CFPA	SAAPPA / SASPA / SAT	DFTS	Winetech
Canning Fruit Producers' Assoc. Submit to: Wiehahn Victor Tel: +27 (0)21 872 1501 inmaak@mweb.co.za	Fruitgro Science Submit to: Louise Liebenberg Tel: +27 (0)21 882 8470/1 louise@fruitgro.co.za	Dried Fruit Technical Services Submit to: Dappie Smit Tel: +27 (0)21 870 2900 dappies@dtd.co.za	Submit to: Jan Booysen Tel: +27 (0)21 807 3324 booysenj@winetech.co.za

			X

Indicate (X) client(s) to whom this final report is submitted.
Replace any of these with other relevant clients if required.

FINAL REPORT

FOR [Click HERE and type year]

PROGRAMME & PROJECT LEADER INFORMATION

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PROJECT INFORMATION

Project number	WW03/14
Project title	Effect of soil surface management practices and soil parameters on soil microbiology and grapevine performance
Project Keywords	ARISA, soil management practices, soil health, soil microbiology, soil quality

Industry programme	**CFPA**	
	Deciduous	
	DFTS	
	Winetech	X
	Other	

Fruit kind(s)	Wine grapes
Start date (dd/mm/yyyy)	01/04/2008
End date (dd/mm/yyyy)	31/03/2011

FINAL REPORT

(Completion of points 1-5 is compulsory)

1. Executive summary

Give an executive summary of the *total* project in no more than 250 words

Soil samples were collected over a two-year period (2009-2010) from an experimental vineyard near Robertson, South Africa (33˚50'S, 19˚54'E). Sampling was done in March (Growing Season) and August (Winter Season). Five different land management treatments were applied that were replicated four times. The cultivation practices were as follows: 1) T1: Clean cultivation during the grapevine growing season - chemical control vine row, mechanical control work row. 3 l/ha glyphosate (360 g/l formulation); 2) T2: Full surface chemical control of weeds during grapevine growing season; 3) T3: Full surface straw mulch, chemical weed control as necessary; 4) T8: Biennial rotation of Triticale / grazing vetch as cover crop. Full surface chemical control of weeds during grapevine growing season; 5) T13: Permanent cover crop in work row, slashed when reaching 30 cm height, chemical control vine row during grape growing season.

Variation in microbial structure was compared over two years by analysing ARISA profiles. The effect of these five cultivation practices was also determined on the activities of the soil enzymes, urease, β-Glucosidase, acid-phosphatase. Fungal diversity under the various treatments remained consistent over the two years of sampling. Bacterial diversity was consistent over the first three sampling times and decreased significantly during the winter season of 2010. Bacterial and fungal community structure differed significantly over the two year period with dissimilarities between seasons. The most profound dissimilarities in bacterial community structure were observed between mulch, clean cultivation and chemical weed control treatments. The soil surface treatments applied to the vineyard caused significant shifts in microbial community structure, highlighting the effect of land management practices on agricultural soil.

The physical indicators analysed were soil texture; soil water content; bulk density and aggregate stability. None of the treatments had limiting physical properties in terms of vine growth. In terms of soil quality, none of the physical conditions created by the treatments resulted in unfavourable soil conditions or quality for crop growth. The chemical indicators analysed were soil pH, EC, extractable N, P, K and organic matter content. Of these indicators measured, none yielded values below the specific indicator threshold values, thus no management intervention is needed to obtain optimum soil quality conditions, for optimal vine growth. In terms of the biological indicators, the high soil microbial biomass and soil

respiration found in the straw mulch treatment, suggests that there are more active functioning microbes. It was expected that the straw mulch treatment would yield the highest PMN rate. This was not the case in the study with the exact opposite occurring where the treatment, which had the highest organic matter content, presented to lowest PMN rate. Reasons for this occurrence is not clear.

The study also investigated the possible differences in soil quality which could be caused as a result of agricultural traffic within the treatment plots. For this reason, the *pedoderm* was studied to reveal differences in soil management practices. With regard to soil chemical properties, the chemical indicator, N and OM content was generally higher *In* tracks than *Between* tracks. The exchangeable cations (Ca, Mg, Na and K) measured all had higher values for *Between* tracks than *In* tracks. This occurrence was found to be more prevalent within the 0-50 mm soil depth, a feature common in conservation type soil management where pedodermal expression is greatest. Overall, the treatment that can be rated most sustainable in terms of yielding the most desired soil quality was the straw mulch treatment. The land use sustainability of the other treatments did not yield results below the threshold values.

The earthworm counts were very low and were therefore not conclusive. The micro-anthropod study concluded that the annual cover crop treatment yielded the highest number of micro-anthropods, which was not expected given the high soil microbial activity in the straw mulch treatment.

2. Problem identification and objectives

State the problem being addressed and the ultimate aim of the project.

The primary objective of this work is to investigate the effects of common soil surface management practices on the microbial populations of bulk soil, and at the root / soil interface and on physical and chemical parameters within the soil on the ARC experimental farm in Robertson, in the Boland region of South Africa. It is, furthermore, to identify practices which will promote diversity and balance amongst favourable soil microorganisms, increase soil organic matter contents, and facilitates consistent growth, yield and disease resistance in grapevines.

3. Workplan (materials & methods)

List trial sites, treatments, experimental layout and statistical detail, sampling detail, cold storage and examination stages and parameters.

The original workplan included sites in the Helderberg region to determine the impact of soil type on microbial populations. In February 2009, vines were removed at Eikendal trial. We therefore decided to continue the sampling at Lushof and Cordoba during the July/August 2009 sampling. After no genomic DNA could be obtained from the July/August 2009 and April 2010 sampling at Lushof and Cordoba, it was decided to exclude these two sites from the microbiological data set. Genomic DNA isolated at these sites were of poor quality and could not be amplified by PCR. As the soil chemical and physiological properties required the digging of profile pits this particular part of the study could also not continue at Lushof and Cordoba as it is situated on private property and the digging of profile pits was not allowed at that stage. The Lushof and Cordoba studies were therefore removed from the study.

The trial was set up in a Chardonnay/Richter 99 vineyard in November 1992 at the Agricultural Research Council Infruitec-Nietvoorbij Research farm near Robertson. The town of Robertson (33˚50'S, 19˚54'E) is situated in the Breede River Valley region of the Western Cape, South Africa. Robertson is within a semi-arid climatic region with high temperatures in summer and cooler temperatures in winter than the Mediterranean climate of the Western Cape (Bonnardot, Carey and Strydom, 2000). The mean annual rainfall amounts to 278mm, of which most rainfall events occur during winter. The soil cover treatments were established between vines that were spaced 1.5 m in the row and 2.75 m between rows (Fourie, 2010). The experiment was a completely randomised design, with five treatments replicated four times.

The treatments included: i) no cover crop, post-emergence chemical control of a 1 m wide strip in the vine row and mechanical control in the work row from just before grapevine bud break (end of August) to just before harvest (end of January); ii) no cover crop, full surface post-emergence chemical control from the end of August to the end of January; iii) full surface straw mulch packed out annually approximately two weeks after grapevine bud break at a density of 8 tons/ha; iv) annual cover crop: crop rotation triticale (100 $kg.ha^{-1}$) and grazing vetch (50 $kg.ha^{-1}$), 2 yr/specie. Sprayed with an herbicide before bloom, and v) perennial cover crop: permanent perennial rye grass (14 $kg.ha^{-1}$) chemical weed control on the ridges.

3.1 Molecular microbiology

Soil samples were taken from various treatments (excluding samples from Lushof and Eikendal) mid February 2009. Only the top 15 cm soil layers were sampled.

DNA isolation

Soil samples from every plot were used for DNA extraction. DNA was extracted from 0.35g of soil by using the ZR Soil Microbe DNA extraction kit (Zymo research USA). Extracted and purified DNA was separated on a 1% agarose gel and visualized using ultra violet light.

PCR amplification

PCR reactions were performed on the DNA using fungal and eubacteria specific primer sets to evaluate its application in automated ribosomal intergenic spacer analysis (ARISA). Eubacterial specific primers for the 16 rDNA intergenic spacer region of the bacterial rRNA operon were used to access to bacterial diversity with ARISA. The fungal diversity was determined by using fungal specific primers in the PCR reactions.

PCR reactions were done using a GeneAmp PCR System 2400 (AppliedBiosystems, USA). The reaction mixture contained 1 µl of the purified genomic DNA extracted from soil, 500 nM of each primer and 23 µl of KapaTaq readymix (KapaBiosystems, South Africa) in a total volume of 25 µl. The PCR conditions consisted of an initial denaturing step of 3 min at 95 °C followed by 40 cycles of 95 °C, for 30 s, 51 °C for 30 s and 72 °C for 30 s. The reaction was completed with a final extension at 72 °C for 5 min and then cooled and held at 4 °C. PCR for each sample was performed in triplicate and pooled to eliminate background noise form the ARISA profile and reduce error due to PCR bias.

Automated Ribosomal Intergenic Spacer Analysis (ARISA)

The PCR products of every sample were run on a ABI prism sequencer to obtain an electropherogram of the different fragments length and fluorescent intensity. F-ARISA PCR samples were run along with LIZZ 660 which contained sizes from 60bp to 660bp in length. B-ARISA samples were run with ROX 1.1 which varied from 20 to 900 bp. The GeneMapper 4.1 software converted fluorescence data to an electropherogram and the peaks which represented fragments of different sizes are termed operational taxonomic units (OTU). The heights of the peak indicate the relative abundance of the fragment of the total product. The length was calculated using the size standards by plotting a best fit curve and extrapolating fragment sizes from the sample.

Data analysis

Data was analysed by using the Genemapper 4.1 software.

3.2 Soil physical, chemical and biological parameters

Soil properties analysed in the past 15yrs of existence of the trial are being captured in a database and serves a guide to suitable/useful indicators as well as a possible reference/baseline to compare future results. A composite sample for each of the 20 plots was taken with a soil auger at a depth of 20cm in mid February 2009. Soils were air dried and sieved through a 2mm sieve and stored for analysis. The analysis conducted was based on soil properties analysed in past and recommended in literature and served as the primary criteria for indicator selection.

Soil sampling

The soil was obtained from Agricultural Research Council's Experimental farm near Robertson (33°49'44.51"S, 19°53'9.28"E). Soils were sampled on three occasions (February 2009, July 2009 and May 2010) for analysis during the study. Soil classification was also conducted in June 2010 on five soil 1m^3 profile pits excavated a day prior to the field classification. The dominant soil forms identified within the study site is the Augrabies form.

For the first set of samples, a selection of 20 soils was used for the initial characterization of the study site. Composite samples, of the topsoil for each sampling location, were made in order to identify possible changes in soil properties which may have occurred as a result of the different soil management treatment. Sampling was done to a depth of 200 mm at all 20 locations.

For the second set of samples, the sampling depth of 50 mm was used in order to evaluate the soil quality of the pedoderm, as defined by Fey and Mills (2004), in comparison to that of the traditional sample of the plough depth of 0-200 mm. The pedoderm is a "*thin layer of soil at the interface with the atmosphere, a few millimetres to centimetres thick, within which certain properties exhibit a marked vertical change in expression sometimes not readily detected through field observation" (Fey and Mills, 2004)*.

The properties that are often found to be different relative to the bulk of the surface horizon typically include the organic matter content, plant nutrients, microbial activity and aggregate stability (Fey and Mills, 2004; Fey and Mills, 2006).

In addition to refining the analysis to the pedoderm for the various treatments, pedoderm samples were also taken *between* the tracks and *in* tracks for each soil management treatment. A total of 80 samples were collected to a depth of 50 mm.

A third set of soil samples were collected solely for the assessment of biological properties. Biological soil properties are sensitive to seasonal changes, thus the sampling time for assessment of biological soil properties is recommended to be taken in late autumn or early spring and at the end of cropping season (Steenberg, 1999). The sampling for biological properties was done after routine agricultural operations as to not influence the microbiota (Steenberg, 1999).

Statistical procedures

The experimental design was a randomised block design with 5 treatments randomly allocated in 4 blocks. Analyses of variance was performed on the data obtained using SAS (SAS, 1990) to identify differences between treatments. Student's t-test of least significant difference was calculated at the 5% and 10% significance level to identify differences between treatment means. The Shapiro-Wilk test was performed to test for non-normality (Shapiro and Wilk, 1965). The statistics was conducted by the Agrimetry division of the Agricultural Research Council- Infruitec.

3.2.1 Physical indicators

Soil texture

The relative proportions of various particle sizes of soil namely sand, loamy sand, sandy loam and sandy clay loam and are further subdivided classes according to the relative percentages of course, medium and fine sand (Soil Classification Working Group, 1991). The particle size distribution of a soil defines the proportions of the various particle sizes the soil contains (Gee and Bauder, 1986). The method used to determine the particle fractionation consist of pre-treatment of soil to destruct the soil aggregates by chemical treatment to remove binding substances such as carbonates, organic matter, iron oxides and siliceous cementing agents (Gee and Bauder, 1986). Following the pre-treatment, the soil is dispersed by means of hexametaphoshate and the various size fractions of the suspension extracted at time intervals, which are calculated from Stokes' equation for the sedimentation of spherical particles (Gee and Bauder, 1986).

