Nitrate and ammonium levels as an indication of soil fertility: An investigation into the soil fertility of organic versus conventional soil management practices.

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ABSTRACT

This study involved an assessment of inorganic N fluctuations in organic or conventionally-managed vineyard soils. Nitrate and ammonium content of the soil profile was measured at five intervals between April and September so as to assess the extent of nitrate leaching during winter. In all treatments, nitrate and ammonium levels declined between April and July. There was a slight but significant rise in inorganic N ($p < 0.05$) towards the end of July. The conventional treatment showed a slightly higher rate of nitrate leaching as compared with the organic treatments (not significant). Towards spring, there was an indication of a quicker rate of recovery of nitrate levels in the organic treatments. In the soil profile (0-90 cm) there was a significantly ($p < 0.05$) higher inorganic N concentration in the upper 15 cm.

INTRODUCTION

Soil nitrogen (N) is an essential nutrient for plant growth and as such, is an important factor to consider in agriculture. A short introduction on the fate of N in terms of the forms and transformations illustrates the number of stages at which there is the potential to influence the fate of N. At this point, soil management practices are able to influence N flux in the agricultural setting.

Nitrogen in the soil is subject to a number of transformations. Organic N is converted to ammonium through the process of mineralization – a process which is brought about by the activity of micro-organisms. Ammonium may subsequently be taken up by plants or by soil micro-organisms. The ammonium ion may become fixed by clay minerals (Mengel and Scherer, 1981) or by organic matter and this decreases the likelihood of leaching and enhances retention of N in the soil. Nitrogen may also be lost to the atmosphere in the form of ammonia. Ammonium may be converted to nitrate by nitrification (McLaren, 1976; Starr, 1983) – a process brought about by nitrifying bacteria. Several factors affect the accumulation of these bacteria, and thus the rate at which nitrification proceeds. Nitrification is dependent on the C:N ratio of organic residues with a high ratio generally preventing the release of ammonia. Factors that further inhibit nitrification include a poor supply of oxygen, low soil pH (nitrification proceeds between pH 5 – 8) or temperature (optimal activity occurs between 25 °C and 35 °C), soil aridity (Robinson, 1957) or waterlogging. Once nitrate has been formed, it is available to plants and micro-organisms for uptake. Gaseous loss of N may occur due to denitrification of nitrate (Reddy et al., 1978). Furthermore, nitrate is readily leached with water moving downwards through the soil profile.

The matric forces between dry and wet soil provides the potential for water movement. In some cases the lateral movement of water may be as pronounced as the downward movement due to the pull of gravity. In a stratified soil column, downward moving water is likely to pass through soil horizons, in which soil properties differ. Fine textured soil offers more attraction to water movement, therefore movement from the upper finer grain material may be restricted as it encounters the coarser underlying layers. In such soils, the underlying layer may act as a barrier to free water drainage and cause a relatively high field moisture level. However, a large amount of rainfall would effectively overcome this problem and facilitate downward movement of water by causing a build-up of water at the soil interface. The upward movement of water from the water table is also dependent on soil texture. There is generally less upward water conduction in compact clay soils compared with more loamy soils (Brady, 1990).

Nitrate leaching occurs when there is a large amount of soluble inorganic N in the soil at times when high levels of precipitation lead to drainage of water below the rooting zone. The amount leached depends not only on rainfall, but on the amount and timing of fertilization. Different farming practices influence nitrate leaching from the soil. Leaching may be restricted by synchronizing the application of fertilizers with demand by plant (Thomsen et al., 1993). In addition, the presence of a cover crop during the wet winter months is thought to reduce the amount of leaching during this period (e.g. Lewan, 1994). A catch crop can reduce the content of inorganic N in the soil profile during a period when no main crop is present. Catch crops such as N_2-fixing *Medicago* sp.are able to benefit soil fertility, in terms of an increase in crop grain yield when the catch crop is ploughed into the soil. In comparison, fallow periods are marked by a high export of nutrients from the system (Whitbread *et al.*, 2000).

Excessive use of chemical fertilizers leads to an increased leaching beyond the root zone. Cause for concern is the resultant contamination of groundwaters and increased pollution. Efficient management practices can be beneficial both to the environment and to the farmer in terms of minimizing leaching by restricting input (Everts *et* al., 1989). Across similar fertilizer applications (i.e. field conditions), differences in leaching rates can by attributed to differences in soil physical properties. Therefore specific application of fertilizer according to the properties of the site can be allow optimal fertilization whilst minimizing loss through leaching (Ersahin, 2001). This would entail application of fertilizers during periods of rapid uptake by crops.

The application of inorganic fertilizers is generally synchronized with a period of rapid uptake by crops. In theory this should restrict the amount of inorganic N being leached from the soil. Minimum loss of N is important both from an economical and environmental perspective. In the first case, farmers aim to restrict cost by limiting fertilizer input. Excess chemical fertilization encourages nitrate leaching which is a major concern in terms of its polluting effects on groundwater (Foster *et al.*, 1986). Hansen *et al.* (2000) found that N leaching from organic agricultural systems was lower than for conventionally-managed systems and that N input into the organically managed system was only 70% that needed in the conventional system. Differences in the leaching between the conventional and organic systems can be attributed to differences in total N input and the choice of crops in the rotations since the clay content and the percolation is kept constant for the same soil type.

Since mineralization is temperature-dependent, low winter temperatures may be expected to decrease nitrification. This would therefore suggest that N loss is restricted during the winter months. This study is undertaken during the wet, winter months ~~as an indication of~~ the extent of inorganic N loss during a period of low mineralization and high rainfall.

METHODS

This study was conducted within a pre-existing field trial at Nietvoorbij Centre for Vine and Wine, Stellenbosch. The field trial was a vineyard which had been converted to organic management procedures. The motivation for the project was an increased international demand for organically grown produce and the vineyard was one of three field trials used to evaluate the effect of different soil management practices on factors including grape production, wine quality and soil fertility. The existing project was designed ~~in the hope of~~ gaining insight into the comparative sustainability of the organic versus conventional methods both in terms of economic viability and soil fertility.

The field trial used in this experiment was a 15-year old vineyard, planted 2 x 1.5 m. The field was divided into plots, each having one of six different soil management practices. There were six treatments, each treatment was replicated four times in a randomised block design. Conventional management practices included Treatments 1, 2 and 6. Organic management procedures were applied to Treatments 3, 4 and 5.

