄⁺ fertilisers either increased the population or the efficiency of microbes responsible for nitrification in soils.

CONCLUSIONS

Ridging of waterlogged soil increases N release in winter and spring, mainly because of better drainage and consequently more favourable mineralisation conditions. Ridged soil contains higher organic material contents which enhance the mineral N release. Little fertilisation, if any, is therefore needed by wine grapes during the budburst/bloom period for ridged soil.

After a period of about five years, liming had no effect on N mineralisation and adjustments to N fertilisation recommendations because of differences in pH seem unnecessary. It is, however, documented that increased N mineralisation is obtained for a certain period after a soil is limed. The duration of this period of increased mineralisation is uncertain for the soils of the Western Cape wine producing areas and needs further investigation.

Although soil water is regarded as a major soil factor affecting N mineralisation, no clear effect of irrigation on the N mineralisation rate was obtained in the soil. This could be traced back to a general lack of significant or logical differences in soil water contents between treatments because of unnatural soil-depth-restricting plastic sheets in the case of irrigated plots.

The natural, relatively high, initial mineral N content in soils and the decrease in mineral N content throughout the growing season indicate that reductions in spring N fertilisation should be considered but that post-harvest fertilisation, irrespective of the soil management practice, is important. The priming effect of post-harvest fertilisation on microbial activity, leading to enhanced N release during winter, could be so effective that fertilisation during budburst may not be necessary in many cases. The extent of leaching of mineral N is also unknown. It also appears as if a high initial spring N content is more prone to (as yet unaccountable) N losses. This is an aspect that merits further investigation in the light of growing concern over global pollution. Analyses of the mineral N content of soil in spring could, therefore, serve as indicators of whether previous fertilisation was adequate or whether additional N should be applied.

Threshold values, where the mineral N content in soil becomes too low for utilisation by vines, may exist and will have to be determined. This amount of mineral N should be subtracted from the total amount available in soil during spring to determine whether the N reserves at that stage are adequate for the season at hand.

LITERATURE CITED

- BLACK, C.A., 1968. Soil-plant relationships. John Wiley & Sons, New York.
- BONDE, T.A. & ROSSWALL, T., 1987. Seasonal variations of potentially mineralizable nitrogen in four cropping systems. *Soil Sci. Soc. Am. J.* **51**, 1508-1514.
- CASSMAN, K.G. & MUNNS, D.N., 1980. Nitrogen mineralisation as affected by soil moisture, temperature, and depth. *Soil Sci. Soc. Am. J.* **44**, 1233-1237.
- CLAY, D.E., CLAPP, C.E. & MOLINA, J.A.E., 1990. Influence of nitrogen fertilization, tillage, and residue management on a soil nitrogen mineralisation index. *Commun. Soil Sci. Plant Anal.* **21**, 323-335.
- CONRADIE, W.J., 1980. Seasonal uptake of nutrients by Chenin blanc in sand culture: I. Nitrogen. *S. Afr. J. Enol. Vitic.* **1**, 59-65.
- CONRADIE, W.J., 1986. Utilisation of nitrogen by the grape-vine as affected by time of application and soil type. *S. Afr. J. Enol. Vitic.* **7**, 76-82.
- CONRADIE, W.J., MYBURGH, P.M. & VAN ZYL, J.L., 1995. Field lysimeters for the determination of the leaching losses occurring from a granitic soil during the first five years after having been cultivated to different depths and planted to grapevines. *Plant Soil*, to be submitted.
- CORTEZ, J., 1989. Effect of drying and rewetting on mineralization and distribution of bacterial constituents in soil fractions. *Soil. Fert. Soils* **7**, 142-151.
- HARMSEN, G.W. & VAN SCHREVEN, D.A., 1955. Mineralization of organic nitrogen in soil. In: Norman, A.G. (ed.). *Advances in Agronomy*, Vol. 7. Academic Press, New York. pp. 299-398.
- JENKINSON, D.S. & AYANABA, A., 1977. Decomposition of carbon-14 plant material under tropical conditions. *Soil Sci. Soc. Am. J.* **41**, 912-915.
- MYBURGH, P.A., 1989. Die gebruik van operdwalle om 'n marginale, hidromorfe grond se fisiese toestand vir wingerdbou te verbeter. M.Sc. Agric. thesis. Univ. Stellenbosch, 7600 Stellenbosch.
- MYBURGH, P.A. & MOOLMAN, J.H., 1991. The effect of ridging on the soil water status of a waterlogged vineyard soil. *S. Afr. J. Plant Soil* **8**, 184-188.
- NYBORG, M. & HOYT, P.B., 1978. Effects of soil acidity and liming on mineralization of soil nitrogen. *Can. J. Soil Sci.* **58**, 331-338.
- PEACOCK, W.L., CHRISTENSEN, L.P., HIRSCHFELT, D.J., BROADBENT, F.E. & STEVENS, R.G., 1991. Efficient uptake and utilization of nitrogen in drip- and furrow-irrigated vineyards. Proc. Int. Symp. Nitrogen in Grapes and Wine, 18-19 June 1991, Seattle, Washington. pp. 116-119.

- SAAYMAN, D., 1982. Fertilisation of winegrapes. Farming in South Africa. VORI series 100, Private Bag X5026, 7600 Stellenbosch.
- SOIL CLASSIFICATION WORKING GROUP, 1991. Soil classification – a taxonomic system for South Africa. Department of Agricultural Development Memoirs of the Natural Agricultural Resources of South Africa No. 15, Pretoria.
- STEVENSON, F.J., 1986. Cycles of soil: Carbon, nitrogen, phosphorus, sulphur, micronutrients. John Wiley & Sons, New York.
- TABATABAI, M.A., FU, M.H. & BASTA, N.T., 1992. Effect of cropping systems on nitrification in soils. *Comm. Soil Sci. Plant Anal.* **23**, 1885-1891.
- THE NON-AFFILIATED SOIL ANALYSIS WORK COMMITTEE, 1990. Handbook of standard soil testing methods for advisory purposes. Soil Sci. Soc. South Africa, P.O. Box 30030, Sunnyside 0132.
- WHITE, C.S., GOSZ, J.R., HARMER, J.D., & MOORE, D.I., 1988. Seasonal, annual and treatment-induced variation in available nitrogen pools on nitrogen-cycling processes in soils of two Douglas-fir stands. *Biol. Fertil. Soil* **6**, 93-99.