THE EFFECT OF MULCHING ON TREE PERFORMANCE AND FRUIT QUALITY OF 'CRIPPS' PINK' APPLES

BY

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously, in its entirety or in part, been submitted at any university for a degree.

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Signature   Date

SUMMARY

Three field trials were conducted to investigate the effects of mulching on the chemical and biological aspects of the soil as it is reflected by tree performance and fruit quality in 'Cripps' Pink' orchards.

In the two trials at Lourensford Estate, where only the soil type differed between sandy silt loam (sandy) and heavy silt loam (heavy), mulches where used as an additive to the soil surface together with a standard, commercial, inorganic fertilization program. Four different mulch types: compost, wood chips, vermi-compost and a geotextile fabric, were compared to a bare surface control in a randomized complete block design.

At the heavy silt loam site (site 1), the wood chips treatment was the most effective in regulating diurnal soil temperatures in the top 10 cm of soil (2009/10), whereas all mulches regulated average diurnal soil temperature similarly and more effectively than the control at the sandy silt loam site (site 2).

After two seasons of treatment at site 1, the vermi-compost treatment significantly increased soil phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), zink (Zn) and boron (B) significantly compared to the control. The wood chips treatment increased Na, K and Ca and compost only increased soil K significantly compared to the control. For site 2, only wood chips (Na and K) and vermi-compost (Na, K and Mg) showed significant increases in soil nutrient elements compared to the control.

Yield efficiency was significantly increased by the wood chips (both seasons) and vermi-compost (only 2009/10) treatments compared to the control in site 1. In site 2, none of the treatments differed significantly in yield efficiency compared to the control treatment.

The number of roots and fine feeder roots were increased (not sign) by the wood chips and geotextile treatments compared to the control. In site 1, all treatments improved the number of roots compared to the control treatment, in contrast with site 2, where the number of roots of the control, compost and vermi-compost treatments was more similar.

Fruit quality showed significant differences between the wood chips and vermi-compost treatments compared to the geotextile and control treatments for malic acid, at site 1, at harvest in 2009. This did not differ significantly from the compost treatment.

Leaf mineral analysis only showed significant differences at site 2, in 2010, with significantly increased for the following minerals and treatments: Mn (compost and geotextile treatments versus other treatments), Fe (control treatment compared to all treatments except compost), Zn (compost compared to all other treatments) and B (control and compost versus vermi-compost, wood chips and geotextile).

Fruit mineral analyses showed no differences between treatments at harvest 2009 for either site and 2010, for site 1. At site 2, the Ca percentage of fruit from the wood chips treatment was significantly higher than that of all treatments, except the geotextile treatment.

Only in the 2010 analysis at site 2, the mycorrhizal colonization was significantly influenced, where all the mulching treatments showed an increase compared to the control. However, the same trend was observed at site 1.

At site 1and 2, the compost, wood chips and vermi-compost treatments in general showed a decreasing trend in percentage plant parasitic and increasing trend in percentage free living nematodes from 2009 to 2010. In general, the geotextile and control treatments showed an increasing trend in the percentage plant parasitic and decrease in percentage free living nematodes. However, this was not the case at 0 – 15 cm soil depth for site 1.

In the third trial, at Elgin Experimental Farm (Elgin), bare surface chemical control was compared to mulching in the tree row (mulch) and mulching together with regular application of compost tea (mulch + compost tea). All treatments were combined with different inter row management practices to compose a total of eight different treatments. In the tree row, the control treatment received standard rates of inorganic fertilizer, which was compared to the mulched only treatment.

Both the percentage of soil carbon and cation exchange capacity was significantly increased by all the mulch treatments compared to the control. Furthermore, all the mulches increased various soil minerals significantly, however of which only P was significantly increased in both the leaves and fruit. The rate of soil microbial activity and mycorrhizal root colonization was significantly increased by mulching treatments, but resulted in a significantly lower yield efficiency compared to the inorganic control treatment. This can be ascribed partly to the microbial activity of the compost mulch during spring, although it was not quantified *per se* and to the increase in tree vigour at the end of the trial. The slow rate of N mineralization was reflected indirectly by the significantly lower fruit N for the mulched treatments and the lower rate of microbial activity during spring at this site. With regards to the addition of the compost tea, no significant contributions were evident in terms of tree performance, soil minerals or microbial activity over a period of seven years, compared to the application of mulch only.

Compared to the trial at Lourensford Estate, with no significant differences in fruit mineral composition between treatments after two years, fruit mineral analyses of the Elgin trial showed significant differences between treatments after six (2009) and seven (2010) seasons for P for some treatments. Only in 2010 more treatments showed significant differences for N, Mn, Fe and Zn as well.

Regarding fruit quality, in agreement with the results at Lourensford Estate, differences were not persistent across all seasons for treatments.

OPSOMMING

Veldproewe is geloods om die effek van verskillende deklae op grond chemiese en – biologiese aspekte en die effek daarvan op boom prestasie en vrugkwaliteit in ‘Cripps’ Pink’ appelboorde te ondersoek.

In die eerste twee proewe te Lourensford Landgoed, waar slegs die grondtipe verskil het tussen die sanderige slik leem (ligter) en swaarder slik leem (swaar) gronde, is deklae toegedien saam met ‘n standard bemestingsprogram en mikro-besproeiingstelsel. Vier deklaagtipes: kompos, houtspaanders, vermi-kompos en geotekstiel material, is vergelyk met die onbedekte, skoon bewerkte, kontrole in ‘n total ewekansige blokontwerp.

By die swaar grondtipe (perseel 1), was die houtspaanderbehandling die effektiefste om die daaglikse skommelings in grondtemperatuur te reguleer in die boonste 10 cm, teenoor die sanderige perseel (2), waar al die deklae die daaglikse grondtemperatuur meer effektief as die kontrole behandeling gereguleer het.

By perseel 1, het die vermi-behandeling ‘n betekenisvolle toename getoon teenoor die kontrole behandeling in grond fosfaat (P), kalium (K), kalsium (Ca), magnesium (Mg), natriuim (Na), mangaan (Mn), sink (Zn) en boor (B). Alhoewel dit nog nie tans gekwantifiseer kan word nie, is ‘n gedeelte van die toename heel moontlik te wyte aan die

samestelling van die deklaag. Die houtspaander- en komposbehandelings het ‘n betekenisvolle verskil in toename tot gevolg gehad in grond K en Na in vergelyking met die kontrole. In die geval kan die toename van die komposbehandeling aan die invloed van die sampestelling van die deklaag toegeskryf word, maar nie in die geval van die houtspaanderbehandeling nie. Die geotekstielbehandeling het, soos verwag, nie betekenisvolle verskille ten opsigte van die kontrole getoon nie, aangesien die samestelling van die geotekstielmateriaal nie voedingstowwe tot die grond kan toevoeg nie. By perseel 2, het beide die houtspaander- en geotekstielbehandelings betekenisvolle toenames in grond elemente (K, Mg) getoon teenoor die kontrole behandeling. Die ander elemente het nie noemenswaardige verskille teenoor die kontrole getoon nie. Weer eens kan die toename in die vermi-kompos toegeskryf word aan die samestelling van die deklaag, maar nie in geval van die houtspaanders nie, wat ‘n moontlike rol van ander faktore soos temperatuur en grondvog in die opname en beskikbaarheid van voedingselemente toon.