Soil Water Content

In order to determine the gravimetric water content of a particular soil sample, the water mass must be determined by drying the soil to constant weight and measuring the soil sample mass after and before drying. The water mass (or weight) is the difference between

the weights of the wet and oven dry samples. The criterion for a dry soil sample is the soil sample that has been dried to constant weight in oven at temperature at 105°C. The complete method can be found in the Appendix section of this document. The soil water content was determined for the 0-50 mm soil composites and calculated using the moist weight and oven dried weight (FSSA, 2007).

$$\textbf{(g.g}^{-1}\textbf{)} = \frac{\text{(weight of moist soil - weight of oven dry soil)}}{\text{weight of oven dry soil}} \qquad \textbf{Equation 1}$$

Bulk Density

The bulk density was determined by means of the core method (Blake and Hartge, 1986). This is done by driving a cylinder of known volume ($V_{cylinder}$) into the soil and thereby obtaining a core of natural soil. The soil is then weighed and dried and the amount of water and dry soil (m_{dry}) is determined. By dividing the mass of dry soil by the volume of cylinder, a number for bulk density (ρ_b) is obtained (Lyon *et al.,* 1955).

$$\textbf{Soil bulk density (g.cm}^{-3}\textbf{)} = \frac{\text{oven dry weight of soil (g)}}{\text{volume of soil (cm}^3\text{)}} \qquad \textbf{Equation 2}$$

The relative bulk density (RBD) was calculated relative to the lower limit of the threshold value (Carter, 2006) for optimal root and plant growth.

$$\textbf{Relative bulk density} = \frac{\text{measured bulk density (g.cm}^{-3}\text{)}}{1.5\ \text{g.cm}^{-3}} \times 100 \qquad \textbf{Equation 3}$$

Aggregate stability

The water aggregate stability was determined by wet-sieving of the 0-50 mm soil composite for each treatment, *Between* tracks and *In* tracks. The method is based on the mass of soil aggregates remaining on a sieve fraction, following cycles of wet sieving (Herrick, Whitford, de Soyza, Van Zee, Havstad, Seybold and Walton, 2001) comparing the different aggregate fractions remaining after wet sieving, with the dry aggregate fractions.

A total of ten sets (one sample per treatment and position) and of samples were used for this analysis. The same set of samples that were used for particle size distribution (soil texture) was used in the water aggregate stability analysis.

The wet sieving consisted of rinsing 10 g of air-dried sample of soil with distilled water through a nest of three sieves (> 2 mm, 0.25-2,0 mm, and 0.106-0.25 mm). The portions remaining in the respective sieves were then quantitatively transferred to porcelain evaporative dishes and dried at 105˚C overnight.

The results obtained from the method used in the study are limited to comparing the particle size percentages of water stable aggregates (WSA) with that of the dry sieved aggregates. The water stable aggregates were calculated as follows:

$$\textbf{Percentage Water stable aggregates} = \frac{\text{mass of aggregates in fraction (g)}}{\text{initial sample mass(g)}} \times 100 \qquad \textbf{Equation 4}$$

The ratio of water stable aggregates to dry-sieved aggregates (DA) and the ratio of water stable aggregates to the texture analysis fractions (TAF) were calculated as follows:

$$\textbf{Aggregate stability ratio} = \frac{\text{water stable aggregates of fraction } \boldsymbol{a} \text{ (\%)}}{\text{dry-sieved aggregates of fraction } \boldsymbol{a} \text{ (\%)}} \qquad \textbf{Equation 5}$$

Where ***a*** denotes the specific particle fraction (>2 mm, 0.25-2,0 mm, and 0.106-0.25 mm) obtained from particle size analysis.12

3.2.2 Chemical indicators

Soil pH

The soil pH was measured after 10 g of 2 mm fraction of air dried soil was shaken with 50 ml of distilled water and the tip of a glass electrode inserted in the supernatant of the solution (Thomas, 1996).

Electrical conductivity (EC)

The soil electrical conductivity was measured after 10 g of 2 mm fraction of air dried soil was shaken with 50 ml of distilled water and the tip of a conductivity meter was inserted in the supernatant of the solution (Rhoades, 1996).

Extractable Potassium

The cations, including potassium, were extracted using a 1 M ammonium acetate extract at pH 7 (Tan, 1996).

Extractable Phosphorous

The available phosphorous was extracted by means of the Bray 2 method (Kuo, 1996).

Soil Organic Carbon and Nitrogen

Organic carbon and nitrogen was determined by dry combustion total C and N by complete combustion using a Eurovector Euro EA Elemental Analyzer. Stock amounts of C and N were calculated from the bulk density and sample depth (Lee et al., 2009) as illustrated below.

Stock C (kg.ha^{-1}) = %C × ρ_b (kg.m^{-3}) × 0.05m **Equation 6**

Soil Organic Matter (SOM) content

The soil organic matter content was initially determined by loss on ignition, which yielded values that did not correspond with the estimated value, calculated from the organic carbon content (Conradie, 1994). For this reason, the organic matter content which was determined from the organic carbon percentage determined from complete dry combustion. The calculation is presented below.

%SOM = 1.72 × % C **Equation 7**

The samples were sealed and stored at 8˚C until analysis was conducted. The various treatment samples were analyzed for soil microbial biomass, potential mineralizable nitrogen and soil respiration.

The samples were sealed and stored at 8˚C until analysis was conducted. The various treatment samples were analyzed for soil microbial biomass, potential mineralizable nitrogen and soil respiration.

Soil Microbial Biomass (SMB)

Soil microbial biomass as determined by an adapted method of the microwave irradiation-microbial biomass carbon method (Islam and Weil, 1998) with field moist samples (equivalent to 10 g dry weight). Soils were irradiated twice at 600 W for 70 sec and temperature of the samples measured. The temperature of irradiated samples ranged from 70-86℃. The irradiated samples along with non-irradiated (control) samples were then incubated for 10 days at room temperature. Following the incubation period, samples were quantitatively transferred to 500 ml beakers with distilled water and water was removed by

evaporating the sample on a water bath. Dried samples were then milled and carbon and nitrogen determined by dry combustion with an elemental analyzer (Eurovector).

Potential Mineralizable Nitrogen (PMN)

Potential mineralizable nitrogen as determined by incubating soil samples and the amount of ammonium produced in that period was used to indicate the capacity for nitrogen mineralization (Gugino *et al*., 2007). Air dried samples were sieved and two 8 g soil samples were weighed into 50 ml bottles. To one bottle, 40 mL of 2 M KCl was added and shaken on a mechanical shaker for 1 hour, filtered and the soil extracts were analyzed for ammonium concentration. To the second bottle, 10 ml of distilled water was added, then hand shaken and incubated for 7 days at 30°C. After the incubation period, 30 mL of 2.67M KCl was added to the second bottle and shaken for 1hour on the mechanical shaker, filtered and the soil extracts were analyzed for ammonium concentration.

Soil Respiration (SR)

Soil respiration was determined by incubating field moist samples (equivalent to 10g dw) in 50ml bottles sealed for a period of incubated for 7days at 30°C. Following the incubation period, the headspace in the sample bottle was collected using a syringe. The headspace samples collected was then analyzed by for CO_2, C_2H_4 and O_2 by means of gas chromatography.

3.2.3 Biological indicators

Soil micro-arthropods

During sampling composite soil samples were taken at the various sampling sites with the aid of a soil auger. Samples of the top 7.5cm soil layer were collected from the sampling sites since micro-arthropods are known to be more abundant in this layer. The samples were taken to the laboratory and microarthropods were extracted with the Berlese-Tullgren extraction chamber. The organisms were later sorted into different orders and families, depending on the extent of identification possible with the use of current keys. Another sampling is scheduled for July 2009.

Enzyme essays

Composite soil samples were taken from various treatments. These samples were sieved and subsequently air-dried for 48hr at room temperature (22°C).

Activities of the selected enzymes *viz.* B-glucosidase, acid phosphatase and urease were determined with the appropriate substrate of each at their respective optimal pH values (Tabatabai, 1982). Methods used are summarised in Table 1.

Table 1. The methods used to determine enzyme activity in soils

Recommended name[a]	**Assay conditions**[b] **[Substrate]**	**Optimum pH**
Acid phosphatase	*p*-Nitrophenyl phosphate [25mM]	6.5
β-glucosidase	*p*-Nitrophenyl- β-glucopyranoside [25mM]	6.0
Urease	Urea [80mM]	Non-buffered

[a]Methods according to Tabatabai (1982)
[b]Values in parentheses are substrate concentrations under the respective assay conditions. The product of reactions for glucosidase and phosphatase is *p*-Nitrophenol = pNP

4. Results and discussion

State results obtained and list any benefits to the industry. Include a short discussion if applicable to your results.
This final discussion must cover ALL accumulated results from the start of the project, but please limit it to *essential* information.

Milestone	**Achievement**
1. Biological, physical and chemical analyses on samples obtained from established vines	Objective completed
2. Earthworm studies	Objective completed
3. Microbial diversity studies	Objective completed

4.1 SOIL MICOBIOLOGY

4.1.1 Microbial diversity

Seaosonal effects

No significant differences were obtained (p≥0.05) when the soil surface treatments (T1-T13) were compared using repeated measures ANOVA. Fungal diversity remained constant over the two year sampling period, and higher diversity was observed during the growing season (Fig. 1a & b).

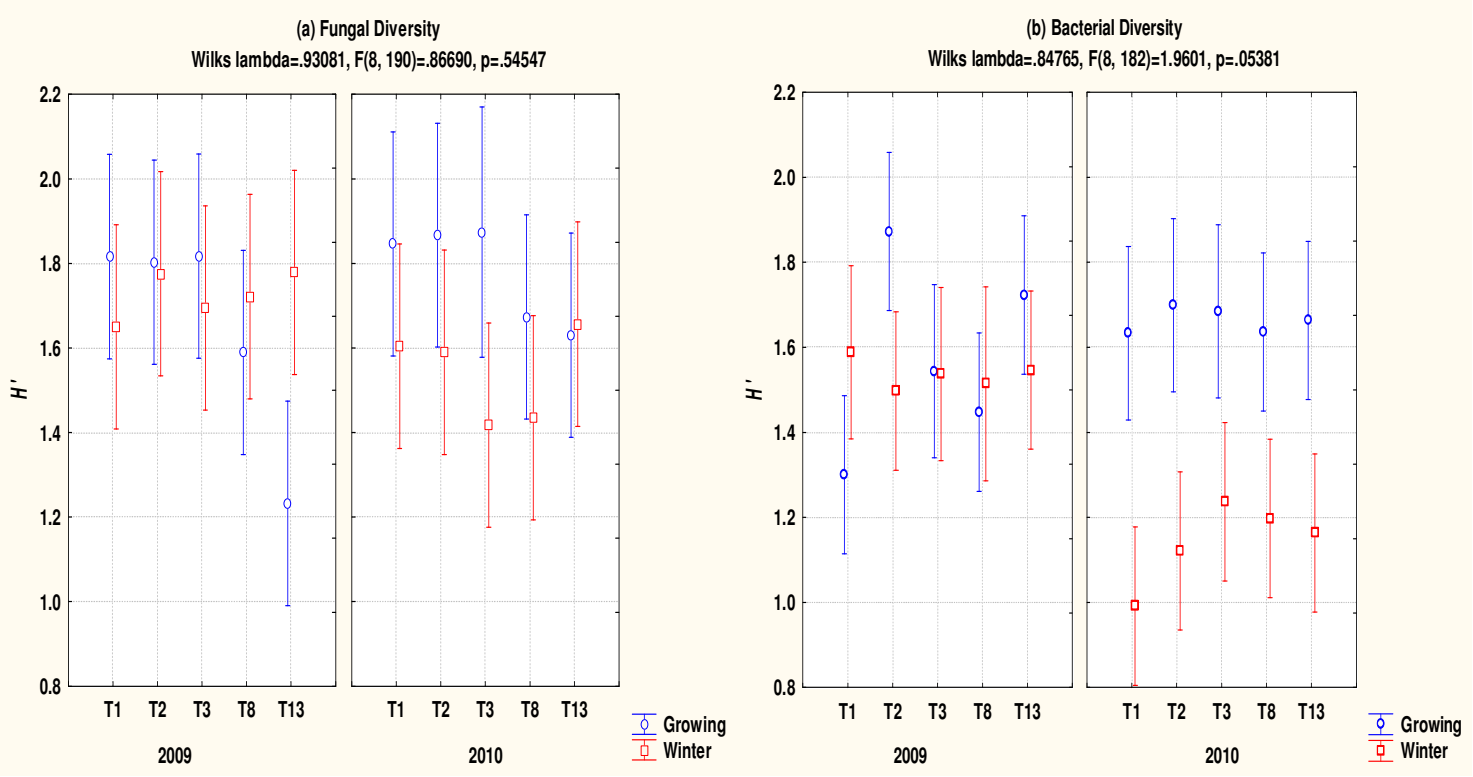

Figure 1: ANOVA results of the five different soil surface treatments, with treatment 1 (T1) as the control. Bacterial and fungal diversity based on the Shannon diversity (*H'*) index was compared between each treatment over four seasons (two years).

No significant differences were obtained (p≥0.05) when the soil surface treatments (T1-T13) were compared using repeated measures ANOVA. Fungal diversity remained constant over the two year sampling period, and higher diversity was observed during the growing season (Fig. 1a & b). Similarly, bacterial diversity also remained relatively consistent over two years, although fluctuations in diversity were observed during 2009 (Fig. 1b & 2b). During 2010, bacterial diversity was much lower during the winter season than compared to the growing season (Fig. 2b). Further analysis revealed a significant difference (p≤0.05) in bacterial diversity between treatments during 2010.