Fertilization of the conventional treatments was chemical (Limestone/Ammonia/Nitrate, LAN). Equal amounts of fertilizer were applied across these treatments in the year prior to sampling and the most recent application had taken place four weeks prior to the first sampling. The vine row was kept weed-free by application of herbicides. The fertilizer contained ammonium and nitrate on a 1:1 ratio, thus fertilization added equal amounts of each form of N to the soil. Treatment 1 underwent full surface chemical weed control and was the only treatment in which no covercrop was sown. The covercrop (*Medicago* sp.) was sown during April in the work row of the remaining five treatments. Treatment 6 included Effective Micro-organism Technology which is intended to accelerate the formation of humus from organic matter. Organic treatments each received equal amounts of organic fertilizer in the form of compost. Compost and wheat-straw was applied to the vine row and compost was applied to the work row. Treatment 4 had an application of Penac K which has the effect of stimulating soil micro-organism activity. Treatment 5 had the additional use of Effective Micro-organism Technology. The details of specific soil applications for each treatment are included in Appendix A. The field had been managed under the experimental conditions for one year prior to the data collection.

Data collection started in April and ended in September when the first new growth in the vines was detected. Samples were taken on 26 April, 13 June, 6 July, 25 July and 12 September. Within each treatment, samples were taken either alongside the vine or midway between the vine rows. These are referred to as the vine row and work row subtreatments respectively. Soil cores were made using a soil borer. Four depths were sampled; 0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm. At each sampling time, a total of 192 samples were bagged and transferred to Infruitec laboratories for analysis of inorganic N.

STATISTICAL ANALYSIS

Analysis of variance was made using the General Linear Model procedure. Data was analysed using a Split-plot design (ANOVA, $p < 0.05$). Means were separated using the Least Squares Difference. An initial analysis of the results revealed that there were several values with high residuals. Sixteen of the 873 data values had residuals of greater than 4 standard errors. These values were not restricted to any one treatment and tended to occur in the surface soil samples. These were considered to be outliers and were replaced with an average value.

RESULTS

The large data set and high number of variables allows representation of the data in a number of different ways. Firstly, variation of inorganic N over time was considered. Secondly, an investigation of N variation with depth, and finally, differences in these patterns among treatments and subtreatments.

Table 1: Mean nitrate and ammonium values (±S.E.) for treatment, subtreatment, time and depth.

Within column values with different letters are significantly different (LSD, $p < 0.05$)

Treatment	NITRATE (µg.g^{-1})	AMMONIUM (µg.g^{-1})
1	2.51 ± 0.38a	2.93 ± 0.16c
2	1.59 ± 0.21ab	3.87 ± 0.20ab
3	0.83 ± 0.07b	4.23 ± 0.19a
4	1.40 ± 0.12b	3.42 ± 0.17bc
5	1.27 ± 0.11b	3.50 ± 0.13abc
6	2.57 ± 0.44a	3.76 ± 0.19ab
Subtreatment		
vine row	2.20 ± 0.20a	3.62 ± 0.10a
work row	1.22 ± 0.08b	3.59 ± 0.10a
Time		
26-Apr	4.16 ± 0.66a	5.98 ± 0.13a
13-Jun	2.22 ± 0.12b	4.83 ± 0.17b
06-Jul	0.76 ± 0.05c	2.84 ± 0.11c
25-Jul	0.78 ± 0.06c	2.15 ± 0.08d
12-Sep	1.69 ± 0.25b	3.29 ± 0.12c
Depth (cm)		
0-15	2.92 ± 0.37a	4.02 ± 0.14a
15-30	1.30 ± 0.13b	3.55 ± 0.14b
30-60	1.26 ± 0.11b	3.45 ± 0.15b
60-90	1.31 ± 0.10b	3.39 ± 0.14b

VARIATION WITH TIME

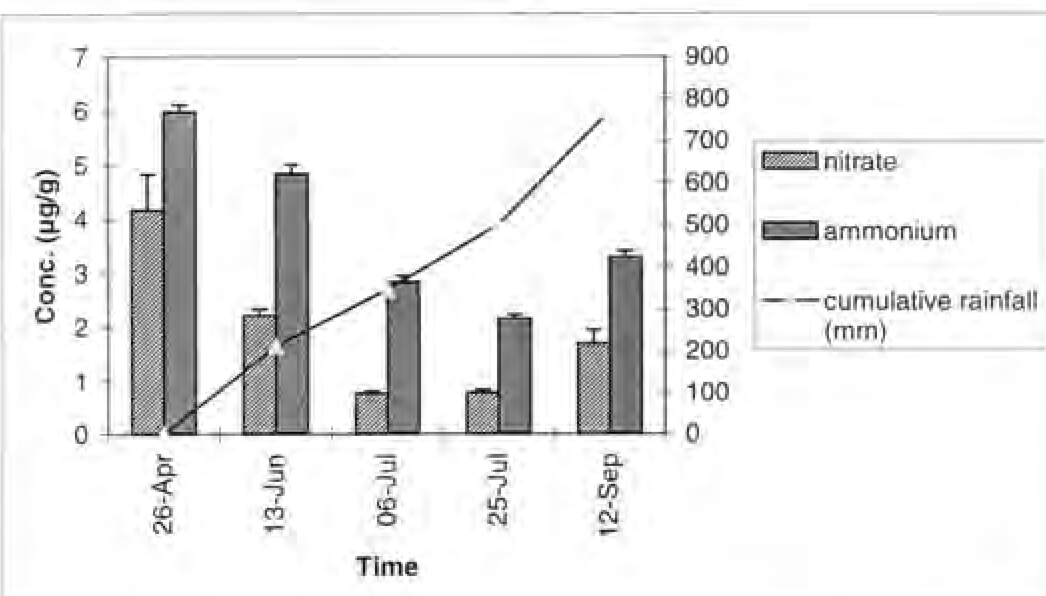

Fig. 1: Graph showing variation of nitrate and ammonium with time (0-90 cm soil average)

Mean ± SE or SD? Was significance tested?

The most noticeable trend was that of the change in inorganic N content of the soil over time (see Figures 1, 2, 3). These graphs ~~above~~ mentioned do not include treatment-specific differences, but are an assessment of ammonium and nitrate variation averaged across the field. It is evident that both nitrate and ammonium decreased from a maximum in late April to a minimum in July and that levels increased thereafter. The decrease in inorganic N is presented in terms of an increasing cumulative rainfall.