Op 30 cm diepte in perseel 1, het die vermi-kompos behandeling betekenisvolle hoër Na, K, Mg en P getoon as die kontrole. Die houtspaanderbehandeling het betekenisvolle hoër Na, K en Ca getoon as die kontrole. Geen een van die ander behandelings het enige betekenisvolle veranderinge ten opsigte van voedingselemente getoon nie. Vir perseel 2 by die gronddiepte, het die houtspaanderbehandeling betekenisvolle toenames in grond Na en K getoon teenoor die kontrole. Geen van die ander behandelings het enige betekenisvolle veranderinge ten opsigte van voedingselemente getoon nie. By hierdie dieper gronddieptes is ‘n soortgelyke verandering in elemente waargeneem as by die vlakker gronddieptes vir perseel 1, in geval van P en K. Mg en Na het volgehoue verandering vir die vermi-komposbehandeling in die dieper gronddieptes getoon vir die makro-elemente, maar nog nie in geval van mikro-elemente nie. In perseel 2 – het toenames in K en Mg in die vermi-komposbehandeling ook voortgeduur en die veranderinge vir beide persele mag toegeskryf word aan die samestelling van die deklae *per se*. Dit blyk dat die veranderinge in die komposbehandeling nie so konstant voorgekom het in die materiaal wat in die proewe toegedien is nie. Nietemin kan die kompos- en vermi-komposbehandelings ook ander grond faktore beïnvloed en die bydra van die minerale elemente afkomstig uit die samestelling van die deklaag moet eers bereken word alvorens afleidings gemaak word.

By beide persele het die komposbehandeling die opbrengseffektiwiteit verminder in vergelyking met die kontrole behandeling. Die opbrengseffektiwiteit is betekenisvol verhoog in die houtspaanderbehandeling (beide seisoene) en vermi-komposbehandeling (net 2009/10) in vergelyking met die kontrole in perseel 1. In perseel 2 het teen behandeling betekenisvol in opbrengseffektiwiteit verskil ten opsigte van die kontrole nie.

Die aantal wortels en fyn, voedingswortels het ‘n dramatiese (nie-betekenisvolle) toename getoon by die houtspaander- en geotekstielbehandelings. In perseel 1 het alle behandelings die aantal wortels verhoog ten opsigte van die kontrole in kontras met perseel 2, waar die aantal wortels in die kontrole, kompos- en vermi-komposbehandelings ongeveer dieselfde was.

Stamwaterpotensiaal het onveranderd gebly ongeag van die behandeling, wat moontlik beïnvloed is deur die hoë besproeiingskedulering siklus. Geen verskille tussen behandelings of persele is gevind nie.

Alhoewel dit net in die tweede seisoen (2010) gemeet is, was daar geen betekenisvolle verskille in gemiddelde loot groei van eenjaarlote tussen die behandelings of persele nie.

Vrugkwaliteit het betekenisvolle verskille getoon in appelsuur (malic acid) in die houtspaander- en vermi-komposbehandelings teenooor die geotekstie- en kontrole behandelings in perseel 1, by oes 2009. Laasgenoemde het nie betekenisvol van die kontrole behandeling verskil nie. Hierdie verskille het nie na opberging voortgeduur nie. Geen betekenisvolle verskille in vrugkwaliteit het voorgekom by perseel 2, tydens oes, of na opberging nie. Gedurende oes 2010, asook na opberging, is geen verskille in vrugkwaliteite van enige persele opgemerk nie.

Behandelingsverskille in blaar-analises is waargeneem tussen vermi-kompos- en die ander behandelings, met uitsondering van die geotekstielbehandeling in Februarie 2009, perseel 1. Geen ander betekenisvolle verskille vir enige element het voorgekom tussen behandelings in perseel 2 nie. Gedurende 2010 is geen betekenisvolle verskille tussen behandelings ten opsigte van blaar-analises gevind vir perseel 1 nie.

Betekenisvolle verskille in blaar- en vrugmineraal-analises was in perseel 2 teenwoordig as volg: Mn (kompos- en geotekstielbehandelings teenoor al die ander behandelings), Fe (kontrolebehandeling teenoor alle ander behandelings behalwe die komposbehandeling), Zn (komposbehandeling teenoor al die ander behandelings) en B (kontrole en komposbehandelings teenoor vermi-, houtspaander- en geotekstielbehandelings (gedurende 2010.

Die vrugmineraal-analises het geen verskille getoon tussen behandelings by oes 2009 vir enige perseel, of 2010 vir perseel, 1 nie. By perseel 2 was die Ca persentasie in die vrug in die houtspaanderbehandeling betekenisvol hoër as die van die ander behandelings, uitgesonder die geotekstielbehandeling.

By perseel 1, het al die behandelings die persentasie mycorrhiza-kolonisasie verhoog in vergelyking met die kontrole, alhoewel dit nie betekenisvol was nie. By perseel 2 was daar wel ‘n betekenisvolle toename in die persentasie mycorrhiza-kolonisasie by al die deklaagbehandelings in vergelyking met skoonbewerking van die kontrole behandeling.

Die persentasie plant-parasitiese nematodes was baie variëerend met gronddiepte by beide persele. Die houtspaander- en vermi-komposbehandelings in perseel 1 het ‘n afwaartse tendens getoon in die persentasie plant-parasitiese en toename in persentasie vry-lewende nematode vanaf 2009 na 2010, in die 0-15 cm diepte. In teenstelling, het die geotekstiel- en komposbehandeling ‘n toenemende tendens getoon in die persentasie plant-parasitiese en klein afname in persentasie vrylewende nematodes vanaf 2009 tot 2010. Geen betekenisvolle verskille in nematode getalle is waargeneem in gronddiepte 15 -30 cm grond in die perseel nie.

In perseel 2 is geen betekenisvolle verskille in aantal nematodes gevind gedurende die twee seisoene tussen behandelings of binne persele op 0-15 cm gronddiepte nie. Nietemin het die houtspaander-, kompos- en vermi-komposbehandelings die persentasie plant-parasitiese verlaag en die van die vry-lewende nematode verhoog vanaf 2009 tot 2010, in vergelyking met die kontrole in die 15-30 cm gronddiepte. Slegs die houtspaanderbehandeling het betekenisvolle verskille getoon teenoor die kontrole. Die geotekstiel- het dieselfde tendens as die kontrole behandeling getoon, met ‘n toename in persentasie parasities- en afname in persentasie vry-lewende nematode. Die kontrole en geotekstielbehandelings het nie betekenisvol van mekaar verskil nie.

Die aantal erdwurms en meso-fauna was baie laag tydens die eerste twee jaar by beide die persele en data is daarom nie statisties verwerk nie.