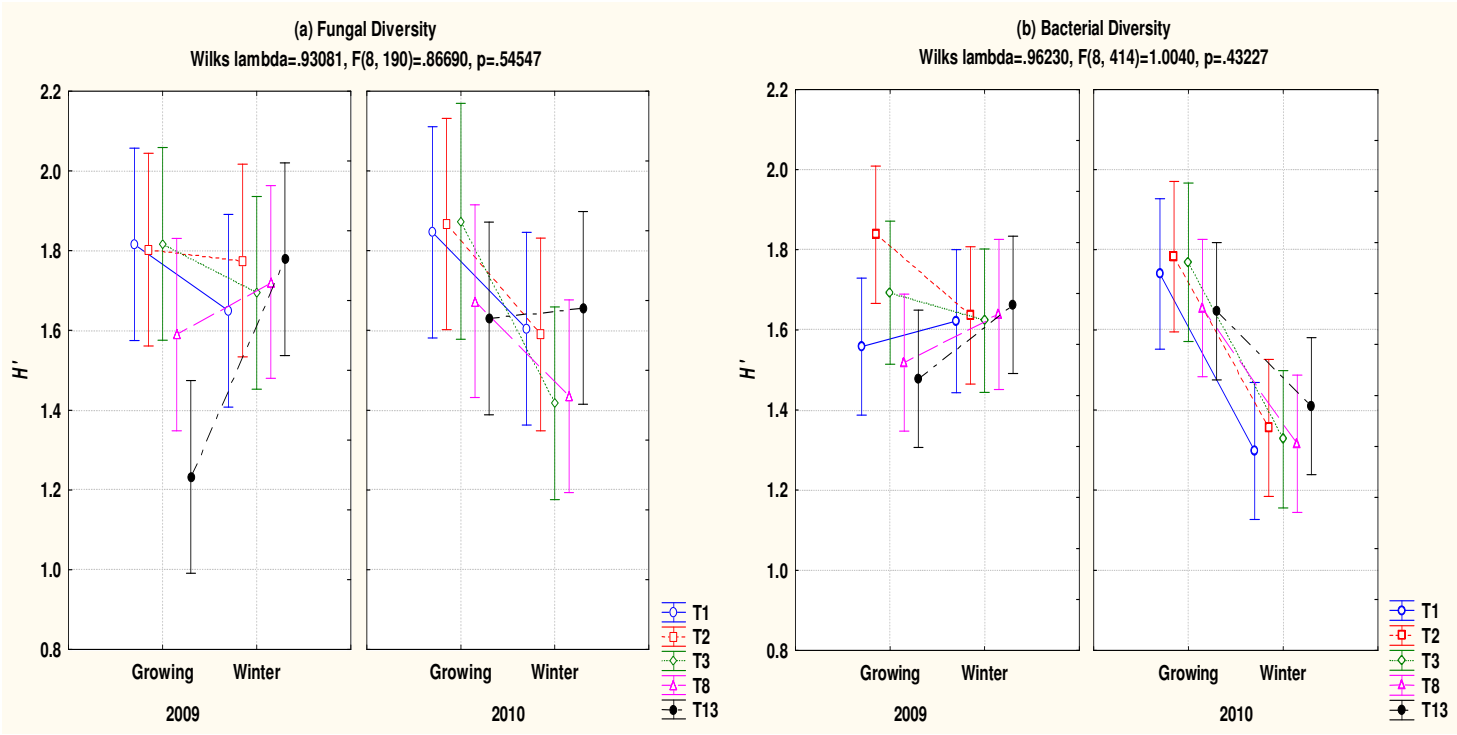

Figure 2: ANOVA results of the five different soil surface treatments, with treatment 1 (T1) as the control. Bacterial and fungal diversity based on the Shannon diversity (*H'*) index was compared between each treatment over four seasons (two years).

4.2.2 Microbial community structure

Treatment effects (Pairwise comparisons)

The largest significant differences in bacterial community structure were observed between T2 (chemical control) and T3 (mulch) during both years with the highest R-statistics. T1 (clean cultivation) and T2 showed the most dissimilarities compared with other treatments during 2009. During 2010, T3 was dissimilar to all the other treatments. Significant differences in fungal community structure were observed between most of the treatments with the highest dissimilarities between T1 and T2 (Table 1).

Significant differences were obtained ($p \leq 0.05$) when treatments were compared using ANOSIM analysis. Significant differences were observed between seasons over two years. These seasonal differences were also evident during each year. The largest R-statistic (0.841) was observed seasonally in 2010, indicating a large difference in bacterial community structure. This difference is also observed in bacterial diversity (Fig. 2b). Further significant differences were observed only within the Growing seasons (Table 2). Pairwise comparisons were used to show between treatments the differences occurred.

Table 1: ANOSIM results displaying seasonal effects. Significant effects are represented by the p-value (p≤0.05) and the R-statistic for both bacteria and fungi. The R-statistic falls in the range of -1 to 1 with a value of 1 suggesting similarity of replicates within a treatment compared to replicates in other treatments.

Pairwise Comparisons (Groups)	Bacteria				Fungi			
	2009		2010		2009		2010	
	R	p	*R*	p	*R*	p	*R*	p
T1 vs T2	0.333	0.011	0.160	0.064	0.639	0.003	0.252	0.029
T1 vs T3	0.136	0.151	0.268	0.003	0.187	0.097	0.463	0.022
T1 vs T8	0.281	0.031	0.128	0.142	0.248	0.062	0.109	0.110
T1 vs T13	0.224	0.033	0.192	0.097	0.441	0.000	0.115	0.104
T2 vs T3	0.592	0.003	0.396	0.023	0.733	0.002	0.288	0.023
T2 vs T8	0.356	0.011	0.064	0.300	0.626	0.002	0.072	0.200
T2 vs T13	0.274	0.051	0.003	0.471	0.559	0.002	0.040	0.233
T3 vs T8	0.016	0.442	0.325	0.021	0.144	0.148	-0.032	0.555
T3 vs T13	0.061	0.204	0.373	0.015	0.443	0.001	-0.052	0.592
T8 vs T13	0.124	0.053	0.148	0.082	0.444	0.001	0.011	0.378

Seasonal effects

Table 2: ANOSIM results displaying treatment effects. Significant effects are represented by the p-value (p≤0.05) and the R-statistic for both bacteria and fungi. The R-statistic falls in the range of -1 to 1 with a value of 1 suggesting similarity of replicates within a treatment compared to replicates in other treatments.

			Bacteria		Fungi	
	Season	Groups	*R*	p	*R*	P
2009	Growing Season	T1,T2,T3,T8,T13	0.205	0.000	0.398	0.000
	Winter Season	T1,T2,T3,T8,T13	0.064	0.145	-0.018	0.542
2010	Growing Season	T1,T2,T3,T8,T13	0.188	0.007	0.107	0.020
	Winter Season	T1,T2,T3,T8,T13	0.068	0.135	-0.023	0.622

Enzyme studies

There were no significant differences between the treatments of acid-phosphatase and only T13 significantly differed from T2 and T8 of the urease treatments (Table 3). For the treatments of β-Glucosidase, T13 differed significantly from T1 and T3. There were no significant differences between the treatments of *β-Glucosidase, acid-phosphatase* and

urease when the results of the three sampling periods were combined. As a result of this we used Fishers' unprotected test to compute the LSD for the interaction (TMT.Season). The protected test does not determine the LSD of the interaction if it is not significant. No real distinct pattern could be observed for this interaction.

Table 3. Mean of difference between treatments within combined seasons. Analysis of variance (ANOVA) was used to test for differences between the treatments within combined season. The data was acceptably normal with homogeneous treatment variance. Treatment means were separated using Fishers' unprotected t-test least significant difference (LSD) at the 5% level of significance.

VARIATES	Glucosidase	Phosphatase	Urease
TMT			
T1	142.6 bc	72.8 a	75.5 ab
T2	171.8 abc	90.1 a	64.9 b
T3	134.5 c	106.1 a	72.7 ab
T8	173.7 ab	109.9 a	61.9 b
T13	183.0 a	102.2 a	83 a
SEM	12.11	12.28	5.38
Probability	0.059	0.263	0.102
LSD(5%)	ns	ns	ns
Season			
Feb2009	107.0 b	75.1 b	61.8 b
Feb2010	243.4 a	128.6 a	66.2 b
Sept2010	133.0 b	85.0 b	86.7 a
SEM	10.18	6.34	3.22
Probability	<0.001	<0.01	<0.001
LSD(5%)	29.41	18.32	9.30
TMT.Season			
T1.Feb2009	93.2 f	53.5 f	66.3 cdef
T1. Feb 2010	213.9 c	101.8 abcde	59.4 def
T1.Sep2010	120.5 ef	63.3 ef	100.6 a
T2. Feb 2009	89.7 f	56.2 ef	47.7 ef
T2. Feb 2010	280.7 ab	128.8 abc	67.4 cdef
T2.Sep2010	145.1 def	85.4 def	79.6 bcd
T3. Feb 2009	96.2 f	79.6 def	68.3 cde
T3. Feb 2010	195.2 cd	145.6 a	64.0 cdef
T3.Sep2010	112.1 ef	93.2 bcdef	85.9 abc
T8. Feb 2009	135.1 def	99.8 abcdef	59.7 def
T8. Feb 2010	224.9 bc	125.3 abcd	44.7 f
T8.Sep2010	161.0 cde	104.5 abcde	81.2 bcd
T13. Feb 2009	120.5 ef	86.6 cdef	67.0 cdef
T13. Feb 2010	302.3 a	141.5 ab	95.5 ab
T13.Sep2010	126.1 ef	78.5 def	86.4 abc
SEM	22.18	16.88	7.97
Probability	0.206	0.743	0.027
LSD(5%)	63.31	48.59	22.84
CV%	28.3	29.5	20.1

SEM is the standard error of the mean.
LSD is the t-test least significant difference at the 5% level.
Means within the columns followed by the same lower case letter did not differ significantly at 5% level.
CV% is the coefficient of variation of each experiment.
Data were analysed using the statistical program GenStat (2010).

When the seasons were separated a different picture about the treatments were observed (Table 4). There were no significant differences between the treatments of β-Glucosidase in at the different sampling dates. Similarly there were no significant differences between the treatments of acid-phosphatease and urease (except for T13 that differed significantly from the other treatments) for February and September of 2010. In February 2009 the acid-phosphatease in treatment T8 was significantly higher than in T1 and T2. This shows that when analysing the treatments by combining the sampling dates, the enzyme activity was affected, which means that there is seasonal effect rather than a treatment effect on the analysis.

Table 4. Mean of difference between treatments (season separated). Analysis of variance (ANOVA) was used to test for differences between treatments. The data was acceptably normal with homogeneous treatment variance. Treatment means were separated using Fishers' protected t-test least significant difference (LSD) at the 5% level of significance.

VARIATES	**Glucosidase (Feb 2009)**	**Glucosidase (Feb 2010)**	**Glucosidase (Sept 2010)**
TMT			
T1	93.2 a	214 a	120.5 a
T2	89.7 a	281 a	145.1 a
T3	96.2 a	195 a	112.1 a
T8	135.1 a	225 a	161.0 a
T13	120.5 a	302 a	126.1 a
SEM	14.79	28.2	14.65
Probability	0.193	0.087	0.188
LSD(5%)	ns	ns	ns
CV%	27.7	23.2	22.0
VARIATES	**Phosphatase (Feb 2009)**	**Phosphatase (Feb 2010)**	**Phosphatase (Sept 2010)**
TMT			
T1	53.5 c	102 a	63.3 a
T2	56.2 bc	129 a	85.4 a
T3	79.6 abc	146 a	93.2 a
T8	99.8 a	125 a	104.5 a
T13	86.6 ab	141 a	78.5 a
SEM	10.47	22.4	14.43
Probability	0.037	0.676	0.378
LSD(5%)	32.26	ns	ns
CV%	27.9	34.8	34.0
VARIATES	**Urease (Feb 2009)**	**Urease (Feb 2010)**	**Urease (Sept 2010)**
TMT			
T1	66.3 a	59.4 b	100.6 a
T2	47.7 b	67.4 b	79.6 a
T3	68.3 a	64.0 b	108.9 a
T8	59.7 ab	44.7 b	81.2 a
T13	67.0 a	95.5 a	86.4 a
SEM	4.16	8.92	12.79
Probability	0.023	0.022	0.442
LSD(5%)	12.83	27.50	ns
CV%	13.5	27.0	39.42

SEM is the standard error of the mean.
LSD is the t-test least significant difference at the 5% level.
Means within the columns followed by the same lower case letter did not differ significantly at 5% level.
CV% is the coefficient of variation of each experiment.
Data were analysed using the statistical program GenStat (2010).

4.2 SOIL PHYSICAL PROPERTIES

4.2.1 Soil texture

Since soil texture is an inherent property of the soil, the determination thereof was only done on a few treatment plots for use of characterization of the soil. With the dominant soil texture being sandy clay loam (Table 5).