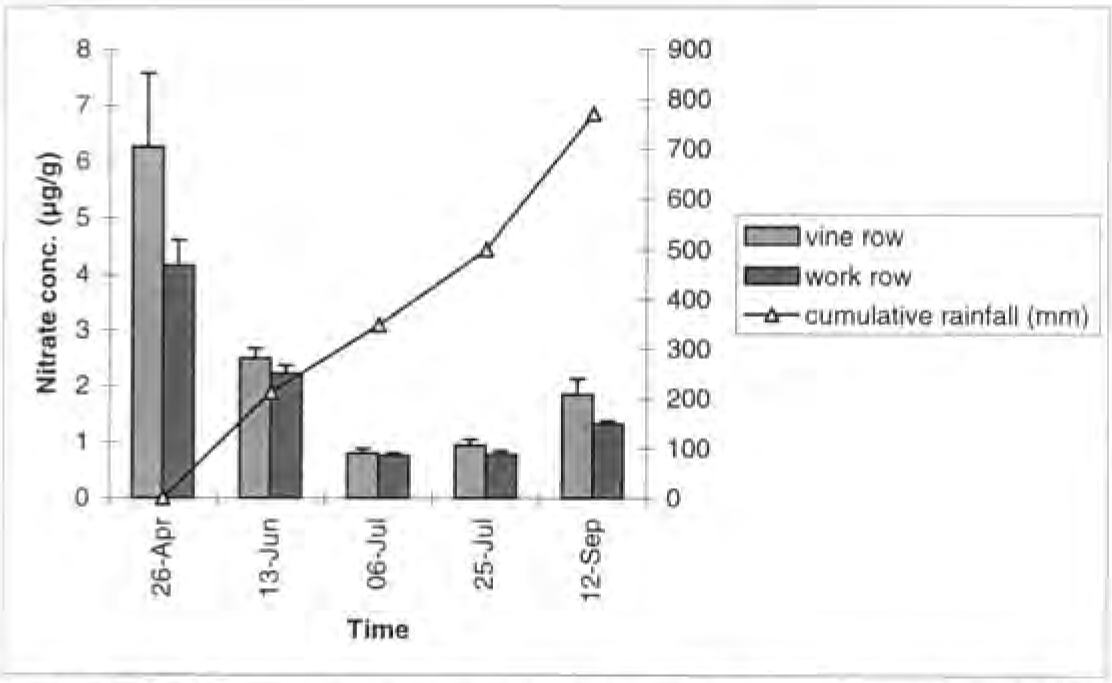

Fig. 2: Graph of nitrate concentration in the work row and vine row over time (0-90 cm soil average)

Mean ± SE or SD? Was significance tested?

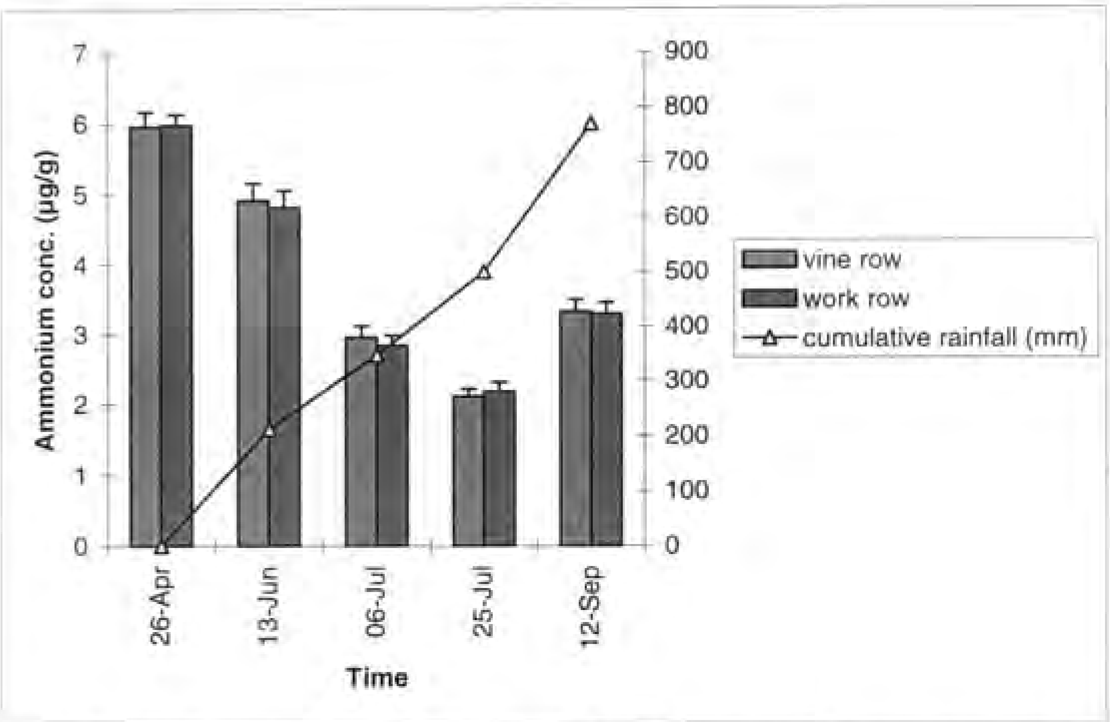

Fig. 3: Graph of ammonium concentration in the work row and vine row over time (0-90 cm soil average) Mean ± SE or SD? Was significance tested?

Nitrate was consistently lower than ammonium for the duration of the sampling period. The inorganic N in the vine and work rows both followed a similar pattern. Nitrate values were significantly lower in the work row, while there was no significant difference between the vine row and work row for ammonium (see Table 1). The maximum nitrate value in the work row was 4.16 ± 0.45 $\mu g.g^{-1}$. Nitrate decreased significantly with the second and third sampling intervals and reached a minimum of 0.76 ± 0.04 $\mu g.g^{-1}$ during early July. Three weeks later the levels were similar; however, there was a small but significant increase in nitrate by the middle of September. In the case of ammonium, the maximum work row value was 5.98 ± 0.15 $\mu g.g^{-1}$. This had decreased significantly at each sampling time until a minimum of 2.17 ± 0.14 $\mu g.g^{-1}$ was observed in late July. There had also been a significant increase by the middle of September.

VARIATION WITH DEPTH Across the Board For All Treatments

An investigation of inorganic N variation with depth revealed that the highest values for both ammonium and nitrate were ~~observed~~ obtained in the upper layer (0-15 cm). This was significantly higher than the concentrations ~~of~~ in the lower depths, which were not significantly different from each other (Table 1).