By die derde proef, is ‘n skoonbewerkte oppervlak, wat chemiese beheer (kontrole) behels het, vergelyk met deklaagbehandelings in die boomry (deklaag) en behandelings waar kompostee saam met die deklaag toegedien was in die boomry (deklaag + kompostee). Al die behandelings is gekombineer met verkillende tussenry behandelings wat ‘n totaal van agt verskillende behandelings behels het. Hierdie verslag konsentreer slegs op die behandelings in die boomry, waar die kontrole behandelings wat ‘n standaard bememestings program ontvang het, vergelyk word met die deklaag behandelings, wat geen alternatiewe bemesting ontvang het nie en as organise alternatiewe beskou word in ‘n ‘Cripps’ Pink’ appelboord. Klem in die verslag is gelê op die hoof effekte van die behandelings op vrugkwaliteit.

Beide die persentasie grondkoolstof en die katioonuitruilkapasiteit het ‘n betekenisvolle toename getoon by al die deklaagbehandelings in vergelyking met die kontrole behandeling. Terselfdetyd, het al die deklaagbehandelings ook verskeie grondminerale betekenisvol verhoog, waarvan slegs P betekenisvol in beide die blare en vrugte verhoog is. Die tempo van grondmikrobe aktiwiteit en micorrhiza-kolonisasie van die wortels is betekenisvol verhoog deur die deklaagbehandelings, maar het gerealiseer in ‘n betekenisvolle laer opbrengseffektiwiteit in vergelyking met die anorganiese, kontrole behandeling. Dit kan onder andere toegeskryf word aan die mikrobe aktiwiteit van die komposdeklaag gedurende die lente – alhoewel dit nie per se in die studie gekwantifiseer is nie, sook die toename in vegetatiewe groeikrag aan die einde van die proeftydperk. Dit is wel indirek gereflekteer deur die betekenisvolle, laer vrug N van die deklaagbehandelings en die laer tempo van mikrobe aktiwiteit gedurende die lente by die deklaagbehandelings op die perseel. Wat die toedienning van kompostee betref, het dit geen betekenisvolle bydra gelewer in terme van gewasprestasie, grondminerale of microbe-aktiwiteit oor ‘n tydperk van sewe jaar in vergelyking met die behandelings waar die deklaag geen kompostee ontvang het nie.

In vergelyking met die proef by Lourensford Landgoed, met geen betekenisvolle verskille in vrug mineral-analises tussen die behandelings oor ‘n tydperk van twee jaar nie, het die proef te Elgin wel betekenisvolle verskille tussen behandelings na 6 (2009) en 7 (2010) jaar getoon in geval van P, vir sekere behandelings (4,7,8 versus 1,2,6). Slegs in 2010 het meer behandelings betekenisvolle verskille getoon vir N, Mn, Fe en Zn.

Rakende vrugkwaliteit - in ooreenstemming met resultate van 2009 vir perseel 1 te Lourensford Landgoed - het beide seisoene betekenisvolle verskille ten opsigte van appelsuur getoon in Elgin. Die verskille het egter nie konstant in al die behandelings voorgekom nie. Stysel afbraak, totaal oplosbare stowwe en fermheid het ook betekenisvolle verskille tussen behandelings getoon in Elgin – maar dit was nie konsekwent oor behandelings of seisoene nie en het ook nie voorgekom in die Lourensford Landgoed persele nie.

DEDICATION

Dedicated to my family

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CONTENTS

This thesis presents a compilation of manuscripts where each paper is an individual entity and some repetition between chapters, therefore, has been unavoidable. The different styles used in this thesis are in accordance with the agreements of different journals that will be used for submission of manuscripts from this dissertation.

General Introduction

The addition of organic material to the soil is generally known to influence some of the soil's physical, chemical and biological aspects (Trisdal, 1989). Of these, the improvement of soil physical aspects such as texture and structure are seen as the main benefits of organic amendments, as the mineral content of organic materials is known to be low (Shiralipour et al., 1992). Studies have however shown crops could be produced effectively on full organic systems, when these materials are supplied in adequate quantities. However, this method is mainly used for annual crops (Hadas et al., 2004).

When these organic materials are mechanically incorporated into the soil, it is known to enhance the soil biological aspects in various ways (Dick, 1992). These include, increased mineralization rates, a suppression of some diseases and nutrient cycling (Pinamonti, 1998). However, in established orchards, such as in these trials, the incorporation of the materials into the soil is not advised in the tree row, due to the disturbance and possible damage it could cause to roots. In such instances organic materials are amended to the soil surface as mulches (Trisdal, 1989).

With surface applications, the effect of organic material on the soil's physical, chemical and biological aspects is questionable. Nevertheless, studies indicate that the addition of organic mulches decreased the fertilizer requirements (Evanylo et al., 2008), decreased soil bulk density, and increased soil carbon and cation exchange capacity (Tiquia et al., 2002), as well as improved soil structure (Pinamonti et al., 1995).

Additional benefits from mulching include milder and less fluctuating soil temperatures and increased water availability in the upper soil layers (Mathews et al., 2002). Temperature regulation is achieved by the mulching layer buffering the soil layers from direct radiation and thereby reducing the evaporation of soil water (Haynes, 1980). This would allow the roots to grow into the upper soil layers to form a feeding zone of fine roots in an environment rich in oxygen (Trisdal, 1989). This would increases the crop's potential to absorb any additional fertilizer amendments and ensures effective use of fertilizers in order to meet crop demand and produce high quality crops.

The aim of this thesis was to determine if mulching had the ability to influence tree performance combined with fertilized or as an alternative method of organic fertilization. In addition, we aimed at differentiating between various materials on their affectivity when applied as a mulch.

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Literature Review

The effects of mulching on certain soil aspects and tree performance

1. Introduction

In comparing many soil management practices, Trisdal (1989) found that frequent tillage reduced the amount of organic carbon (C), nitrogen (N) and sulphate (S), in the surface soils and reduced the physical properties of these soils. In some cases, tillage even tended to decrease the yield due to damage to the roots. Compared with covered soils, bare surfaces also reduced the amount of organic C. Regarding these findings, alternative methods are needed to suppress weeds in orchards, due to the concerned effects of herbicides and soil tillage on the environment and crop performance (Merwin & Brown, 2009). In general, a management system should cause as little disturbance as possible to the soil and the biological activity should be preserved. The system used should increase organic material in the soil, enhance aeration to the roots and reduce the loss of moisture (Pinamonti *et al*., 1995). Mulching provides such a system. A mulch can be defined as any material forming a protective cover over the surface of the soil (Walsh *et al*., 1996).

Forge *et al*. (2003) indicated that, a large variety of organic materials can be used as mulches to improve crop performance in various ways. He found that the yield and growth was increased in apples in high density productions systems by using a simple mulch like shredded office paper. In general the mulching also reduces evaporative water loss from the soil surface to enhance root growth in this area. Mathews *et a*l. (2002) found that, the positive effects which organic mulches had on the soil temperature regulation and moisture preservation were more important than the material itself as a source of mineral N supply. Nevertheless, the availability of minerals for plant uptake may also be affected by the application of mulches mainly through its effect on the soil biological aspects.