Table 5. Soil texture classes determination for 0-50 mm soil composites for the five soil management practices

Treatment Name	Position	Textural class
Mechanical	*Between tracks*	Sandy clay loam
Mechanical	*In tracks*	Sandy loam
Chemical	*Between tracks*	Sandy loam
Chemical	*In tracks*	Sandy clay loam
Straw mulch	*Between tracks*	Sandy clay loam
Straw mulch	*In tracks*	Loam
Annual cover crop	*Between tracks*	Sandy loam
Annual cover crop	*In tracks*	Sandy loam
Perennial cover crop	*Between tracks*	Sandy clay loam
Perennial cover crop	*In tracks*	Sandy clay loam

4.2.2 Soil Water Content

The water content obtained for the various treatments are given in Table 6. Statistically, the straw mulch treatment had significantly higher water content between tracks. The variations in water content in *Between* tracks and *In* tracks within the treatments were not significantly different. A common pattern observed in the data was the higher water content *In* tracks than *Between* tracks for the cover crop treatments.

Table 6. Gravimetric water content of 0-50 mm soil composites *Between* tracks and *In* tracks.

Treatment Name	Position	Gravimetric water content (g/g, %)	t-test *
Mechanical	*Between tracks*	3.90	b
Mechanical	*In tracks*	4.41	a b
Chemical	*Between tracks*	4.95	a b
Chemical	*In tracks*	3.94	b
Straw mulch	*Between tracks*	6.34	a
Straw mulch	*In tracks*	6.10	a b
Annual cover crop	*Between tracks*	4.25	a b
Annual cover crop	*In tracks*	4.80	a b
Perennial cover crop	*Between tracks*	3.80	b
Perennial cover crop	*In tracks*	4.99	a b

* Means with the same letter are not significantly different. Data differ significantly at the 5% level.

A possible reason for this could be the regular occurrence of traffic in these plots due to usual field operations needed by cover crops in comparison to the straw mulch treatment. For the same reason, the straw mulch treatments soil water content *Between* tracks and *In* tracks are relatively the same due to the limited traffic and tillage taking place in these plots and as a result, the *In* track position is not as defined and sunken, as in the case of the cover crop treatments.

The chemical treatments had higher soil water contents *Between* tracks than *In* tracks. In a study conducted by Ferrero, Usowicz and Lipiec (2005) on the impacts of tractor traffic on vineyard soil properties, no differences in terms of soil water content were found for tilled soils verses the soils with a permanent cover which was contrary to what was found in this study. The reason for this could be the sample depth used for the analysis. In this study, the sample depth of 0-50 mm, allowed for the analysis of soil properties within the pedoderm, which is often different from the bulk top soil horizon. It is known that pedodermal expression is maximal under conservation practices and minimal under conventional cultivation practices (Mills and Fey, 2004). The higher water content observed *Between* tracks in the chemical treatments is attributed to the ease with which water penetrates cultivated soils, in comparison to the cover crop treatments in which surface crust feature was more pronounced.

4.2.3 Bulk Density

Bulk density affects plant growth due to its effect on soil strength and soil porosity. High soil densities have a direct effect on vine performance due to the effect it has on the distribution, and functional capacity of the root system to extract water and nutrients from the soil (Lanyon, Cass and Hansen, 2004). The technique used to determine bulk density core method as recommended in the Cornell Soil Health Manual (Gugino, et al., 2008) produced results which were not near the norm for the Robertson area (1.4-1.7 g.cm-3) and obtained in unpublished data for a study conducted by the ARC (Hoffman, 2011) (Table 7).

The dryland cultivated vineyard soils in this semi-arid area were not suited for use of the core method for determining bulk density. Soils in this area are prone to surface crusting and this too was observed during soil sampling. The surface crust varied between 3-5 mm thick and the removal of the surface crust is recommended (Hoffman, 2011) if the soil core technique is to be used. In this case, an adjustment to the core volume was made in order to account for the effect of the soil crust. Due to the high variation obtained during measurement, the

clod method is recommended for future bulk density determinations for soils in the semi-arid area. The revised values calculated for the bulk density is listed in Table 8.

Table 7. Bulk density values obtained from core method of Soil Health Manual and Revised bulk density

Treatment Name	Soil Health Manual Method Bulk density ($g.cm^{-3}$)	Revised Bulk density ($g.cm^{-3}$)
Mechanical	0.95	1.19
Chemical	1.11	1.39
Straw mulch	1.33	1.66
Annual cover crop	1.11	1.66
Perennial cover crop	1.06	1.39

Overall, the bulk density was significantly higher *In* tracks than *Between* tracks. This was expected, due to the pressure exerted on the soil by the tractor tyre in the tracks. The critical bulk density for root growth varies with different textures and for sandy clay loam soil, the threshold values for root growth for different soil types were measured by Morris and Lowery (1988). The bulk density values, for the various plot treatments and positions, in comparison to the threshold value, are given in Table 8.

The relative bulk density (RBD) can be calculated relative to this threshold values in order to rate the bulk density in relation to the root and plant growth. If the relative bulk density is less than 80%, it is considered to be within the low range, 82-87% the optimum range and greater than 90%, within a high range which is generally associated with soil conditions that inhibit root growth (Carter, 2006).

Table 8. Critical bulk density values for root growth for different soil textures (adapted from Morris and Lowery, 1988)

Treatment Name	Position	Textural class	Revised Bulk density ($g.cm^{-3}$)	Threshold Bulk density ($g.cm^{-3}$)	t Grouping*
Mechanical	*Between tracks*	Sandy clay loam	1.19	1.55-1.75	*d*
Mechanical	*In tracks*	Sandy loam	1.62	1.55-1.75	*a*
Chemical	*Between tracks*	Sandy loam	1.39	1.55-1.75	*c*
Chemical	*In tracks*	Sandy clay loam	1.42	1.55-1.75	*bc*
Straw mulch	*Between tracks*	Sandy clay loam	1.66	1.55-1.75	*a*
Straw mulch	*In tracks*	Loam	1.57	1.45-1.60	*ba*
Annual cover crop	*Between tracks*	Sandy loam	1.66	1.55-1.75	*c*
Annual cover crop	*In tracks*	Sandy loam	1.57	1.55-1.75	*ba*
Perennial cover crop	*Between tracks*	Sandy clay loam	1.39	1.55-1.75	*dc*
Perennial cover crop	*In tracks*	Sandy clay loam	1.56	1.55-1.75	*bc*

* Means with the same letter are not significantly different. Data differ significantly at the 5% level.

In terms of the threshold values for bulk density as defined by Carter (2006) and that of Morris *et al.,* (1988) In tracks of the mechanical and the straw mulch treatment and Between tracks of the annual cover crops, the relative bulk densities (above 90%) are generally associated with soil conditions that inhibit root growth (Table 9).

Table 9. Bulk density and relative bulk density of *Between* tracks and *In* tracks

Treatment Name	Position	Bulk density ($g.cm^{-3}$)	Relative Bulk density (%)
Mechanical	*Between tracks*	1.19	68.00
Mechanical	*In tracks*	1.62	92.57
Chemical	*Between tracks*	1.39	79.43
Chemical	*In tracks*	1.42	81.14
Straw mulch	*Between tracks*	1.66	94.86
Straw mulch	*In tracks*	1.57	89.71
Annual cover crop	*Between tracks*	1.66	94.86
Annual cover crop	*In tracks*	1.57	89.71
Perennial cover crop	*Between tracks*	1.39	79.43
Perennial cover crop	*In tracks*	1.56	89.14

Statistically, the straw mulch treatment had the highest bulk density in comparison to the other treatments. This occurrence is expected, since the soil has not been tilled for 18years with annual layering of straw for mulching. At this stage, it is worth mentioning that the straw plots were most difficult to sample soil from. Results in Table 6 show t grouping which demonstrates that the effect of treatments is mainly pronounced in the sections between the tracks. Tracks complicate the experiment and seem to have a greater influence than the treatment itself.

4.2.4 Aggregate stability

The water stable aggregates (WSA) at various depths as a percentage of the total soil from the various treatments are depicted in Figure 3. The percentages WSA of each depth fraction, in and between tracks for each treatment, are depicted in Figure 4. The ratio of WSA to dry-sieved aggregates (DA) calculated can be used as measure of indicating the structural stability of the soils under the various soil management treatments (Table 10). The ratio of WSA to texture analysis fractions (TAF) was also calculated and is given in Table 11.

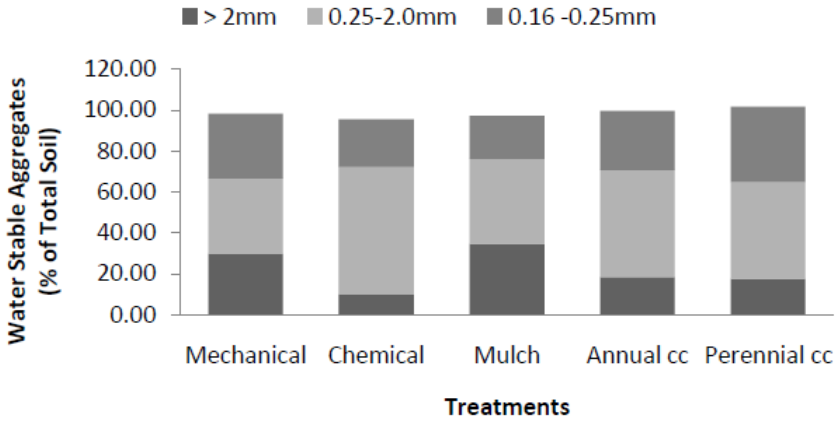

Figure 3. Water stable aggregates of various soil management treatments

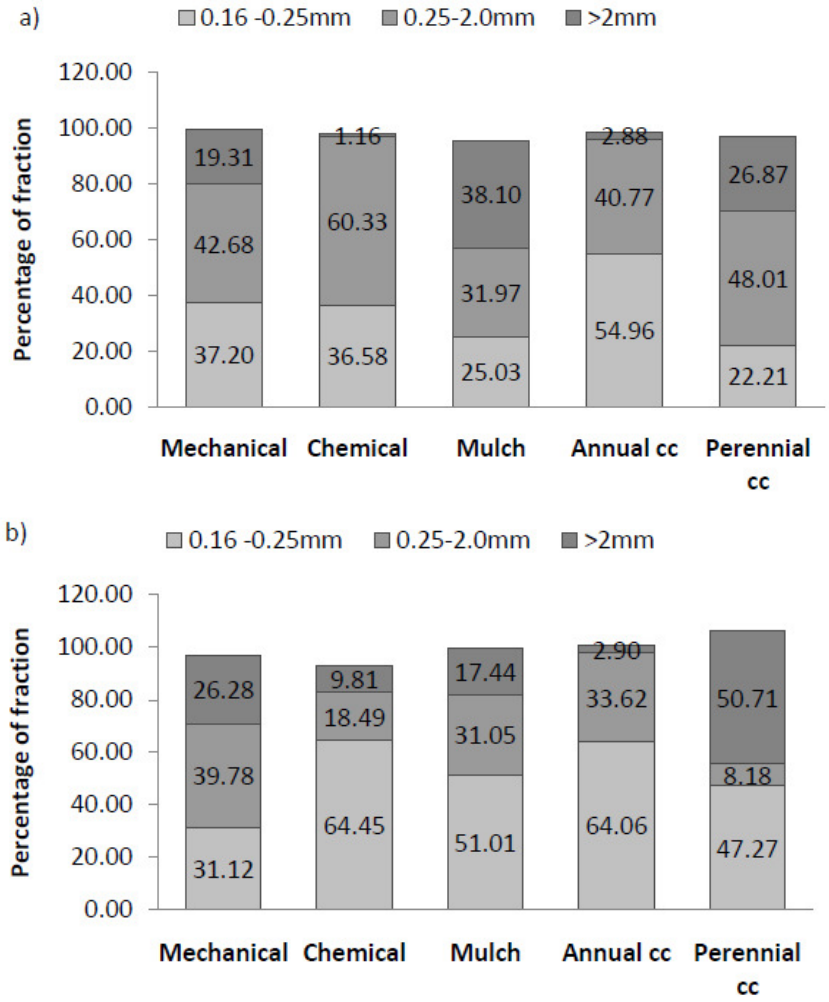

Figure 4. Water stable aggregates in three fractions of soil obtained (a) *In* tracks and (b) *Between* tracks of various soil management treatments

Table 10. Ratio of Water Stable Aggregates (WSA) to dry-sieved aggregates (DA) for soil management treatment plots

Treatment Name	0.106 - 0.250 mm	0.25- 2.00 mm	>2.00 mm
Mechanical	3.55	1.26	0.46
Chemical	2.03	1.68	0.20
Straw mulch	31.56	6.61	0.37
Annual cover crop	54.76	8.97	0.20
Perennial cover crop	11.60	1.47	0.27

Table 11. Ratio of Water Stable Aggregates (WSA) to texture analysis fractions (TAF) for soil management plots

Treatment Name	0.106 - .250 mm	0.25- 2.00 mm	>2.00 mm
Mechanical	0.44	1.32	0.96
Chemical	0.32	2.31	0.29
Straw mulch	0.30	1.40	0.61
Annual cover crop	0.40	1.96	0.38
Perennial cover crop	0.54	1.45	0.29

From the ratios calculated, the treatment with the highest percentage of the largest particle fraction (>2 mm fraction) can be considered to have more water stable aggregates than treatments with lower percentages for that specific particle fraction.