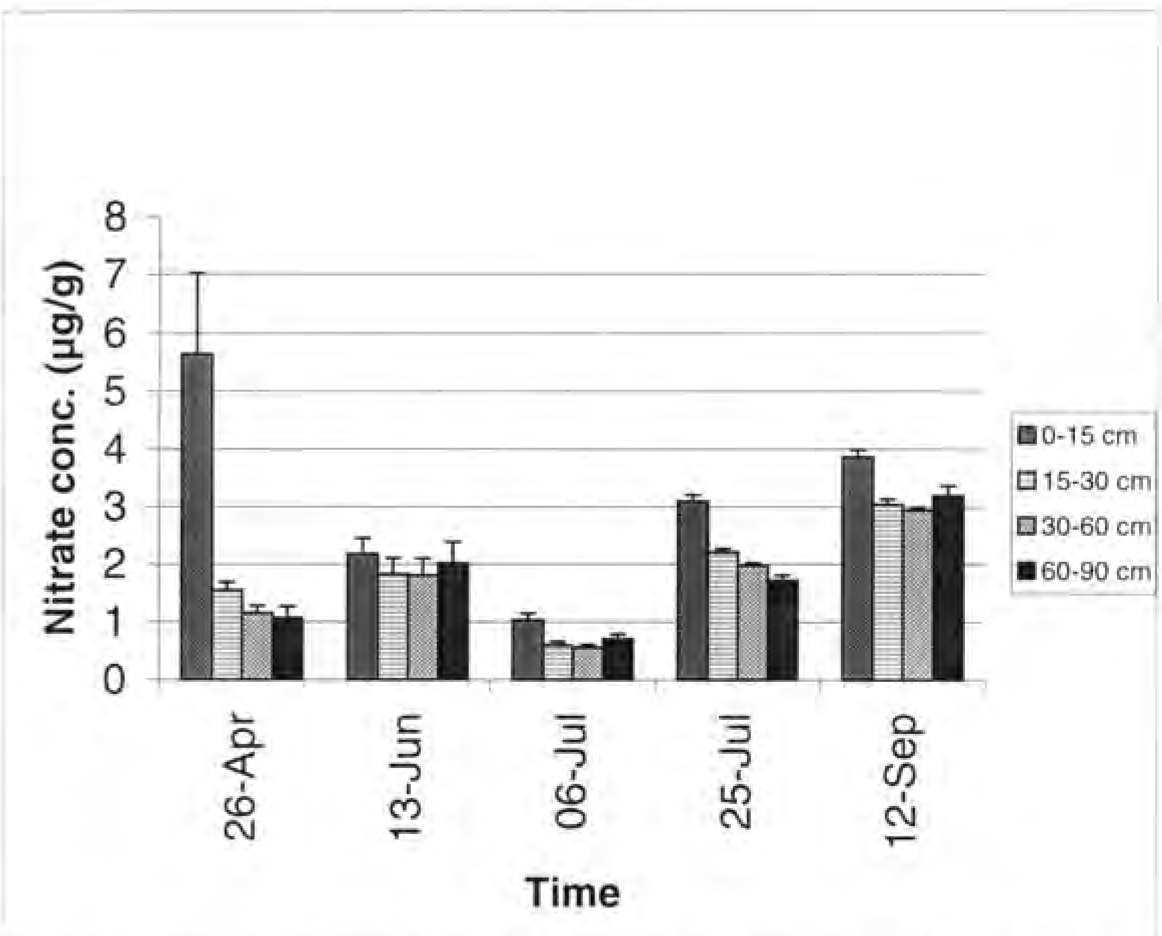

Fig. 4: Depth-specific variation of nitrate in the work row over time. Mean ± SE or SD? Was significance tested?

Nitrate and ammonium flux at specific depths was investigated to give an indication of total variation over time (Fig. 4). Ammonium levels were consistently higher than nitrate levels for the duration of the sampling period (Table 1). The first sampling (April) shows that the difference in nitrate concentration between the upper and lower depths was greatest. From the first to the second sampling period, nitrate leaching had occurred. This was suggested by a substantial decrease in nitrate of the 0-15 cm layer and an associated increase in nitrate content of the 60-90 cm layer. Surface layer nitrate continued to decline until early July, however there was no evident increase in the underlying layers. This could indicate loss of nitrate below 90 cm and may have been ~~a~~ in response to a particularly high rainfall event. Upper layer nitrate values ~~proceeded~~ continued to increase for the remainder of the data collection period. This is possibly explained by an increase in the rate of mineralization at this time. An increase in nitrate was also observed at 60-90 cm. This however is probably not due to enhanced mineralization as a rise in ambient air temperatures would not have affected the soil temperature at this depth. It is more likely that the increase is due to leaching from the surface and this is supported by the precipitation data which shows that rainfall increased over this time period.

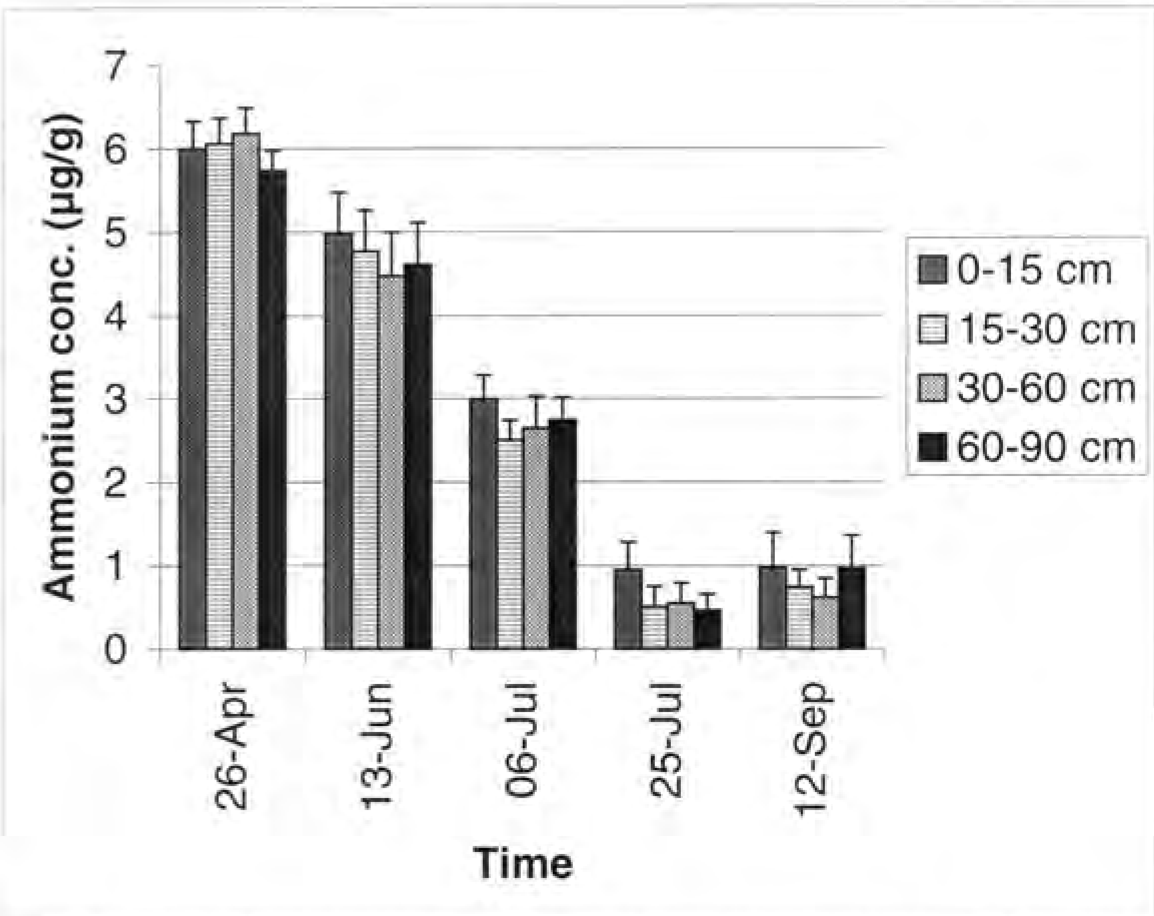

Fig. 5: Depth-specific variation of ammonium in the work row over time. Mean ± SE or SD? Was significance tested?