Suppression of some diseases, mineralization rates and nutrient cycling as know as the most important biological aspects influenced by the soil food web with the addition of organic material to the soil (Pinamonti, 1998). Nematodes are the most abundant multi-cellular organism on the earth and are ubiquitous within the soil food web as they take part at different trophic levels (Ferris *et al*., 2001). Since nematodes are easily classified, compared to techniques using DNA analysis, analysing nematode communities provides an easy method to determine the status of the soil food web (Forge *et al.*, 2003).

2.1 Soil

2.1.1 Soil Water

A major factor in apple quality is fruit size. Since fruit size is greatly influenced by water deficit, it is recommended that water supply be optimized to enhance the number of large fruit (Naor *et al.*, 1997).

On soils where herbicides are used to control the weeds, a crust may form on the bare surface. This crust may cause low infiltration of water and high runoff rates. When these bare soils are on a slope, runoff can cause erosion (Trisdal, 1989). Organic mulches can reduce the impact of raindrops on surface sealing and thereby increase the infiltration tempo. This way erosion is reduced by the increased water infiltration rate and the decrease in runoff velocity (Smets *et al.*, 2008). In frequently tilled soils, initial water infiltration is high in the loose soil. Thereafter it is restricted by the subsoil with small pores. Further infiltration rates will then be controlled by the subsoil. Crusts tend to form in the subsoil when upper soils are tilled extensively. This will restrict penetration by water and roots (Trisdal, 1989). In contrast, simple mulches such a straw has shown to increase soil aggregate stability, which improved the soil permeability for water penetration and aeration to the deeper layers (Pinamonti *et al*., 1995).

Organic mulches, such as straw, have further shown to increase the amount of available water in the soil (Trisdal, 1989), by reducing evaporation from the soil surface (Pinamonti *et al*., 1995). This will reduce moisture stress between irrigations and can even increase irrigation intervals (Baxter, 1970). In addition the availability of water in the surface layers, which are prone to drought conditions, would enable root to utilize this area and effectively increase the rootn zone (Trisdal, 1989; Pinamonti *et al*., 1995).

Accordingly, Wooldridge (1992) announced that, a straw mulch applied on ridges in an pear orchard expanded irrigation intervals with more than double, compared to herbicide control, causing a 45% decrease in the total amount of water used for irrigation through the season.

Furthermore, Trisdal (1989) indicated that weeds can also be controlled effectively with organic mulches. Weed control is important since they are able to compete for water and minerals within the same root zone as the crop (Brown & Tworkoski, 2004). However, the thickness of the mulch will strongly influence the abundance of weeds present (Walsh *et al.*, 1996). Accordingly, green mulches have also shown to reduce crop yields, as they increase the total nutrient (especially N) and water demand within in the same root zone (Trisdal, 1989).

2.1.2 Soil temperature

Gur *et al.* (1972) stated that the optimum root growth temperature for several apple rootstocks seems to be near 25°C. Furthermore, he reported that increased supra optimal root temperatures of 35°C caused anaerobic respiration in the roots, with the formation of acetaldehyde and ethanol due to a lack of oxygen supply. These products are transported upwards in the tree and cause damage to the leaves. Symptoms in the leaf can be detected by a decrease in chlorophyll content and the formation of intervenous necrosis. Gur *et al.* (1972) announced that these supra optimal root temperatures are also responsible for a decrease in the production of cytokinin in the roots.

In summer, upper soil temperatures can be very high. This will have an effect on the activity of the roots and even kill some finer roots (Trisdal, 1989). Pinamonti *et al.* (1995) found a compost mulch to regulate the temperature of soil by reducing the daily range and creating a more constant temperature suitable for root activity. The ability of organic mulches to regulate the soil temperature is closely correlated with its ability to reduce evaporative water loss (Othieno, 1971). The combined effects of water availability and temperature regulation will increase the effective utilization of the soil surface layers for mineral uptake (Othieno, 1971; Trisdal, 1989).

Mathews *et al.* (2002) reported that a synthetic mulch controlled evaporative water loss as effective as organic mulches, but it lacked some of the other benefits organic material had on the soil. According to Glover *et al.* (2000), addition of organic material with mulching together with the effect of water availability in the soil will influence the soil biological aspects such as, nutrient cycling and mineralization rates which could further increase crop performance (Wooldridge, 1992).

2.1.3 Soil mineral content

The two main forms in which N is applied to the soil as inorganic fertilizer, are ammonium (NH_4^+) and nitrate (NO_3^-). These two forms have different effects on the soil, availability of other elements and the morphology of the root system. The pH of the soil is strongly influenced by the source of N; NO_3^- causes the pH to rise, whereas NH_4^+ will cause a decrease. When N is applied entirely as NH_4^+, it causes a reduced absorbance of potassium (K), phosphorus (P), magnesium (Mg), calsium (Ca), manganese (Mn) and iron (Fe) when compared to N applied entirely as NO_3^- (Bhat, 1983).

The source of N applied to apples will influence the root morphology. With NO_3^- as the only source, the plant will form long and thin roots with very little root hairs. Whereas NH_4^+ as the only source, causes short and thick roots, covered in long thin root hairs over their entire length. NO_3^- creates roots with well spread lateral branches, whereas NH_4^+ causes roots to form clusters. The volume of soil explored by the root system can thus be greatly influenced by source of N applied. This will have an indirect effect on the absorption of other minerals (Bhat, 1983).

Mulches can be made from different organic materials with variable properties. This can cause mulches to have different effects on the soil food web, as well as the mineralisation of the elements such as N and P (Forge *et al*., 2003).

Lakatos *et al*. (2001) stated that nearly all the transformation of N and C from organic material is done by microorganisms in the soil. These microorganisms also play a significant part in the availability and transformation of minerals like Ca, Mg, P, Mn, K, Fe and zink (Zn), and will therefore influence plant nutrition (Lakatos *et al*., 2001). Applying a manure mulch to the surface will increase the number of nitrification - and cellulose degrading bacteria in the soil (Lakatos *et al*., 2001).

Microbial decomposition of organic materials like animal manure or bio-solids with high amounts of N will result in a high level of N mineralization (Forge *et al*., 2003). Shredded paper and sawdust decomposition will result in N immobilisation, because of the greater C:N ratio (Forge *et al*., 2003). However, the extend of such immobilisation is not known when these high C organic materials are applied as a mulch to irrigated orchards together with N fertilization (Forge *et al*., 2008). Neilsen *et al*. (2003) found that N immobilisation can be overcome when the orchard was regularly fertigated together with the mulch.

On coarse-textured soil, high density apple orchards under drip irrigation are likely to develop deficiency symptoms of K due to the depletion of K from the soils. The application of an alfalfa mulch to such soils has shown to inhibit the tendency of K-depletion (Neilsen *et al*., 2003). The concentrations of Ca, K and Mg, together with root development, are increased in the upper soil layer using a sawdust mulch (Szewczuk & Gudarowska, 2004).