From the results above, the treatments yielding the largest ratio of stable aggregates >2 mm are the mechanical and straw mulch treatments. The same conclusion can be drawn from the ratio of water stable aggregates to dry aggregates as well as the ratio of water stable aggregates to texture analysis fractions. The better structural stability in the mechanical and straw mulch treatment plots could be related to the organic matter content of the soils. Organic matter content plays an important role in aggregation of soil particles. Since the straw mulch treatment plots have the highest organic matter content in comparison to the remainder of the treatment plots, the ratio of water stable aggregates was expected to be larger. The presence of earthworms is also a contributing factor to the higher structural stability. In an earthworm study conducted on the site by Maboeta (2010), the earthworms (adults, juveniles and cocoons) were most abundant in the straw mulch treatment plots.

The presence of termites is also a contributing to aggregation. Termites bring large quantities of clay sized particles from the subsurface to the surface and in the process the clay particles are glued together by the fluid excreted by the termites (heuweltjies, Duiker et al., 2003). The mechanical treatment plot was the only plot that tested positive (effervescences in 10% solution of HCl) for the presence of a "*heuweltjie*" within the plot.

The larger ratio of water stable aggregates despite lower organic matter content could be due to the presence of termites. In addition to the contribution of the termite secretion to aggregation, the concentration and type of cations present also play a role in aggregation. The presence and concentration of divalent cations also contribute to aggregation, with calcium having the stronger ability than magnesium to flocculate clays (Duiker et al., 2003). The calcium concentration of the mechanical plot was also the highest (Table 12) of the treatment plots and thus the contribution of calcium concentration to aggregation is plausible.

Table 12. Exchangeable cations for the 0-50 mm soil composites

	Exchangeable cations (cmol(+)/kg)			
Treatment Name	**Ca**	**Mg**	**Na**	**K**
Mechanical	15.80	4.26	0.45	1.23
Chemical	14.46	4.39	0.45	1.30
Straw mulch	14.29	5.73	0.45	1.28
Annual cover crop	10.99	4.63	0.51	1.13
Perennial cover crop	11.61	5.31	0.49	1.51

4.3 SOIL CHEMICAL PROPERTIES

4.3.1 Soil pH

The soil pH was measured to determine the acidity or alkalinity of the soil. The treatment data is presented in the table and figures below. From figures 5 and 6, it is clear that no major differences exist between treatments in terms of soil pH. The differences in soil pH that do occur, relates to soil depth, with the pH increasing by at least 1 unit from 0-50m to 0-200 mm soil depth. No treatment or position differences $p>0.05$ were found. The t-test reveals significant differences between the treatment means for mechanical vs. annual and perennial cover crops. The chemical and straw mulch treatments show statistically insignificant differences from other treatments.

Furthermore, these pH values indicate high base saturation in all plots that supports the exclusion of base saturation from the minimum data set (MDS) in this case, as part of soil quality assessments.

4.3.2 Electrical conductivity (EC)

Electrical conductivity results were obtained from the analysis of the 0-50 mm soil fraction as well as the 0-200 mm soil composite. Below is a graphical representation of the two sampling positions and soil depths (Figures 7 and 8).

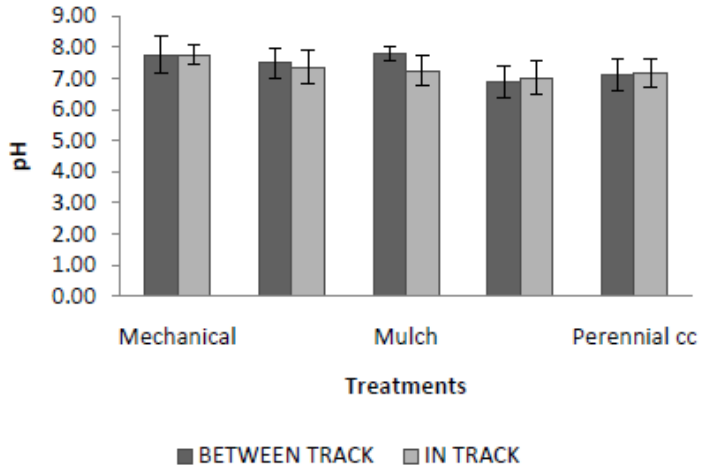

Figure 5. Average soil pH (H_2O) of 0-50 mm soil depth *Between* tracks vs. *In* tracks

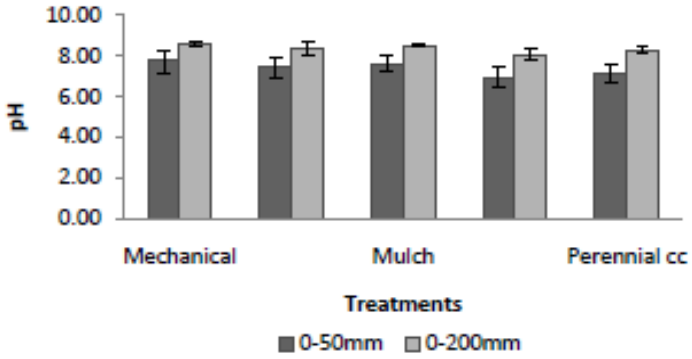

Figure 6. Soil pH of 0-50 mm vs. 0-200 mm soil composite

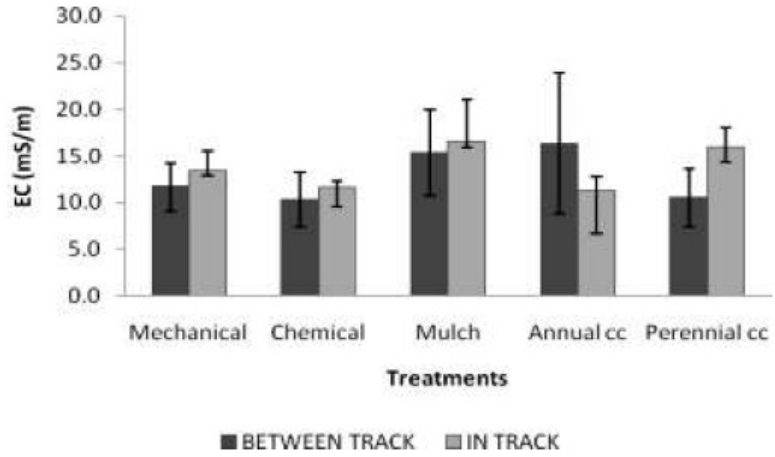

Figure 7. ECe of 0-50 mm sample *Between* tracks and *In* tracks

In most of the treatments, the EC was higher *In* track than *Between* tracks, but this variation was not statistically significant. The possible reason for the higher salt content *In* tracks, could be due to salts accumulating in micro-depressions of tracks as well as poor infiltration

occurring in tracks due to surface crusts that were observed during soil sampling (data not shown).

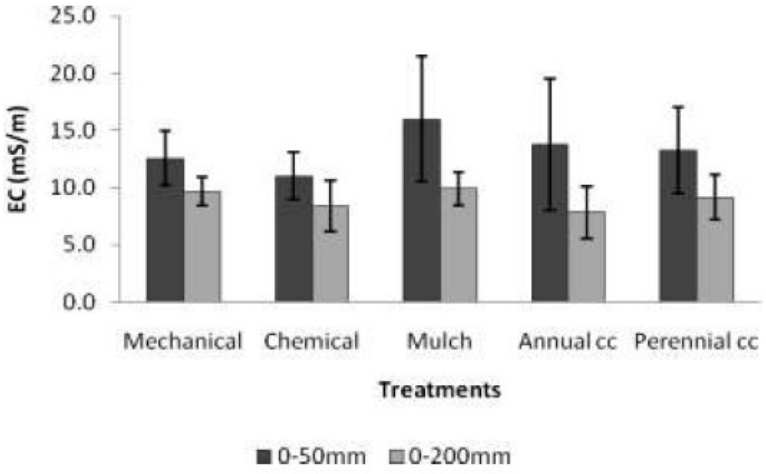

Figure 8. Average soil EC of 0-50 mm vs. 0-200 mm soil depth

At the 0-200 mm soil depth, no significant differences with regards to EC was found between the treatments. At the 0-50 mm soil depth, only the straw mulch treatment had significantly higher EC than the chemical treatment.

The 0-50 mm soil composites in all treatments exhibit higher EC values in comparison to the 0-200 mm soil composites. Most of the salt accumulation occurs at the soil surface and thus less depth averaging (0-50 mm) reveals more distinct differences between treatments. This observation corresponds with that found in other studies where the pedoderm soil properties are compared to that of the bulk top soil horizon (Karlen, Wollenhaupt, Erbach, Berry, Swan, Eash and Jordahl, 1994; Mills and Fey, 2004).

The annual cover crop treatment had an EC which was higher *Between* tracks in comparison to *In* tracks. The annual cover crop treatment bucks the general trend and is difficult to interpret. Soil salinity is an important factor when considering the soil's suitability for specific crop production. Vineyards are relatively resistant to saline condition below 400 $mS.m^{-1}$ (Richards,1954) and thus the differences found, in terms of electrical conductivity, should not impact on crop yield.

4.3.3 Extractable N, P and K

For each of the plant macro nutrients evaluated, concentration norms as determined by the ARC-Infruitec/Nietvoorbij and that of the Fertilizer Society of South Africa (FSSA) were used

to compare the obtained value with the desired value for vineyards. The nitrogen percentage and the bulk density were used to calculate the stock amounts (Lee, Hopmans, Rolston, Baer and Six, 2009) of nitrogen (Figure 9).

The nitrogen content was generally higher in the straw mulch treatment in comparison to the other treatments for the 0-50 mm and the 0-200 mm soil composites but this difference was not statistically significant due high variance of EC values. Under no-till practices, increases in nutrient concentration in the pedoderm in comparison to bulk top soil nutrient concentration is common (Karlen *et al.*, 1994) and the same trend were found in this study.

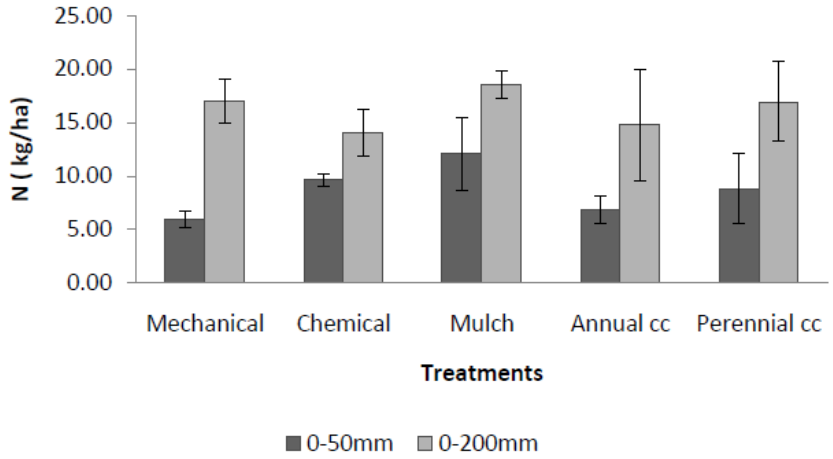

Figure 9. Nitrogen content of 0-50 mm and 0-200 mm soil

Phosphorous (P) application for vines is done more as a phosphorous deficiency precaution, rather than a phosphorous requirement. This is done since the P requirement for vines is relatively low (0.7 kg.ton-1) in comparison to other plant nutrients (N requirement for vines amounts to 4kg N. ton-1). Soils, which have clay contents greater than 15% (as in with these soils), require a phosphorous content of 30 $mg.kg^{-1}$ for viticultural soils (Conradie, 1994). Phosphorous content was only analyzed for the 0-200 mm soil composites of the five treatments and not assessed for between tracks and in tracks of the various treatments. The straw mulch treatment exhibited the highest P concentration, but not significantly different from the other treatments. Generally all sample plots had P concentration values above the crop requirement level (Figure 10).

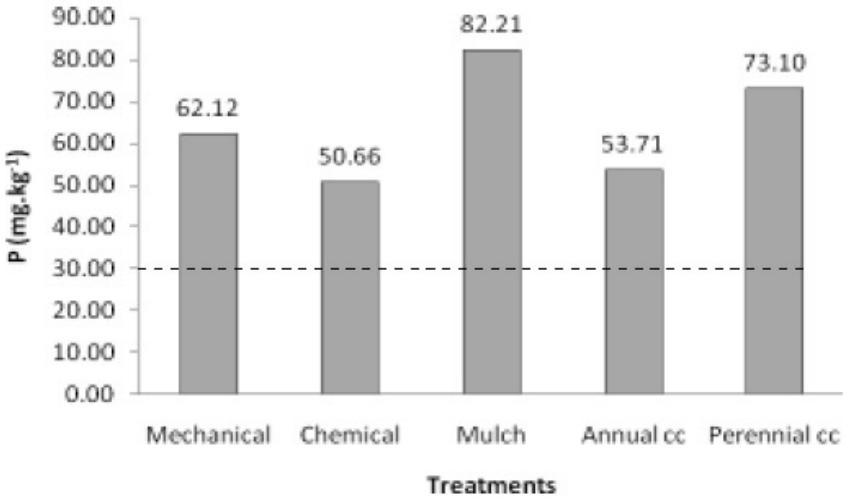

Figure 10. Phosphorus concentration of 0-200 mm soil composites relative to the P requirement (--) for vineyards

In soils with an exchangeable potassium concentration above 5 $cmol_c$.kg-1, as with the soils for the study area, the norm for potassium fertilizer is 80-100 mg.kg-1 (Conradie, 1994). The recommendation was made specifically for the viticultural dark coloured, structured, alluvial, clay loam soils of the Breede River Valley (Conradie, 1994). The potassium content of the soil depths measured both had concentrations above the requirement for wine grapes (Table 13). Where potassium levels are higher than 120 $mg.kg^{-1}$ no potassium should be applied on soils (Conradie, 1994).