Compared with nitrate, ammonium concentration was more uniform across depth. This is expected since a higher degree of retention within the soil column in expected for ammonium. Figure 5 shows that there was a significant reduction in soil ammonium content with time. A constant low level of conversion of ammonium to nitrate could, in theory, explain the decrease of ammonium observed over time. This however, would be accompanied by an associated rise in nitrate values. It is unlikely that the decrease was due to leaching since there is no significant increase in ammonium at the 60-90 cm level.

VARIATION AMONG TREATMENTS

The depth-specific nitrate variation was represented in terms of each treatment separately to give an indication of any treatment-specific differences in leaching.

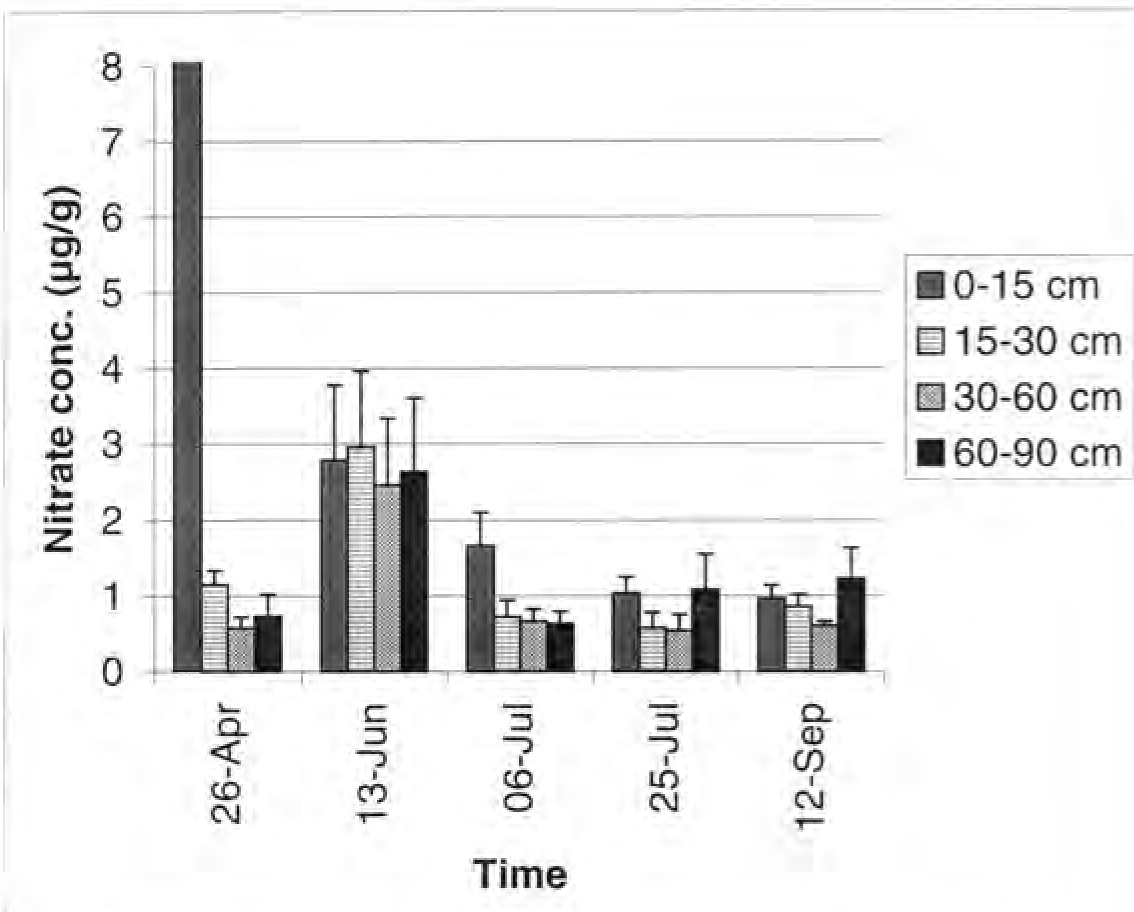

Fig. 6: Graph showing nitrate concentration variation with depth and time for Treatment 1 (off-chart value: 11.91 ± 6.10 µg.g^{-1})

Figure 6 presents the nitrate ~~variation~~ for Treatment 1. There is a deviation from the general patterns observed across the field (Fig. 4). Firstly, there is a trend of increasing nitrate at 90 cm depth from early July onwards. Nitrate content at this depth increases from 0.63 µg.g^{-1} (early July) to 1.23 µg.g^{-1} (September). There is ~~also~~ no apparent increase in surface nitrate during this time. On the contrary, nitrate levels decreased from 1.66 $\mu g.g^{-1}$ to 0.96 $\mu g.g^{-1}$ during this period.

There was a significant effect of treatment on nitrate and ammonium levels (Table 1). Nitrate values for treatments 1 and 6 were significantly different from Treatments 3,4 and 5. Treatment 2 was not significantly different from any of the treatments. In terms of ammonium, Treatment 1 was significantly different from treatments 2,3 and 6. Treatments 3 and 4 had significantly different ammonium levels for the duration of the experiment.

The pattern of variation over time was similar among treatments. Treatments 1 and 6 were initially higher in terms of nitrate content (Fig. 7). Over time the variation among treatments declined. Treatment 3 had the highest initial ammonium content but this effect diminished over time. The statistical significances among treatments over time is given in Tables 2 and 3.

Table 2: Treatment nitrate concentrations (soil profile average) over time (mean ± S.E.)

Within column values with different letters are significantly different (LSD, $p < 0.05$)

Treatment	26 April	13 June	6 July	25 July	12 September
1	6.21 ± 2.26 ab	3.25 ± 0.38 a	1.02 ± 0.16 a	0.94 ± 0.13 ab	2.65 ± 0.84 a
2	2.44 ± 0.47 b	2.98 ± 0.41 a	0.87 ± 0.12 ab	0.60 ± 0.10 bc	1.89 ± 0.69 ab
3	2.06 ± 0.28 b	1.07 ± 0.05 b	0.78 ± 0.12 ab	0.54 ± 0.10 c	0.68 ± 0.17 b
4	2.48 ± 0.50 b	2.14 ± 0.23 ab	0.51 ± 0.05 b	0.93 ± 0.18 ab	1.21 ± 0.18 ab
5	2.10 ± 0.39 b	2.16 ± 0.18 ab	0.53 ± 0.05 b	0.62 ± 0.14 bc	0.95 ± 0.07 b
6	8.84 ± 2.43 a	1.79 ± 0.17 ab	0.82 ± 0.10 ab	1.06 ± 0.22 a	2.78 ± 0.98 a

Table 3: Treatment ammonium concentrations (soil profile average) over time (mean ± S.E.)