Trisdal *et al*. (1978) stated that the addition of organic material to soil seems to be the only practical method to increase the stability and structure of soil aggregates. When soil is frequently tilled, the organic C is removed from the soil through oxidation (Trisdal, 1989). Organic mulches will influence the physical properties of soil by causing an increase in the soil organic matter, porosity and cation exchange capacity (Merwin & Brown, 2009), but decrease the bulk density in the soil (Mathews *et al*., 2002). Mulching with organic material increases the aggregate stability and structure of soil (Smets *et al*., 2008). This will reduce erosion by wind (Walsh *et al*., 1996).

All of these physical aspects will have an effect on the availability of nutrients to the plant and therefore influence growth (Mathews *et al*., 2002).

Neilsen *et al*. (2004) stated that the increase in available mineral content of the soil associated with organic mulches, in combination with enhanced microbial activity and root development may, in part, be responsible for the improved yield and growth of apples.

St. Laurent *et al*. (2008) compared the effects of four different ground management systems (GMS) after 14 years. The GMS were: pre-emergence herbicides; post-emergence herbicides; mowed sod grass; and bark mulch. The bark mulch increased soil moisture content, soil organic matter and mineral concentrations of Fe, Mn, Ca and P compared to the other three GMS.

2.1.4 **Soil microbial**

2.1.4.1 Earthworms

In soils that are being tilled, the number of earthworms is reduced. This is mainly a result of the oxidation of organic C which reduces the availability of food for the earthworms (Trisdal, 1989). In contrast Cockroft & Trisdal (1978) stated that mulch with a an organic material, such as straw, caused an increase in the number of earthworms present in the soil. Earthworms are important for their role in mixing fertilizers, insecticides and organic residues into the soil. The incorporation of organic material to the deeper soil layer is vital since the desired positive effects associated with organic material are required over the entire rooting area. Water infiltration and aeration is furthermore improved by the continuous pores formed from the subsoil to the soil surface by earthworms (Trisdal, 1989).

2.1.4.2 Arthropods

The use of some herbicides is extremely toxic to some arthropods and predatory spiders (Mathews *et al*., 2002). Practices such as soil tillage may reduce the abundance of soil macro fauna with as much as 50% (Mathews *et al*., 2002). Mulching with synthetic - or organic material is seen as an alternative method for managing the orchard understory. The addition of an organic mulch to the soil increased the micro flora and micro fauna activity in the soil. These additional organisms can be seen as prey for general predators (Mathews *et al*., 2002).

Brown & Tworkoski (2004) found the number of herbivorous pests to decrease because of an increase in predators when compost is applied as a mulch. These herbivores are reduced in the part of their life cycle they spend in the soil and are exposed to the predators. Apple orchards treated with a compost mulch showed an increased rate in the predation of codling moth (Brown & Tworkoski, 2004). Compost mulches also proved to be effective in reducing fungal and arthropod pests in apple orchards (St. Laurent *et al*., 2008). The application of compost mulches can help in the suppression of some plant soil diseases such as apple scab, by reducing the build-up of inoculum (Brown & Tworkoski, 2004).

2.1.4.3 Nematodes

Some information about the status of the soil food web can be determened by using the characteristics of the nematode communities as indicators (Forge *et al*., 2003). Nematodes are easily extracted from the soil and identification and classification is relatively easy compared to other techniques for fungi and bacteria (Forge *et al*., 2003). Nematodes form part of the soil food web at different trophic positions, thus changing the structure of the microbial community will result in a change in the structure of the nematode community (Forge *et al*., 2003).

Bongers & Bongers (1998) reasoned that interpretation of long species lists is difficult and nematodes should be allocated into functional groups. It would also be impossible to determine how each species would influence the environment on its own, thus the practical necessity for the functional groups. Based on ecological characteristics, nematodes can generally be divided into functional feeding groups. This range from plant root feeders to bacteria - and fungi feeders. The following groups can be distinguished:

1. Plant feeders
2. Fungal feeders
3. Bacteria feeders
4. Substrate ingestors
5. Animal predators
6. Unicellular eukaryote feeders
7. Dispersal or infective stages of animal parasites
8. Omnivorous

Some nematodes show life cycles of opportunists. They have a short generation time in which a large number of small eggs are formed. This results in a high production rate. They are known as r-strategists and will form a resting phase when conditions become unfavourable. K-strategists have a long generation time in which they form a few large eggs. They are known as persisters and do not respond rapidly to new food resources (Bongers & Bongers, 1998).

Changes in the different decomposition pathways can be detected by the analyses of the different feeding groups. When organic matter with high C:N ratios are decomposed it is dominated by fungal-feeding pathways. The bacterial-feeding decomposing pathway is dominant in N rich material (Ferris *et al.*, 2001). Forge *et al.* (2003) stated that, when microbivorous protozoa and nematodes graze on the microbial biomass, it enhanced N mineralisation and turn over. They found that the abundance of bacterivorous – and fungivorous nematodes can increase under different organic mulches.

When a paper mulch was added to the soil an increased number of protozoa and various nematodes trophic groups was found. This indicated an increase in fluxes of N and P turnover by the microbial biomass even though no N or P was added to the soil by the shredded paper mulch (Neilsen *et al.*, 2008).

Forge *et al*. (2008) commented that previous research that indicated that plant roots and microbial biomass compete for nutrients, may not be accurate, because they did not consider a system in which nutrient cycling will increase along with an increase in C rich material.

Plant growth can also be enhanced by bacterivorous nematodes by mechanisms other than mineralisation (Forge *et al*., 2003). *Pratylenchus penetrans* is known as the root lesion nematode, which cause fine feeder roots to become necrotic and die back when the feed on the. Adding a mulch of composted manure to the soil has shown to decrease the numbers of *P. Penetrans* effectively, thus preventing the formation of a meager root system (Neilsen *et al.*, 2008).

2.1.4.4 Mychorrhiza

Arbuscular forming mycorrhizae (AM) are the most common type to form associations with the roots of apples and are called endomycorrhiza. Plant roots colonized by endomycorrhizae show a positive effect on their growth and development (Derkowska *et al*., 2008). When environmental conditions become stressful, these AM fungi will protect the trees from drought, acidification and salinity stress. Mycorrhizal inocula used on crops in areas with water deficiencies have shown beneficial effects on the quality and the size of the crop (Derkowska *et al*., 2008).

When a plant is grown in an area with high water stress, the roots are more readily colonized by mycorrhizal fungi. Roots covered with mycorrhizae will develop better, in particular as the lateral and fine root numbers seem to increase. Derkowska *et al*. (2008) stated that mycorrhizae help roots with water and mineral uptake from the surrounding soil. When soils are deficient in P, apple roots colonized by mycorrhizae will assist in its effective uptake (Atkinson, 1983). In soil with efficient P, mycorrhizal fungi will increase the uptake of ions like Cu and Zn, however high P levels in soil have shown to decrease the frequency of roots colonized by mycorrhiza (Lakatos *et al*., 2001).

The colonisation rate of mycorrhizae is negatively correlated with organic mulches high in N, P and K (Lakatos *et al*., 2001). Derkowska *et al*. (2008) found compost mulches to decrease the number of roots colonized by AM, but a peat mulch had a positive effect on the frequency of colonized roots. According to Atkinson (1983), a root system with high root density and a large amount of lateral roots have a higher potential for colonization due to contact with hyphae from mycorrhizae.