The potassium concentration for the 0-200 mm soil depth of the straw mulch, annual cover crop and the perennial cover crop treatments is significantly different from each other, with the perennial cover crop exhibiting the highest K concentration (Table 13). The chemical and mechanical treatments showed mixed statistically insignificant results.

Table 13. Extractable N, P and K for 0-200 mm soil composites

Treatment name	N %	P $mg.kg^{-1}$	K $mg.kg^{-1}$
Mechanical	0.08 a	62.12 a	481.00 c b
Chemical	0.06 a	50.66 a	496.00 c b
Straw mulch	0.07 a	82.21 a	499.50 b
Annual cover crop	0.06 a	53.71 a	440.63 c
Perennial cover crop	0.08 a	73.10 a	590.25 a

Means with the same letter are not significantly different. Data differ significantly at the 5% level.

The Exchangeable Sodium Percentage (ESP) was calculated to determine to what extent, the soils sodicity would be influenced at the pedoderm. As observed with the EC measurements, the ESP values were generally higher *In* tracks than *Between* tracks (Table

14). The perennial cover crop treatment plot was the exception, where the ESP value was higher *Between* tracks. The reason for this is not clear, since the measured sodium value *In* tracks was found to be higher than the sodium level *Between* tracks. Soils with ESP values below 5% are also not considered sodic and therefore, the use of ESP should only be considered under these conditions. ESP values, above 15% are regarded as critical due to the effect of sodium on the 52 soil physical properties (Murphy, 2002). The ESP values for the various treatment plots are the range of 1.81-2.89%. The dominant exchangeable cation in the treatment plots is calcium as clearly seen in Table 14.

Table 14. Exchangeable cations *Between* tracks vs. *In* tracks (0-50 mm)

	Exchangeable cations ($cmol_c.kg^{-1}$)									
Treatment Name	Ca		Mg		Na		K		ESP (%)	
	Between tracks	In tracks	Between tracks	In tracks	Between tracks	In tracks	Between tracks	In tracks	Between tracks	In tracks
Mechanical	15.00	16.61	3.96	4.57	0.40	0.50	1.37	1.10	1.86	2.14
Chemical	14.02	14.90	4.14	4.64	0.38	0.51	1.35	1.24	1.81	2.29
Straw mulch	13.05	15.52	5.09	6.37	0.39	0.51	1.31	1.25	1.85	2.06
Annual cover crop	10.30	11.68	4.42	4.83	0.45	0.57	1.07	1.19	2.56	2.89
Perennial cover crop	10.72	12.50	4.71	5.92	0.46	0.51	1.29	1.74	2.37	2.19

4.3.4 Organic matter

The organic matter content is used, in addition to the clay content, as a broad guideline in nitrogen fertilizer recommendations (Conradie, 1994). Heavy soils (>6% clay), as in the case of the 0-50 mm fraction of the study area (where the percentage carbon > 0.9%) no nitrogen fertilizer is required for young vines (Conradie, 1994). For soils with a carbon content of 1%, the total nitrogen concentration amounts to approximately 770 $mg.kg^{-1}$ (Conradie, 1994).

Although the mechanical and annual cover crop treatment seemingly show lower OM% means, these differences are not statistically significant. The percentage of soil organic matter in the 0-50 mm and 0-200 mm soil depths of the five treatments did not differ significantly. The *In* tracks and *Between* track means for the various treatment showed significant differences within treatments (Table 15). Vehicle movement seems to have had a greater effect than the treatment itself (Table 16).

Table 15. Organic matter content for 0-50 mm and 0-200 mm soil composites

	sample depth OM%	
Treatment Name	**0-50 mm**	**0-200 mm**
Mechanical	2.33	1.69
Chemical	3.40	1.27
Straw mulch	3.29	1.29
Annual cover crop	2.34	1.33
Perennial cover crop	3.12	1.46

Table 16. Organic matter content *Between* tracks vs. *In* tracks (0-50 mm)

	OM %	
Treatment Name	**Between tracks**	**In tracks**
Mechanical	2.41	2.25
Chemical	3.72	3.08
Straw mulch	4.11	2.47
Annual cover crop	2.22	2.46
Perennial cover crop	3.85	2.39

Data did not differ significantly at the 5% level.

The worth of determining organic carbon content in soils extends to prediction of soil physical properties such an aggregation, water holding capacity (FSSA, 2007) and aeration (Conradie, 1994). The latter can be determined from the carbon:nitrogen ratio in soils, where a well aerated soil has normally has a C:N of 13 (Conradie, 1994). The C:N values are shown in Table 17. The C:N in the 0-50 mm and 0-200 mm soil depths of the five treatments did as well as for Between tracks and In tracks did not differ significantly.

Table 17. Carbon Nitrogen (C:N) ratio of 0-50 mm and 0-200 mm soil composites

	sample depth C:N	
Treatment Name	**0-50 mm**	**0-200 mm**
Mechanical	12.78	12.48
Chemical	11.52	12.10
Straw mulch	10.83	10.32
Annual cover crop	11.98	13.15
Perennial cover crop	12.10	11.26

Data did not differ significantly at the 5% level.

The variations amongst treatments, in terms of stock OM amounts, are observed to be more apparent in the 0-50 mm than in the 0-200 mm soil composites (Figure 11). With the straw mulch treatment yielding the highest stock OM content with the 0-50 mm soil depth. The OM content of the straw mulch *Between* tracks treatment was also was significantly higher than most of the other treatments.

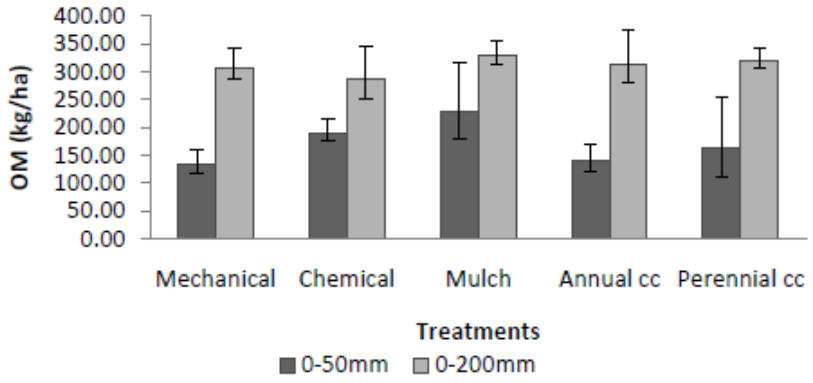

Figure 11. Organic matter content of 0-50 mm and 0-200 mm soil composites

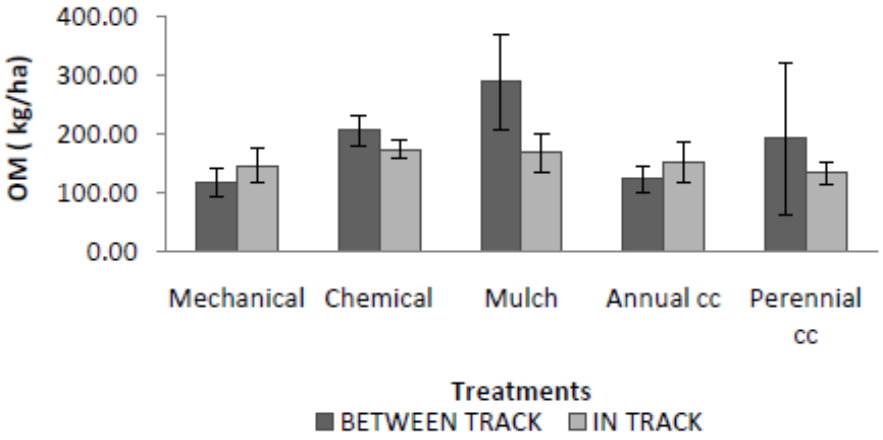

Figure 12. Organic matter content *Between* tracks vs. *In* tracks

The importance of noting such variation is of value when considering a range of soil management treatments potential for soil carbon sequestration. The rationale behind soil carbon sequestration is that an increase of soil organic carbon content, presumably contributes to the reduction in atmospheric carbon dioxide (Ringuis, 2002). A study examining the soil carbon sequestration opportunities and challenges for developing countries in sub-Saharan Africa, highlights the improving agricultural practices and land-use management to increase the agricultural productivity and sequester soil carbon (Ringuis, 2002). Being able to account for the gains of soil organic matter resulting from a specific land use is paramount. The use of smaller sampling increments (pedoderm) provides more pronounced evidence of the influence of the land use management on soil carbon. The difference seen in the soil management treatments of this study is an example of this.

Knowledge of the SOC stock values found in other studies within South Africa is useful, since threshold values for organic matter content were not available at the time of this study. In the

study of Mills and Cowling (2006), old agricultural land, intact and degraded *Spekboom thicket* had been found to have SOC stocks in the range of ±5-10 ton.ha-1 for the 0-100mm soil depth. This range was obtained from graph illustrating soil carbon (ton.ha-1) in the published works of this study (Mills and Cowling, 2010). The SOC obtained in this study for the 0-50 mm soil depth at most yielded SOC of 0.13 ton.ha^{-1} (Table 18).

Table 18. Soil Organic Carbon Stock values for soil management treatments

Treatment Name	SOC kg.ha^{-1}	SOC ton.ha^{-1}
Mechanical	76.96	0.08
Chemical	110.88	0.11
Mulch	133.25	0.13
Annual cover crop	80.49	0.08
Perennial cover crop	95.26	0.10

4.4 SOIL BIOLOGICAL PROPERTIES

4.4.1 Soil Microbial Biomass (SMB)

The soil microbial biomass was measured in order to indicate change in terms of biological activity and is considered to be a rapidly changing and highly dynamic characteristic of soil. Analysis was conducted for each position (*Between* tracks and *In* tracks) per treatment replication, resulting in a total of 40 samples. The results presented in the study were obtained by removing all negative yielding samples (where the initial value was higher than that of the incubated value) from the specific batch and calculating an average value of the replication per treatment. Stock amounts of soil microbial biomass were also calculated using the bulk density and sample depth (Table 19).

Overall the straw mulch treatment yielded the highest soil microbial biomass followed by the perennial cover crop treatment (Figure 13). This result was expected since the straw mulch treatment has the highest organic matter content and the nature of the treatment is the annual additional of organic material in the form of straw. Comparisons *Between* tracks and *In* tracks were not possible since only a few of treatment samples yielded positive results for the analysis conducted. The statistical analysis included the negative values obtained from the method used and revealed no significant differences between treatments or sampling position (*Between* or *In* tracks).

Table 19. Stock soil microbial biomass per soil management treatment

Treatment Name	Soil Microbial Biomass (kg C.ha^{-1})
Mechanical	2.74
Chemical	3.28
Straw mulch	26.13
Annual cover crop	3.78
Perennial cover crop	4.28

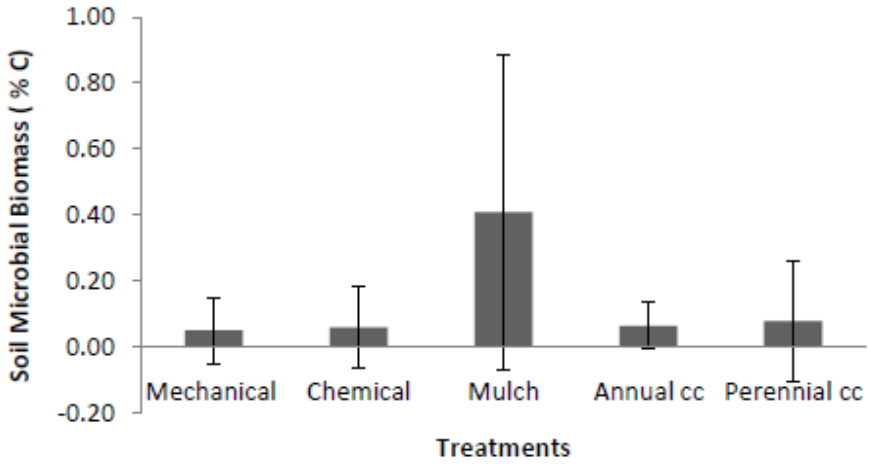

Figure 13. Soil microbial biomass per soil management treatment

4.4.2 Potential Mineralizable Nitrogen (PMN)

The soil nitrogen mineralization potential is defined as the quantity of soil organic nitrogen that is susceptible to mineralization (Standford, Carter and Smith, 1974). Analysis was conducted for each position (*Between* tracks and *In* tracks) per treatment replication, resulting in a total of 40 samples. The results presented in the study were obtained by removing all negative yielding samples (where the initial value was higher than that of the incubated value) from the specific batch and calculating an average value of the replication per treatment. Shown in figures 14 and 15 below are values of PMN estimated from the concentration of ammonium mineralized during the short-term (7days) incubation.