Within column values with different letters are significantly different (LSD, $p < 0.05$)

Treatment	26 April	13 June	6 July	25 July	12 September
1	4.90 ± 0.15 d	3.07 ± 0.51 c	3.05 ± 0.30 ab	1.83 ± 0.19 b	2.61 ± 0.22 b
2	4.99 ± 0.16 dc	6.11 ± 0.45 ab	3.80 ± 0.35 a	2.38 ± 0.21 ab	3.25 ± 0.25 ab
3	7.39 ± 0.49 a	7.16 ± 0.02 a	3.18 ± 0.22 ab	2.57 ± 0.25 a	3.31 ± 0.14 ab
4	6.37 ± 0.18 abc	3.34 ± 0.32 bc	3.00 ± 0.27 ab	1.95 ± 0.20 b	3.16 ± 0.42 ab
5	5.76 ± 0.15 bcd	4.07 ± 0.20 bc	2.11 ± 0.12 ab	2.19 ± 0.17 ab	3.36 ± 0.21 ab
6	6.62 ± 0.43 ab	5.37 ± 0.21 abc	1.92 ± 0.12 b	1.99 ± 0.19 ab	4.01 ± 0.36 a

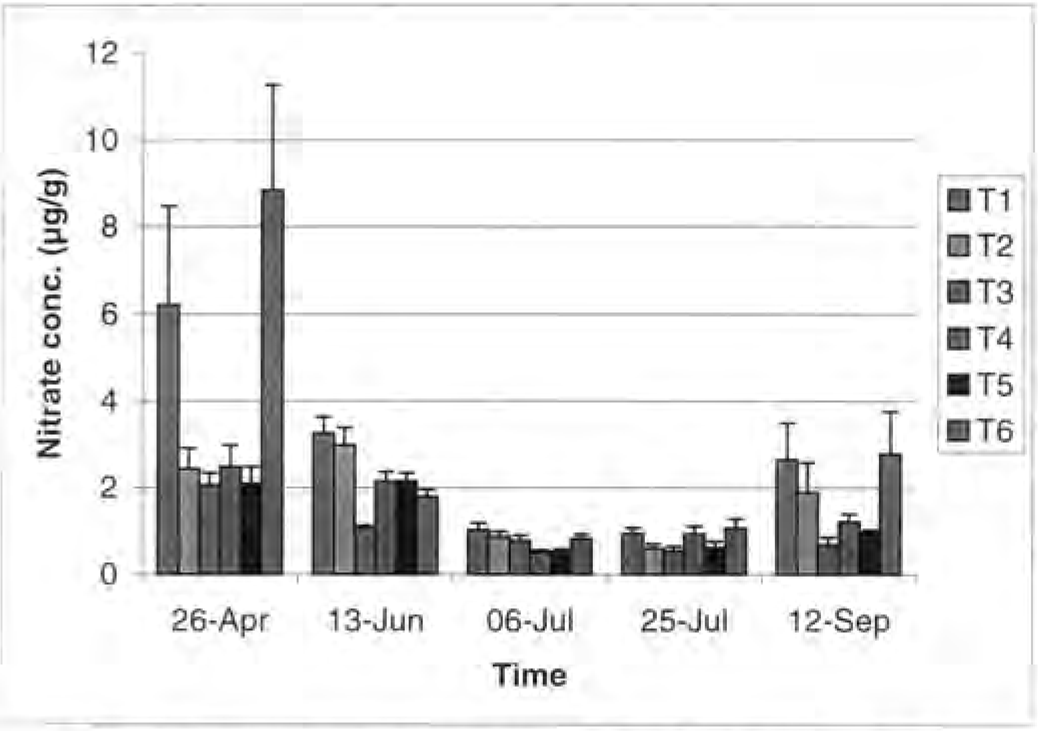

Fig. 7: Graph showing nitrate concentrations among treatments over time (average soil profile content) Mean ± SE or SD? [These are the data in Table 2! Don't present same data twice!!]

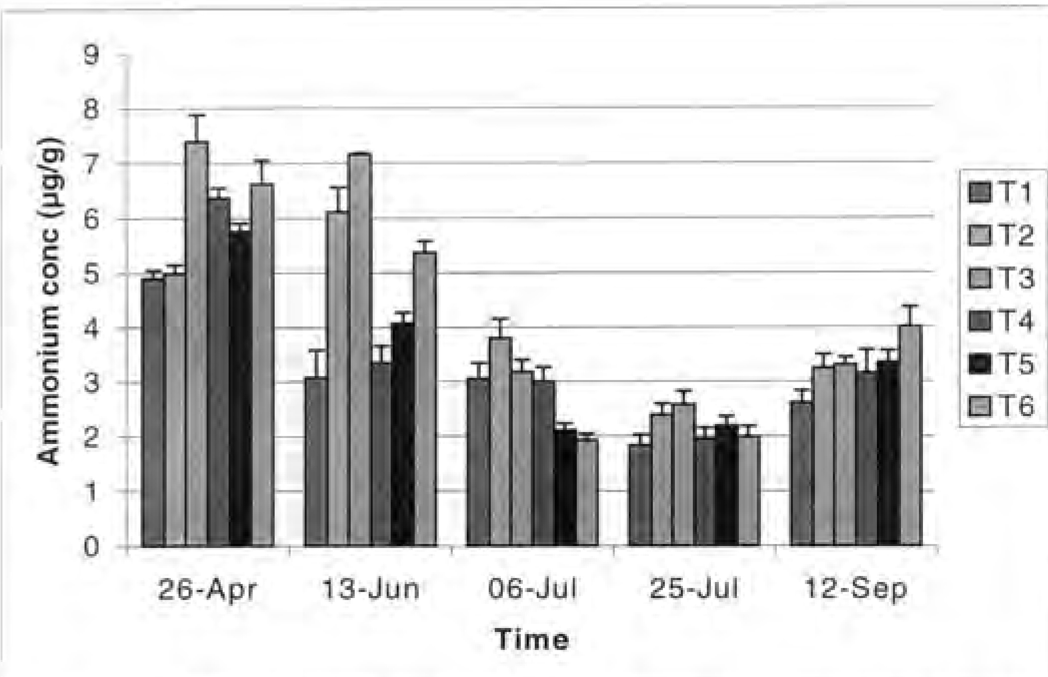

Fig. 8: Graph showing ammonium concentrations among treatments over time (average soil profile content). [Same data as in Table 3!! Don't present same data twice!!].

At the first sampling interval, Treatments 2, 3, 4 and 5 had similar nitrate levels. Treatment 1 had a higher nitrate content and Treatment 6 had a significantly higher content. In June, nitrate of Treatments 1 and 2 remained significantly higher than that of Treatment 3, while Treatments 4, 5 and 6 showed intermediate values. In early July, the only significant difference was observed between Treatment 1 and Treatments 4 and 5. In late July and September, the nitrate level in Treatment 1 remained significantly higher than that of Treatment 3. Throughout the sampling period, the nitrate levels of Treatment 1 did not significantly differ from those of Treatments 2 and 6.