2.2 Roots

Merwin & Brown (2009) reported that ground management systems influenced tree growth and yield above ground and root density and – distribution beneath ground. Where organic mulches are used as a ground cover system, the frequency of shallow roots is increased. The formation of roots in the surface layers of the soil is the effect from temperature control and the enhanced porosity of the soil (Pinamonti *et al*, 1995).

Derkowska *et al*. (2008) stated that parameters of root growth are positively influenced by peat and compost mulches through an increase in root length and the number of root tips formed. The total root biomass was found to increase under some organic mulches (Forge *et al*., 2008). Lang *et al*. (2001) announced that a more active growing root system formed under a mulch consisting out of perforated black polyethylene with 15 cm of sawdust on top. They reported that the mulched trees produce 1.5 times more feeder roots due to the stimulation of the growth of fine roots and to a reduction in death of fine roots.

Atkinson (1983) stated that, when plants have a high ratio of leaf area to root length, the effect of the low root density will be most obvious when the root system is unable to supply water in cases of high evaporative demands.

2.3 Leaves

Bananuka *et al.* (2000) found a larger number of functional leaves at flowering and harvest with different mulches on bananas. The increase in yield could partly be due to this effect on the leaves.

Using sawdust as a mulch on apples increased leaf concentrations of K and Ca and reduced apple fruit physiological disorders (Lang *et al*., 2001; Szewczuk & Gudarowska, 2004). Leaves of apple trees treated with a compost mulch and fertilizer seem to accumulate more nutrients over all (Brown & Tworkoski, 2004). The improvement of soil physical condition such as porosity and water availability, enhanced absorption of minerals (Pinamonti *et al.*, 1995).

When bio-solids are applied to the soil beneath a mulch, suitable conditions are created for the uptake of P by apples according to leaf and fruit analyses (Neilsen *et al*., 2003).

2.4 Fruit

Newly planted apple trees showed an increase in bloom and growth when peat moss or manure compost was applied as a mulch (Mathews *et al.*, 2002). The use of different mulches has shown to increase tree size as well as the trunk cross-sectional area (TCA) in newly planted orchards (Neilsen *et al*., 2004). Neilsen *et al*. (2003) studied the effect of mulching in young apple orchards for 6 growing seasons and found the TCA of paper mulched trees to be more than 50% larger than control trees. In young apple trees there is a positive correlation between trunk diameter and future yield, suggesting that mulching enhances the potential for future production (Mathews *et al*., 2002).

Neilsen *et al*. (2003) found that all five different mulches used in a study in a semi-arid region increased the yield of dwarf apples, despite the optimum supply of water and minerals by drip irrigation to all the treatments. Neilsen *et al*. (2004) found the cumulative yield over 4 years to be greater when a mulch was used in an apple orchard compared to a herbicide strip.

Using mulches in the planting row has shown to increase fruit quality of apples (Szewczuk & Gudarowska, 2004). Szewczuk & Gudarowska (2004) found that mulching with both organic – and inorganic material increased the yield and fruit size in apples. Despite the increased fruit size, these fruit also showed an increase in Ca concentration. When the firmness was investigated, they found apple fruit to be firmer immediately after harvest when the trees were mulched. They also reported that when apple trees were treated with herbicides, the apples lost a larger percent of their weight during storage compared to the fruit from the mulch trees. Lang *et al*. (2001) announced that mulching enhances apple fruit storage quality. They found that the incidence of bitter pit was significantly reduced due to improved Ca nutrition in the tree and the fruit.

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Paper 1

Effect of mulching on soil temperature regulation and contribution to soil fertility on two different soil types planted with apples

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Key words**:** Compost, ‘Cripps’ Pink’, Vermi compost, Polytex PT110 woven geotextile fabric, Root distribution, Organic mulches.

Abstract

A field trial was conducted to investigate the effect of mulching on the chemical conditions of the soil, as well as root formation. Four different mulch types: compost, wood chips, vermi compost and a geotextile fabric, were tested for their ability to regulate soil temperature, increase soil fertility and increase root proliferation. A randomised complete block design was used on two different soil types, heavy silt loam and sandy loam. Mulching had no significant effects on stem water potential at either site. Mulching effectively regulated summer and autumn soil temperatures by reducing temperature peaks. The total number of roots and feeder roots were dramatically increased by the wood chips and geotextile treatments. At the heavy silt loam site, the vermi treatment significantly increased phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), zink (Zn) and boron (B) in the soil. At the

sandy loam site, the wood chips increased K and Na, whereas the vermi compost increased Mg and K in the soil.

List of abbreviations:

Cation exchange capacity (CEC)

Oxidation and reduction potentials (Redox potential)

1.0 **Introduction**

The availability of water for irrigation is showing a decrease worldwide. This tendency is especially important in semi-arid regions facing problems with resources for drinking water. This emphasizes the need to improve efficiency of water usage in agriculture (Naor and Cohen 2003). Furthermore, a water deficit can reduce fruit size, and since the size of apples is a major quality factor, soil moisture should be optimized to ensure a large fruit size (Naor et al. 1997). To monitor water stress in crops, stem water potential has been used in plum and peach orchards to indicate water demands (Choné et al. 2001).

In orchards where weeds are managed by herbicides to form bare surfaces, a crust may form on the surface. On slopes, these bare surfaces and crusts are susceptible to erosion due to runoff (Trisdal 1989). Frequent tillage of soils will ensure a high initial infiltration of water in the upper loose soil that will reduce the runoff. However, extensive tillage of the upper soil causes crust formation in the subsoil, thus, the subsoil will prevent further infiltration (Trisdal 1989). Soil erosion can also be decreased by reducing the runoff velocity and increasing the infiltration rate with the use of an organic mulch (Smets et al., 2008). Organic mulching has been shown to be effective in lifting surface sealing through the reduction of the impact of raindrops (Bronic and Lal 2005; Smets et al. 2008). The use of organic mulches, such as a straw mulch, will increase soil stability and permeability, ensuring deeper penetration of water and increasing the availability of water in the soil. Collectively, these factors increase the volume of soil available to the roots (Bronic and Lal 2005; Pinamonti et al. 1995; Trisdal 1989).

Organic mulching also effectively controls weeds (Forge et al. 2008; Pinamonti 1998; Trisdal 1989) that compete for water and minerals (Trisdal 1989). The effectiveness is strongly influenced by the thickness of the mulch (Brown and Tworkoski 2004). Walsh et al. (1996) found that organic mulches control weeds by smothering and preventing their seed from establishing in the soil. Mathews et al. (2002) found that a polyester fibrefill synthetic mulch controlled weeds equally effective as organic mulching, but lacked other beneficial advantages of organic material on soil properties.

Water stress between irrigation cycles can be reduced with a straw mulch (Baxter 1970). According to Wooldridge (1992), controlling weeds with a straw mulch lead to a 45% decrease in water use per season compared to herbicide weed control. In addition, Glover et al. (2000) stated that nutrient cycling in the soil is affected by the amount of water in the soil. Nutrient uptake is likewise influenced by availability of soil water, as one of the pathways used by roots to obtain nutrients is diffusion.