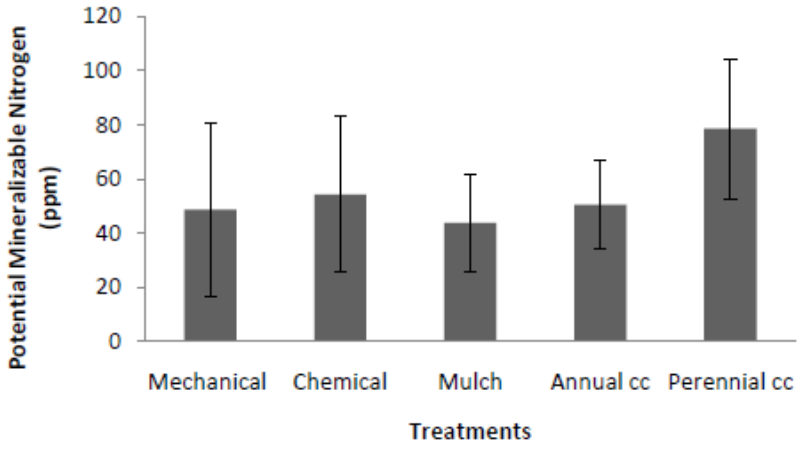

Figure 14. Average potential mineralizable nitrogen for soil management treatments

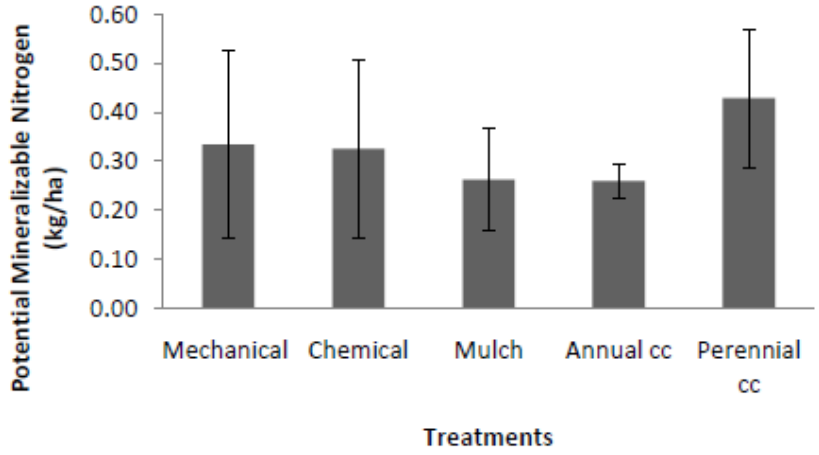

Figure 15. Average potential mineralizable nitrogen (kg.ha^{-1}) for the five soil management practices

The statistical analysis included the negative values (ppm) obtained revealed no significant differences between treatments or sampling position (*Between* or *In* tracks). Using the stock amount of nitrogen, instead of the ppm values, in comparing the PMN of the various treatments provides a means of evaluating the PMN with that of the organic nitrogen determined as part of the chemical indicators. PMN is determined in order to evaluate the capacity of soil organic matter to supply inorganic nitrogen to the crop. The C:N in organic matter determines whether immobilization or mineralization is likely to occur. A C:N ratio of 25 to 30 is considered a critical point for either immobilization or mineralization (Van Cleemput and Boeckx, 2002).

The mechanical treatment had the highest C:N and the lowest amount of available nitrogen with the straw mulch treatment obtaining the lowest C:N ratio and the highest available

nitrogen (Figure 16). This corresponds with work done by Harmsen and Van Schreven (1955) who found that a high C:N is often associated with a low N availability as well as inversely low C:N ratios associated with high N availability (Harmsen and Van Schreven, 1955).

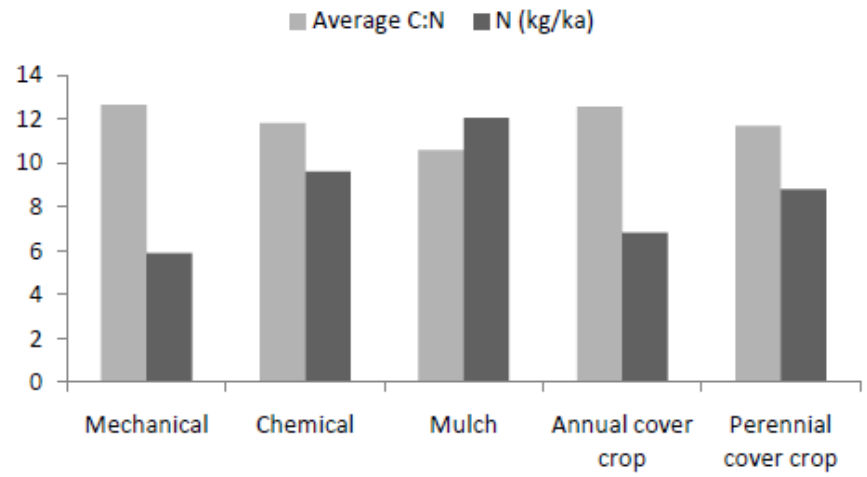

Figure 16. Carbon nitrogen ratio vs. nitrogen availability for the five soil management practices

4.4.3 Soil Respiration (SR)

During the soil respiration process, oxygen is consumed by soil microorganisms and carbon dioxide is generated. Since respiration is essential for all life forms in soil, it provides a measure of the soils biological activity (Jacinthe and Lal, 2006). Soil management practices, which favour residue input and decomposition and that minimize respiratory carbon losses, is in due course likely to result in the net increase in soil carbon stocks (Jacinthe and Lal, 2006). The soil carbon stocks for the pedoderm have been calculated for the various soil management treatments (Table 20).

Table 20. Total Soil Organic Carbon (kg.ha^{-1}) of soil pedoderm per soil management treatment

Treatment Name	Soil Organic Carbon (kg C.ha^{-1})
Mechanical	76.96
Chemical	110.88
Straw mulch	133.25
Annual cover crop	80.49
Perennial cover crop	95.26

The incorporation of plant and animal biomass carbon into the soil organic content (SOC) pool relies strongly on the soil microbial processing thereof. Consequently, high levels of microbial activity, which is directly related to soil respiration, suggests an increase in the

SOC pool. The straw mulch treatment obtained the highest soil respiration rate which incidentally also has the highest organic matter content (Table 20 and Figure 17). The mechanical treatment had the lowest soil respiration rate as well as the lowest organic matter content. Both responses are expected since factors that control respiration includes the supply of organic matter to soil microbes. The above responses concur with the general findings of Jacinthe and Lal (2006) that soil respiration increases nearly proportionally with the amount of residue added to the soil. The results from the statistical analysis conducted found notably lower mean values for the chemical and mechanical crop treatments, with the straw mulch and perennial cover crop treatments having higher respiration rates. The determined values below detection limits of the method were removed from the dataset and these results are presented in Figure 17. Oxygen consumed in the treatments with mulch, annual and perennial cover crops were significantly higher than the other two treatments (Figure 18).

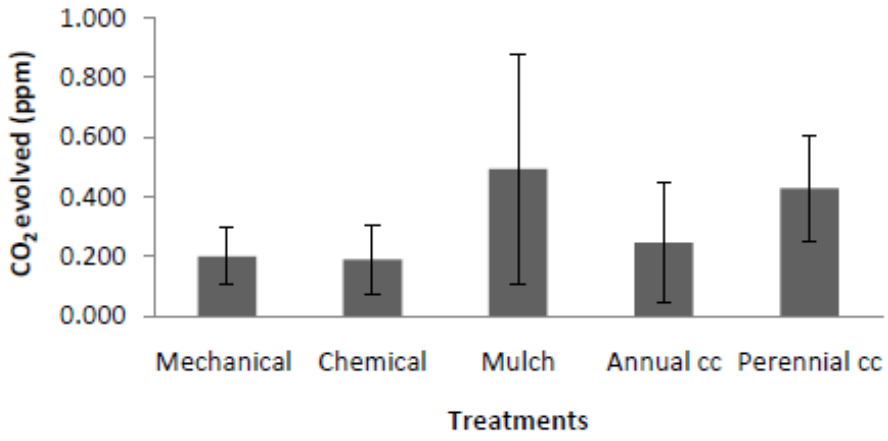

Figure 17. Soil respiration (CO_2 ppm) for the five soil management practices

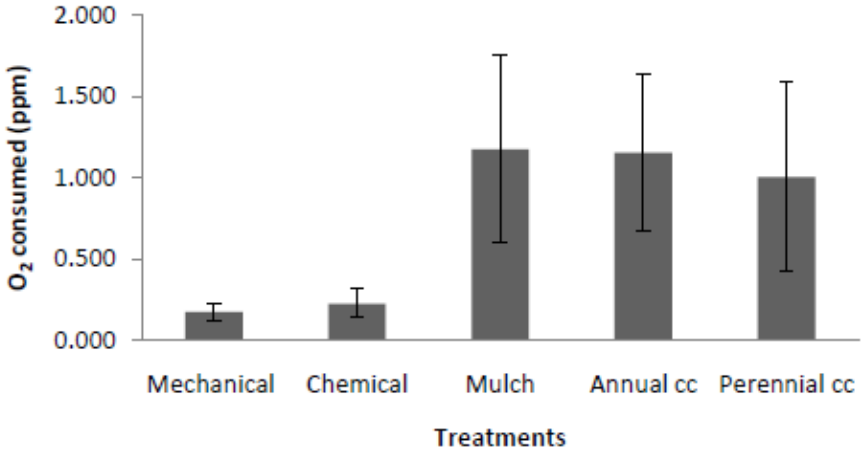

Figure 18. Oxygen consumed during short incubation period for the five soil management practices

The micro-arthropod study did not show any significant difference in mite abundance or diversity in any of the treatment plots (Figure 19). The study identified three collembolan and four mite species which still requires classification. The total amount of micro-arthropods was found to be highest (± 350-400 microanthropods.m^{-2}) in the annual cover crop treatment, with the straw mulch treatment exhibiting the lowest number (below 100 micro-arthropods/m^{-2}) of micro-arthropods. These counts do not compare with soil microbial biomass results or soil organic carbon content, in which the straw mulch treatment plots yielded the highest values in comparison to the rest of the treatments plots. The reason for this occurrence is not clear. The abundance is expected in what are referred to as “hot spots” in the soil. These are zones in the soil located either in the root-rhizosphere, in regions of organic detritus accumulation and also in earthworm-influenced zones (Coleman, 2002).

The earthworm study concluded that no significant differences ($P>0.05$) were found between treatments when earthworms were used as a bioindicator for the Robertson study site over the two years (2008 and 2009). Site T2 did, however, had significantly ($P<0.05$) more earthworms per m^2 than any of the other sites in 2008. It should be noted that the samples from the Eikendal/Lushof/Cordoba generally had the lowest biomass (except site T8 in Robertson in 2008) of all the sampled sites in both years. There were also no cocoons found in this area and only a few juveniles in the shale soils over the two year period (Tables 21 and 22).

It should be noted that the samples from the Eikendal/Cordoba shale area yielded one earthworm each in 2009. There were also no cocoons or juveniles found in this area. The fact that almost no earthworms were found in these sites is a cause for concern which should be further investigated. The history of the management of these soils might provide some insights into the matter.

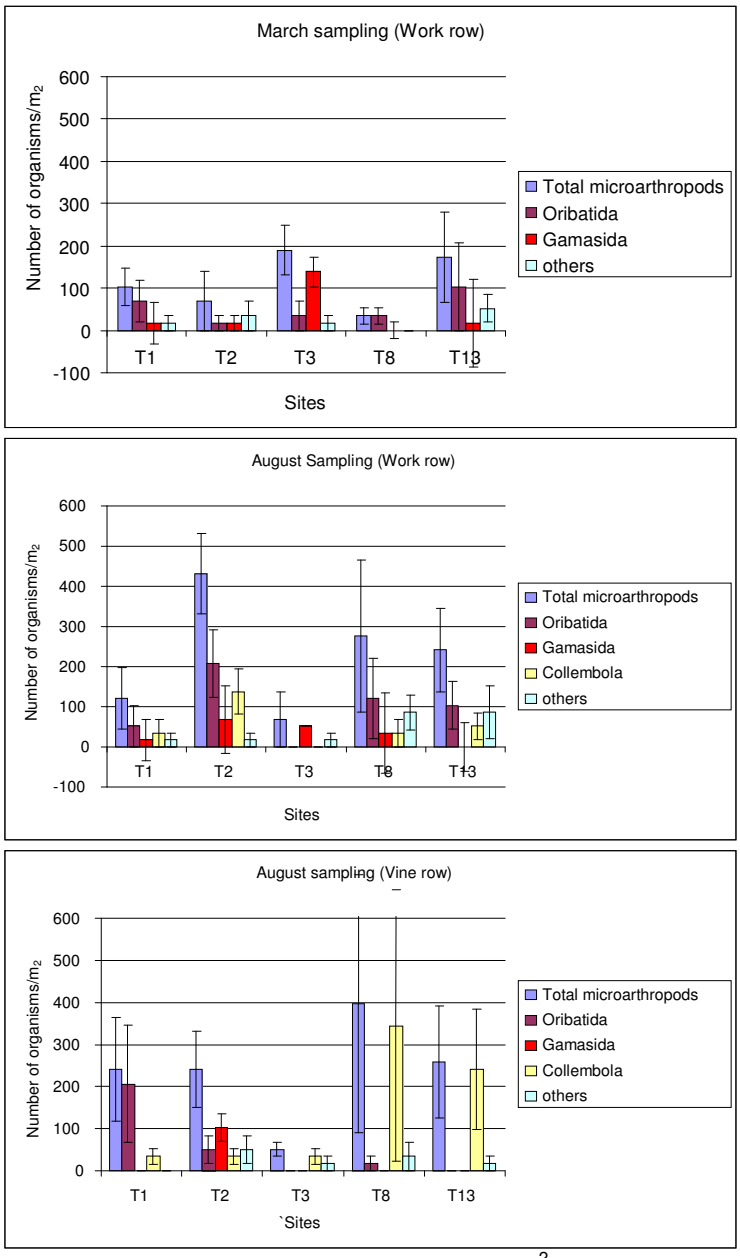

Figure 19. The mean (±SE) number per m^2 of Oribatida, Ganasida, Collembola and other micro-arthropods collected in plots of the five management practices in March and August 2009