Although Treatment 1 had the highest nitrate content, it tended to show the lowest ammonium concentrations among the treatments. During April, Treatment 3 had the highest levels of ammonium. A comparison between Treatments 1 and 3 shows that the ammonium level remained higher in Treatment 3 for the duration of the study. During

April and June the difference was significant. Measurements in early July showed that the difference had become less pronounced; however, by September the difference was once again significant.

Ammonium levels did not differ significantly between Treatments 4 and 5 at any point during the sampling period. Although Treatment 3 tended to show slightly higher values, by the September sampling point, none of the three treatments were significantly different.

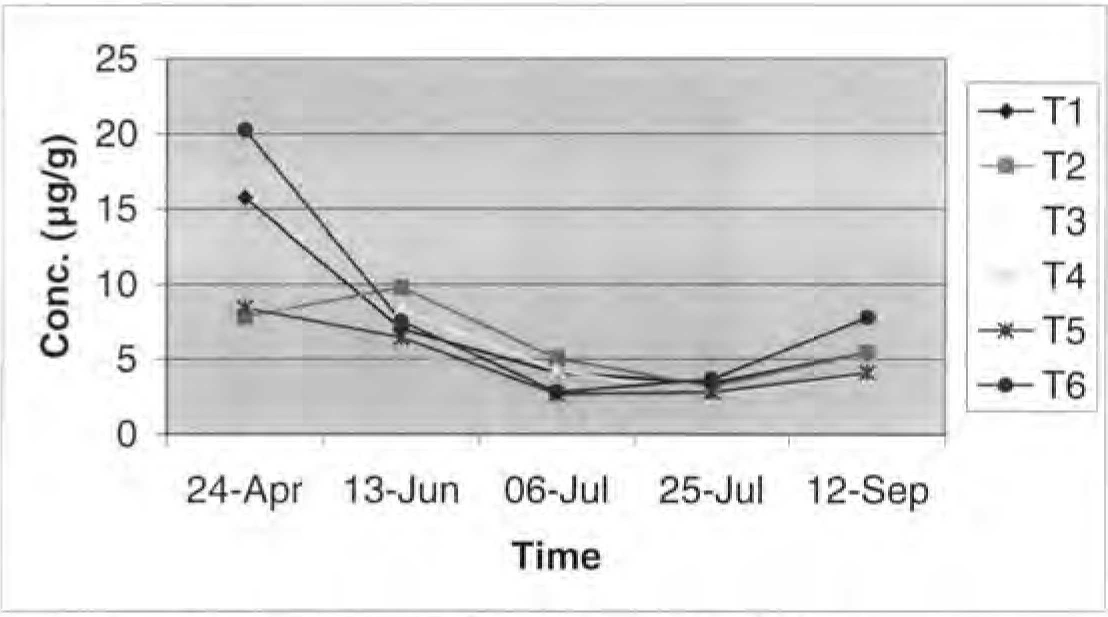

Fig. 9: Vine row total inorganic N of the total soil profile (0-90 cm)

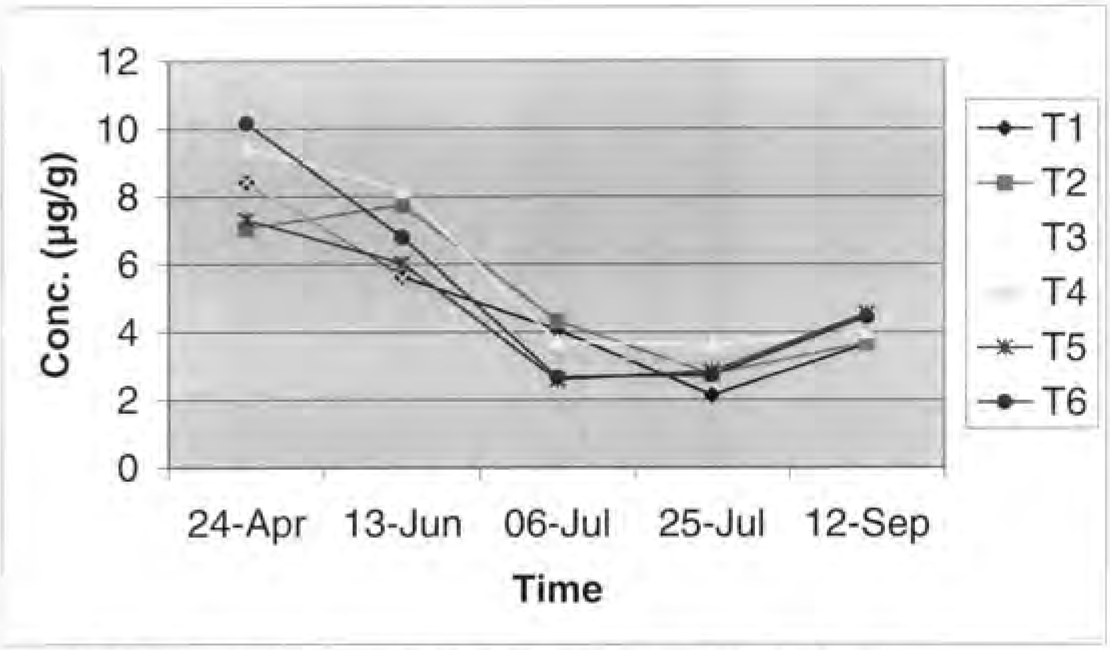

Fig. 10: Work row total inorganic N of the total soil profile (0-90 cm)

Variation of total inorganic N (ammonium and nitrate combined) is illustrated in Figures 9 and 10. A similar pattern is observed both in the vine row and in the work row. Treatments 1, 2 and 6 each received inorganic fertilizer application in the vine row. This explains the high inorganic N concentration in treatments 1 and 6 (Fig. 9), however the comparatively low inorganic N present in the vine row of treatment 2 is unexpected. All treatments appear to undergo a net loss of inorganic N from the system until the end of July, after which time the soil inorganic N content starts to increase.

DISCUSSION

Conventional soil management practices provide the control against which organic treatments may be assessed. This includes differences in N flux within each system of soil management. It is beneficial to assess whether any advantages exist, leading to a preference of a particular management practice over another. This study would assess this in terms of any difference in N retention among different treatments. However, in the broader scope of this experiment, it would include factors such as sustainable economic viability. In this regard, the differences among the different organic treatments or conventional treatments may become apparent.

Studies have shown that organic management practices lead to an increase in soil fertility over time. Poudel *et al.* (2001) found that, ~~when~~ compared to a conventional system, organic systems had an 80 % reduction in cumulative N loss. This effect was not as evident in the present study. ~~Such a discrepancy is not evident in the present study;~~ However some trends are apparent.