Soil temperature has a direct effect on roots through its influence on growth initiation and cessation (Pregitzer et al. 2000). For several apple rootstocks, the optimum temperature for root growth is approximately 25°C (Gur et al. 1972). According to Pregitzer et al. (2000), the physiology of the above ground parts are influenced by the temperature of the soil. Gur et al.

(1972) reported that supra optimal root temperatures of around 35°C lead to the formation of acetaldehyde and ethanol in the roots through anaerobic respiration as well as a decrease in root produced cytokinens. When transported to the leaves, these products can cause damage with symptoms of intervenous necrosis and loss of chlorophyll.

Using organic mulches such as straw (Trisdal 1989) or compost (Pinamonti et al. 1995) will regulate summer soil temperatures by reducing extremes and creating a more stable range suitable for root activity, thus increasing the growth volume for water and mineral uptake by allowing root growth into top soils and even into the mulch (Trisdal 1989).

According to Barzegar et al. (2002), Smets et al. (2008) and Trisdal et al. (1989), the addition of organic material to soil seems to be the only practical method to increase the stability and structure of soil aggregates. Soil structure influences plant growth by affecting root distribution, which has an effect on water and nutrient absorption (Bronic and Lal 2005). Humic substances including humin, humic - and fluvic acid, can protect soil aggregates because of their resistance to chemical breakdown. Humic acid is very efficient in preventing clay dispersion when adsorbed by the clay particles (Bronic and Lal 2005).

Frequent tillage of soils reduces the organic carbon (C) through oxidation (Trisdal 1989), whereas organic mulching will increase the soil organic matter, thereby reducing the bulk density (Mathews et al. 2002) and increasing soil porosity and cation exchange capacity (CEC) (Merwin and Brown 2009). All these factors affect nutrient availability to the plant (Mathews et al. 2002). Lakatos et al. (2001) highlighted the importance of microorganisms in plant nutrition through their ability to transform organic forms of C, N, P, K, Mg, Mn, Fe and Zn into plant available forms. Seeing that different mulches are composed from different materials with variable properties, it will have different effects on the soil food web, as well as the mineralisation of the elements like N and P (Forge et al. 2003).

Wooldridge (1992) reported that microbial decomposition can use a large amount of N fertilizer when a straw mulch is used. This would only be a short-term effect, but would be critical in newly planted orchards. He suggested wood chips instead that decomposes slowly and would lead to less N interception by microbial assimilation and also increase the lifetime of the mulch. Neilsen et al. (2003) found that N immobilisation can be overcome when the orchard was regularly fertigated to compliment the mulch.

St. Laurent et al. (2008) evaluated four different ground management systems namely: pre-emergence herbicides, post-emergence herbicides, mowed sod grass and bark mulch over a period of 14 years. He found that the bark mulch increased soil moisture, organic matter and mineral concentrations of Fe, Mn, Ca and P, compared to the other treatments. The uptake of P and K, which is high in the upper soil layers, was influenced negatively in cultivation practices with grass competition and root damage (Atkinson and White 1980). An application of a sawdust mulch that increased root growth, was reported to overcome this problem in the uptake of Ca, Mg and K from the upper soil layers (Szewczuk and Gudarowska 2004). Similarly, the depletion of K on coarse textured soil in high density apple orchards under drip irrigation, was reduced with a mulch application of alfalfa hay (Neilsen et al. 2003).

Root system distribution and morphology can be influenced profoundly by N, P and Mg, with N being the most influential (Marchner 1995). This was also found by Couts and Philipson (1980) where N and P had the ability to stimulate root growth, whereas K showed no results. The effect of N and P combined was greater than on their own (Couts and Philipson 1980). In cases of severe P starvation periods, the roots will become the dominant sink to acquire more P from the soil (Marchner 1995). Couts and Philipson (1980) also showed that roots which are low in nutrients had an early onset of dormancy and inhibition in the growth of the primary root system was observed in pine trees where the subsoil was deficient in Ca. This implies that nutrition can influence the rate and duration of root growth. The addition of minerals to the soil however, is variable depending on the mulch type, as the effects of microbial decomposition (Lakatos et al. 2001) and improved soil physical properties (Bronic and Lal 2005) on plant nutrient uptake are influenced by organic matter applications.

Well-proliferated root systems and fertile soils are important factors to ensure sustained high fruit production (van Schoor 2009). Mulching influences root development and soil fertility in various ways, by modulating soil water availability (Trisdal 1989), soil temperature (Pinamonti et al. 1995; Trisdal 1989) and nutrient status (Couts and Philipson 1980). As a result of temperature control and increased porosity, the frequency of root formation in the surface layers is increased with the use of an organic mulch (Pinamonti et al. 1995). Derkowska et al. (2008) found a positive influence with peat and compost mulches on root length and the number of root tips formed, while Forge et al. (2008) found the total root biomass to increase under some organic mulches. Lang et al. (2001) recorded a more active root system with 1.5 times more feeder roots with the use of perforated black polyethylene mulch topped with 15 cm sawdust.

Very few studies on the effect of mulching on commercial perennial crops have been done under South African conditions. Kotzé and Joubert (1992) reported that the application of a rooibos tea waste mulch to a sandy soil with newly planted apricot trees had no effect on the soil chemical properties over a six year period. Van Schoor (2009) also concluded that a straw mulch applied to a pear orchard had little effect on the soil chemical composition compared to un-mulched plots after six years of evaluation. Thus, a research proposal was forwarded to revisit the benefits of mulching on a commercial perennial crop (bearing apple orchard). More mulches (organic and inorganic) and two soil types (heavy and light) under the same management were included as treatments and the focus was on quantifying the influence of these treatments on plant nutrition. We hypothesized that the addition of a mulch to the soil surface will influence plant nutrition through regulating soil temperature, increasing water availability, root proliferation and nutrient availability.

Materials and methods

The trial commenced in October 2008, in two orchards adjacent to one another, at Lourensford Estate, Somerset West, Western Cape, South Africa (-34° 2' 31.29", +18° 55' 16.20"). The two ‘Cripps` Pink’ apple orchards were planted in 1998 on M793 rootstocks. Both orchards were irrigated by means of micro sprinklers (5 mm/h for 3 hours twice a week during summer) and received the same management practices. Water runoff was inhibited by a level surface in both orchards with no need for buffer rows. Two different soil types were selected to quantify the influence of soil type on treatment effects. Orchard 1 consisted of a heavier silt loam soil type (Site 1), whereas orchard 2 had a light sandy loam soil type (Site 2). The growth of weeds and cover crop in the inter row was managed by frequent mowing. Weed control in the tree row consisted of herbicide applications.

Treatments consisted of one inorganic- and three organic mulches that were compared to the commercial control of no mulching. The three different organic mulch treatments were: compost, wood chips, and vermi compost topped with wood chips (vermi), whereas the inorganic mulch consisted of a polytex PT110 woven geotextile fabric (geotextile). In the first year of application, the organic plots each received 70 litres of material spread over the four-tree plot (6 m^2). The material was reapplied annually and in the second year, the volume of wood chips was increased to 130 litres to conform to industry practices. Six replications of each treatment were applied to a randomized complete block design with two buffer trees between treatments.