Table 21. Mean biomass (adults and juveniles in grams) and number ±SD of earthworms (unidentified spp.) per m^2 in the evaluated plots during August 2008 in the Robertson (T1–T13), Lushof/Cordoba (*significantly different $p < 0.05$)

Sampling area	**Mean biomass**	**Mean number**		
		Adults	***Juveniles***	***Cocoons***
T1	8.17 ± 10.05	20.83 ± 18.82	26.67 ± 21.99	0.00 ± 0.00
T2	21.63 ± 16.98	154.17 ± 55.72*	116.67 ± 75.28	45.83 ± 60.03
T3	12.58 ± 17.11	58.33 ± 108.01	229.17 ± 213.55	25.00 ± 41.83
T8	4.54 ± 7.79	20.83 ± 18.82	34.67 ± 25.16	2.67 ± 5.96
T13	23.83 ± 28.63	95.83 ± 100.52	70.83 ± 73.51	8.33 ± 12.06
Eikendal & Lushof - Granite	4.96 ± 8.11	12.50 ± 20.92	0.00 ± 0.00	0.00 ± 0.00
Eikendal & Lushof – Shale	5.54 ± 8.84	25.00 ± 38.73	4.17 ± 10.21	0.00 ± 0.00

Table 22. Mean biomass (adults and juveniles in grams) and number ±SD of earthworms (unidentified spp.) per m^2 in the evaluated plots during September 2009 in the Robertson (T1–T13), Lushof/Cordoba (*significantly different $p < 0.05$)

Sampling area	**Mean biomass**	**Mean number**		
		Adults	***Juveniles***	***Cocoons***
T1	3.81 ±2.31	21.33 ± 19.96	26.67 ± 21.99	0.00 ± 0.00
T2	5.85 ± 4.38	53.33 ± 66.40	72.00 ± 45.02	18.67 ± 26.8
T3	6.51 ± 4.20	74.67 ± 43.98	77.33 ± 71.80	13.33 ± 21.27
T8	6.33 ± 4.70	13.33 ± 19.41	34.67 ± 25.16	2.67 ± 5.96
T13	6.92 ± 3.90	66.67 ± 60.16	40.00 ± 27.33	5.33 ± 13.06
Cordoba & Lushof - Granite	6.21 ± 3.08	16.00 ± 16.00	0.00 ± 0.00	0.00 ± 0.00
Cordoba & Lushof – Shale	11.68	2.67 ± 5.96	0.00 ± 0.00	0.00 ± 0.00

4.5 DISCUSSIONS AND CONCLUSIONS

4.5.1 Soil Microbiology

Results illustrated that fungal diversity is consistently lower compared to bacterial diversity during the two-year period. Overall microbial diversity showed a decrease from 2009 to 2010. Microbial diversity did not significantly differ between the various treatments.

Microbial diversity: Seasonal effects

Fungal diversity was similar during the growing seasons with the exception of T13. This treatment had the lowest fungal diversity but the highest diversity during winter. A similar trend was observed for bacterial diversity during 2009. However during 2010, bacterial diversity under this treatment was highest during the growing and decreased during winter. As this treatment is a permanent cover crop (rye grass), the shifts in microbial diversity are probably due to seasonal causes. The most prominent shift in microbial diversity for all treatments was observed between growing and winter season of 2010. Bacterial diversity decreased in winter although these shifts were not significant. Compared to T1, most of the other treatments had higher diversity.

Microbial diversity: Treatment effects

Treatment effects were most prominent when bacterial diversity was compared during 2010. All treatments showed major decreases during the winter season. The highest bacterial diversity was observed under T3 (mulch) and the lowest under the T1 (clean cultivation). During 2009 mulch treatment was the only treatment that remained constant over the two

seasons. The lowest bacterial diversity was observed under the control treatment during the growing season and the highest under T2 (full surface chemical control).

Microbial community structure: Seasonal effects

Microbial community structure was significantly different between all treatments only during the growing seasons of both years with no differences during winter.

Microbial community structure: Treatment effects

Fungal and bacterial community structure showed significant differences between various combinations of treatments, while most of the differences occurred during 2009. Over the two years, the most significant differences in community structure was observed between T2 (full surface chemical control) and T3 (mulch) during all seasons.

4.5.2 Soil Physical Properties

In this study, the soil quality of the pedoderm was characterised by analyzing the selected soil quality indicators and comparing the indicator values with the optimum value required for optimum crop (vine) growth. None of the treatments had limiting physical properties for vine growth. In terms of soil quality, none of the physical conditions created by the treatments resulted in unfavourable soil conditions or quality for crop growth.

4.5.3 Soil Chemical Properties

The optimum pH (H2O) for vineyards range between pH 6-7 (FSSA, 2007), where the treatments pH range from 6.88 to 7.8. This range is suitable for most crops, though slightly alkaline (FSSA, 2007).

The electrical conductivity of the treatments is also within a range that is not harmful to vineyards. The differences observed amongst treatments in terms of the EC, were mostly accounted for by the differences in terms of water holding capacity brought about by the higher organic material accumulation of the straw mulch treatment. As a result, more dissolved salts are present due to the water held by organic matter. It needs to be emphasized that the average EC of the straw mulch treatment is way below the threshold value for viticultural soils.

Nitrogen is applied annually in the form of 50 $kg.ha^{-1}$ LAN, irrespective of vine vigour, to ensure optimum production of dry material. As mentioned earlier, the phosphorous content required for optimal vineyard growth is relatively low. The measured P content in the mechanical, straw mulch and perennial cover crop treatments are double the norm for viticultural soils. Regarding the potassium levels in the various treatments, where potassium levels are higher than 120 $mg.kg^{-1}$, no production management intervention is required.

Organic matter content is not a direct requirement for crop production and at present no norms are available for optimum organic content levels for viticultural soils. The organic matter content as an indicator remains an essential component in the minimum data set due to the direct effects OM content have on overall functionality. Monitoring the accumulation of organic matter in soil due to agricultural practices is beneficial to providing evidence of carbon being sequestered as a result of certain practices.

Generally, the chemical indicators of soil quality measured require no management intervention to obtain optimum soil quality conditions for optimal vine growth. No noticeable differences were found within the treatments in terms of the measured indicators, versus the desired optimum value for the respective indicator.

The study also paid special attention to possible differences in soil quality, which could be the result of agricultural traffic (this includes any form of compaction induced by traffic on the treatment plots). It is widely known that vehicle traffic has direct impacts on soil physical properties such as reducing pore space and increasing the bulk density of soils (Raper, 2004). With the regard to soil chemical properties, the chemical indicators, N and OM content was generally higher *In* tracks than *Between* tracks. The exchange cations measured (Ca, Mg, Na and K) all had higher values for *Between* tracks than *In* tracks. The accumulation of these nutrients *In* tracks could be as a result of the impact of agricultural vehicle traffic, which causes compaction, thus restricting the amount of possible movement of these nutrients deeper in the soil horizon. This occurrence is also more prevalent within the pedoderm of conservation soil management type where pedodermal expression is known to be maximal (Fey et al., 2006).

4.5.4 Soil Biological Properties

Interpreting the soil biological indicators in this study was done with respect to the indicators effect on overall soil function. The soil microbial biomass is related to the microbial catalytic potential and repository for C and N function of soil. Thus SMB should be interpreted as

effects on this function. The high SMB found in the straw mulch treatment suggests more active functioning microbes essential catalytic functions in soil. This corresponds with the determined respiration rate. This response provides a factor when assessing biological properties in that respiration rate should be done so in relation to the amount of fuel (organic matter content) for the process of respiration i.e. comparing total soil carbon content with that of the amount of C losses (CO2) due to respiration.

Soil productivity and N supplying potential is indicated by soil PMN. Generally soils with high levels of nitrogen-rich organic matter have the highest populations of microbes involved in nitrogen mineralization and the highest PMN rates (Gugino et al., 2007). This was not the case in the study with the exact opposite occuring where the treatment which had the highest organic matter content exhibited to lowest PMN rate. Reasons for this occurrence is not clear, but could be related to the method of determination conducted on the extract or the duration of the incubation period.

The soil faunal study, consisting of micro-anthropods and earthworm adundance, was thought to be useful to compare the faunal counts with the various soil biological indicators. The micro-anthropod study concluded that the annual cover crop treatment yieled the highest number of micro-anthropods, which was not expected given the high soil microbial activity in the straw mulch treatment,which was expected to also have the most abundant microoanthropods.

4.6 CONCLUSIONS

4.6.1 Soil microbiology

- Fungal diversity under the various treatments remained consistent over the two years of sampling.
- Bacterial diversity was consistent over the first three sampling times and decreased significantly during the winter season of 2010.
- Bacterial and fungal community structure differed significantly over the two year period with dissimilarities between seasons.
- The most profound dissimilarities in bacterial community structure were observed between mulch, clean cultivation and chemical weed control treatments.
- The soil surface treatments applied to the vineyard caused significant shifts in microbial community structure, highlighting the effect of land management practices on agricultural soil.
- The soil surface treatments had no effect on the enzyme activity.

4.6.2 Soil physical, chemical and biological properties

- None of the treatments had limiting physical properties in terms of vine growth.
- In terms of soil quality, none of the physical conditions created by the treatments resulted in unfavourable soil conditions or quality for crop growth.
- Of the chemical indicators measured, none yielded values below the specific indicator threshold values, thus no management intervention is needed to obtain optimum soil quality conditions, for optimal vine growth.
- In terms of the biological indicators, the high soil microbial biomass and soil respiration found in the straw mulch treatment, suggests that there are more active functioning microbes, microbes essential for catalytic functions in soil.
- It was expected that the straw mulch treatment would yield the highest PMN rate. However, this was not the case in the study with the exact opposite occuring where the treatment, which had the highest organic matter content, presented to lowest PMN rate. Reasons for this occurrence is not clear, but could be related to the method of determination conducted on the extract or the duration of the incubation period.
- The earthworm study concluded that no significant differences were found between treatments when earthworms were used as a bioindicator over the two years (2008 and 2009).
- The microanthropod study concluded that the annual cover crop treatment yielded the highest number of micro-anthropods, which was not expected given the high soil microbial activity in the straw mulch treatment.

4.6.3 Agricultural traffic within the treatment plots

- With the regard to soil chemical properties, the chemical indicators, N and OM content was generally higher *In* tracks than *Between* tracks.
- The exchange cations measured (Ca, Mg, Na and K) all had higher values for Between tracks than In tracks. This occurrence was found to be more prevalent within the 0-50 mm soil depth, a feature common in conservation type soil management where pedodermal expression is greatest.
- Overall, the treatment that can be rated most sustainable in terms of the yielding the most desired soil quality, was the straw mulch treatment.
- The land use sustainability of the other treatments did not yield results below the threshold values.

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5. Accumulated outputs

List ALL the outputs from the start of the project.
The year of each output must also be indicated.

Technology development, products and patents

Indicate the commercial potential of this project (intellectual property rights or a commercial product(s)).

Human resources development/training

Indicate the number and level (e.g. MSc, PhD, post doc) of students/support personnel that were trained as well as their cost to industry through this project. Add in more lines if necessary.

Ms Ilse Mathys obtained her MSc (Soil Science), March 2011.

	Student level (BSc, MSc, PhD, Post doc)	Cost to project (R)
1.	MSc (Soil Science)	R60000
2.		
3.		

Publications (popular, press releases, semi-scientific, scientific)

MSc thesis

Soil health and quality concept in agricultural extension and soil science. An assessment of topsoil conditions in a long-term vineyard soil management trial in Robertson, South Africa

Presentations/papers delivered

Presentations

K. JACOBS, E. SLABBERT, O. CALEB, M. LILLY, C.J. VAN HEERDEN & K.R. DU PLESSIS, The use of ARISA as tool to characterize microbial communities from the environment. 46th Congress of the Southern African Society for Plant Pathology. 25-28 January, 2009.

Posters presentations

P.H. TITUS, K.R. DU PLESSIS, A.H. MEYER & K. JACOBS, Microbial Community Structure in Vineyard Soil Under Different Management Practices. 47th Congress of the Southern African Society for Plant Pathology. Kruger National Park, RSA. 23-26 January, 2011.

4. Total cost summary of project

	Year	CFPA	Deciduous	DFTS	Winetech	THRIP	Other	TOTAL
Total cost in real terms for year 1								
Total cost in real terms for year 2								
Total cost in real terms for year 3								
Total cost in real terms for year 4								
Total cost in real terms for year 5								
TOTAL								