Treatments 1, 2 and 6 had equal amounts of inorganic N applied prior to the initiation of the study. The highest amounts had been applied during the growth season (i.e. during September and December of the previous year). There had been an application of inorganic N approximately four weeks before the first sampling period (appendix A). Nitrate and ammonium were supplied in equal proportions. In these treatments, fertilizer application was uniform across the vine and work rows while the organic treatments had equal application of compost and straw to the vine row. Thus the relatively high initial nitrate values for Treatments 1 and 6 are expected. However, it is not clear Treatment 2 did not show similar values at this time.

The increase in nitrate at depth for Treatment 1 indicates that this treatment is experiencing more leaching as compared with the other treatments. Also, there is no apparent increase towards the latter sampling times (as was observed in the general pattern) and this would suggest lower mineralization (and subsequent conversion to nitrate) in the surface layers. Although the organic treatments also show an increase in leaching from early July onwards, there is an associated increase in surface nitrate during this period

At the first sampling time, there was no significant difference among nitrate contents in the organic treatments. Nitrate was higher (although not significantly so) in Treatment 1 and was significantly higher in Treatment 6. The higher nitrate values evident in the conventional treatments is probably due to the application of inorganic fertilizer during the previous month. Over time there was less variation among treatments and content decreased with time.

Among the various organic treatments, there was no significant differences in nitrate levels for the final sampling time. Similarly, there was no significant differences in nitrate levels among the conventional treatments. In terms of ammonium content, the organic treatments all showed similar values, while the Treatment 1 and 6 had significantly different levels. At this point there was also little evidence to suggest that there was an overall significant difference between the conventional and organic treatments.

Decomposition of organic matter results in the release of N in a form available to the plant for uptake. Penac K has a stimulatory effect on the activity of soil microbes which, in turn, effect the rate of release of nitrate from organic matter. If one compares the nitrate fluctuation of Treatment 4 (treated with Penac K) with that of Treatment 3 and 5, it is observed that from July to September all three treatments show a rise in nitrate levels. The accumulation begins earlier (6 July) and is also more substantial in Treatment 4. For each sampling time, the nitrate values are similar among the organic treatments. The only significant difference is observed during late July, where the nitrate content of Treatment 4 is significantly higher than the remaining values. Treatment 4 shows an advantage in terms of nitrate abundance. This may possibly be attributable to enhanced microbial activity. Treatment 5 does show a higher accumulation of nitrate (and to a lesser extent ammonium) when compared with Treatment 3. This observation is potentially supported by the fact that this treatment included the additional use of Effective Micro-organism Technology – a mechanism of speeding up the rate of humus formation. In essence this would act as a means of limiting the loss of inorganic N through leaching. EM technology was also used in Treatment 6. When compared with the conventional management procedure (Treatment 2), Treatment 6 does show a higher rate of nitrate increase from early July onwards (although not significantly so). This would also be expected on the basis of incorporation of EM technology.

The rate of release of inorganic N from organic matter is largely dependent on the C:N ratio. A high C:N ratio (>30) leads to relatively low levels of inorganic N. In this case the rate of immobilization tends to exceed mineralization. Over time, the C:N ratio of organic material decreases and this leads to an increase in the rate of mineralization. The cover crop used in the previous season had been wheat and this may have contributed to a low rate of mineralization. The alkaline soil conditions (pH 5) of the plot may have contributed to low mineralization rates.

In conclusion, there seems to be no clear evidence supporting either organic or conventional soil management. Nitrate levels decreased as winter progressed and mineralization rates remained low. An increase in inorganic N with the advent of spring suggests an increase in mineralization.

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APPENDIX A

Table A1: Treatment-specific applications:

Treatment	
1	The traditional system of management. Full surface chemical weed control. Pre-germination herbicides were applied, and then again at the end of winter (ie at budbreak). The herbicide used was Roundup which is commonly used for viticulture. 20 Sept 2000: Roundup applied (6L/ha) 28 Sept 2000: LAN applied (14 kg NH_4^+ N/ha and 14 kg NO_3^- N/ha) 23 Oct 2000: Gramoxone (500ml/20L) (weed control on vine row) 14 Dec 2000: LAN applied (14 kg NH_4^+ N/ha and 14 kg NO_3^- N/ha) 22 Mar 2001: LAN applied (7 kg NH_4^+ N/ha and 7 kg NO_3^- N/ha)
2	Rye covercrop in work row. Post-emergence herbicide in vine row. At the end of winter the covercrop is slashed. 28 Sept 2000: LAN applied (14 kg NH_4^+ N/ha and 14 kg NO_3^- N/ha) 23 Oct 2000: Gramoxone (500ml/20L) (weed control on vine row) 28 Oct 2000: Work row covercrop slashed 14 Dec 2000: LAN applied (14 kg NH_4^+ N/ha and 14 kg NO_3^- N/ha) 22 Mar 2001: LAN applied (7 kg NH_4^+ N/ha and 7 kg NO_3^- N/ha)
3	Organic management. Compost and straw applied to vine row 18 Sept 2000: Compost applied on vine row (76 kg organic N/ha) 18 Sept 2000: Wheat straw applied to vine row (3 ton/ha) 28 Oct 2000: herbicide applied to vine row 28 Oct 2000: Work row covercrop slashed 15 Dec 2000: 'Compost tea' 22 Mar 2001: Compost applied to vine row (76 kg organic N/ha)
4	Organic management. Compost and straw applied to vine row (8 tons/ha = 76 kg organic N/ha). Additional stimulation of soil micro-organisms by Penac K. 31 Jul 2000: Penac K (320g/ha) 18 Sept 2000: Compost applied on vine row (76 kg organic N/ha) 18 Sept 2000: Wheat straw applied to vine row (3 ton/ha) 28 Oct 2000: herbicide applied to vine row 28 Oct 2000: Work row covercrop slashed 15 Dec 2000: 'Compost tea' 22 Mar 2001: Compost applied to vine row (76 kg organic N/ha)

5	Organic management. Compost and straw applied to vine row. Effective Micro-organism technology (this has the effect of speeding up formation of humus). 18 Sept 2000: Compost applied on vine row (76 kg organic N/ha) 18 Sept 2000: Wheat straw applied to vine row (3 ton/ha) 28 Oct 2000: herbicide applied to vine row 28 Oct 2000: Work row covercrop slashed 15 Dec 2000: Extended EM (1:300) 15 Dec 2000: 'Compost tea' 22 Mar 2001: Compost applied to vine row (76 kg organic N/ha)
6	Treatment 2 with the additional use of EM technology. 28 Sept 2000: LAN applied (14 kg NH_4^+ N/ha and 14 kg NO_3^- N/ha) 23 Oct 2000: Gramoxone (500ml/20L) (weed control on vine row) 28 Oct 2000: Work row covercrop slashed 14 Dec 2000: LAN applied (14 kg NH_4^+ N/ha and 14 kg NO_3^- N/ha) 15 Dec 2000: Extended EM (1:300) 22 Mar 2001: LAN applied (7 kg NH_4^+ N/ha and 7 kg NO_3^- N/ha)