Soil temperature

Probes (DMF, Continuous logging Soil Moister Probe, DFM Software Solutions CC, South Africa) were installed at one plot of each treatment in September 2009, at both sites (due to financial constrains, a probe was not installed in the geotextile treatment at site 1). The probes measured soil temperatures (^oC) in the soil profile at different depths. Due to availability, we used 60 cm and 80 cm probes. All probes took readings at six depths: the 80 cm probe had sensors at 10, 20, 30, 40, 60 and 80 cm while the 60 cm probe had sensors at every 10 cm from 0 cm to 60 cm. In this study, we will only report on temperatures measured at 10 cm depth.

Leaf water potential

In 2009 leaf water potential was measured during summer as indication of soil water status, using a pressure chamber (PMS Instrument Company, USA, Model: 600). Measurements were taken at noon using three shaded leaves for each treatment block. Fully expanded mature leaves in the middle of long shoots were used. Only leaves at shoulder height (1.5 – 2 m) were used.

Leaves were measured one by one, directly after they were cut from the tree. The reading was recorded when water became visible on the leave petiole (Choné et al. 2001). The average water potential (MPa) from the three leaves of each treatment plot was calculated and used for statistical analysis.

Stem water potential

Due to the huge variation in leaf water potential within the treatments, it was decided to measure summer stem water potential in 2010, as an indication of plant response to soil water status. This was the preferred method (Tsuda and Tyree 2000). Two mature leaves close to the trunk were enclosed in small black plastic sleeves covered with aluminium foil. Leaves were covered for at least 60 minutes to allow equilibration with the stem water potential. To prevent overheating, leaves on the shaded side of the tree were selected. The leaves were placed in the pressure chamber (PMS Instrument Company, USA, Model: 600) with the bag attached and the stem water potential was recorded when water became visible on the leave petiole (Choné et al. 2001).

Root distribution

Root examinations were done in one replication for each treatment in both orchards, due to the destructive nature of the analyses. Only one side of one tree per plot was examined to cause as little as possible disturbance to the plot. The method used was according to Böhm (1979). A trench (1.2 m deep and 1.5 m wide) was dug 30 cm from the planting row and parallel with the trees to open the roots of only one tree in each treatment. The trench wall was smoothed using a spade and roots sticking out were cut to the surface. The roots were exposed by removing 5 to 10 mm of soil from the smooth profile wall. In spots where the soil was very dry and hard, the soil was sprayed gently with water before removing it to prevent damage to any roots. The exposed roots were spray painted white to make them visible for mapping and counting. The mapping of the roots took place directly after exposing and painting the roots, to prevent fine, brittle roots from breaking of. A square frame (100 x 100 cm) with a 10 x 10 cm grid of squares was used to indicate the position of the roots in the profile. For each depth interval, the number of roots was calculated in each class to determine the distribution of the root system through the profile.

Soil mineral analysis

In October 2008, before treatments, soil samples were taken from only four replicates at both sites due to financial constraints. A composite sample was taken from each plot at 0 – 10 cm, 10 - 30 cm and 30 – 50 cm. In the 0 – 10 cm layer, micro - and macro elements were analyzed, but in the 10 – 30 cm and 30 – 50 cm, only macro elements were analyzed.

In October 2010, a composite sample from each plot at both sites was taken at 0 – 10 cm and 10 - 30 cm. In the case of 0 – 10 cm, macro- and micro minerals were analyzed, but in the 10 – 30 cm layer only the macro elements were analyzed. All soil samples were analyzed by a commercial laboratory (BemLab Pty Ltd, Strand, South Africa).

Statistical analysis

Data was analyzed using the Statistical Analysing System (SAS) programme (SAS Institute Inc, 2004, Cary, NC). A general Linear Model (GLM) procedure was used for the analysis of variance. Standard errors and least square means were calculated for treatments. Data was considered significant at a 5 % level.

Results

2008/2009

Leaf water potential

Leaf water potential during summer (data not shown) did not show any significant differences between treatments at either site. According to Choné et al. (2001), leaf water potential measured at mid day can be influenced by various factors apart from soil water availability. According to their findings, mid day stem water potential is a more accurate measurement of the root and soil relationship in water transpiration. Therefore, during the 2009/2010 season, stem water potential measured replaced leaf water potential measurements.

Soil mineral analysis

0-10 cm

The initial soil mineral analysis up to 10 cm depth only showed statistical differences for Mg levels at site 1 (Table 1) before any treatments were applied. The control plots had a significantly higher percentage of Mg compared to wood chips and vermi, but did not differ significantly from the compost or geotextile plots. There were no initial differences between the plots at site 2 (Table 2).

Regarding the level of nutrients of both sites at 10 cm depth (Table 1 and Table 2), site 1 had a higher inherent C, K, Ca, Mg and B percentage, whereas site 2 contained a higher percentage copper (Cu), Zn, Mn and P. Both sites contained equal amounts of Na. Site 1 had a slightly lower pH (KCl) (5.54) compared to site 2 (5.87). This data was not compared statistically between the sites, but it is only used as a platform to differentiate between the soil types at the two sites.

10-30 cm and 30-50 cm

The soil mineral analysis at 10 – 30 cm (Table 3 and Table 4) and 30 – 50 cm (Table 5 and Table 6) showed no initial significant differences between any of the elements at either site.

Site 1 (Table 3 and Table 5) had higher inherent percentage K, Ca, Mg and C, whereas site 2 (Table 4 and Table 6) had a higher percentage P. There were no initial significant differences in the Na percentage between the sites. As in the 0 – 10 cm analysis, the pH (KCl) was slightly lower at site 1 (10-30 cm: 5.34 and 30-50 cm: 5.27) compared to site 2 (10-30 cm: 5.79 and 30-50 cm: 5.76). The data between the two sites are used as indication of initial differences between the soil types.

2009/2010

Stem water potential

Stem water potential showed no significant differences between treatments at either site in 2010 (Table 7).

Soil temperature

Daily minimum soil temperature at 10 cm soil depth at site 1 [from late spring (Nov 2009) to the end of summer (Feb 2010)] is shown for a single replication in all treatments (Fig 1). The minimum temperature throughout late spring and summer was the lowest in the control treatment and the highest in the wood chips treatment. On average, the wood chip treatment was 1.5 °C warmer than the control treatment and at times differed by more than 2 °C. All three organic mulch treatments had higher minimum temperatures throughout the season compared to the control treatment. The average temperatures of the vermi treatment were similar to that of the wood chips, while the compost treatment only differed slightly from the control treatment. The variation in temperatures between days was also the biggest in the control treatment and the smallest in the wood chip treatment. The vermi and compost treatments showed intermediate variations between days.

Daily minimum soil temperature at 10 cm depth at site 2 [from late spring (Nov 2009) to the end of summer (Feb 2010)] is shown for a single replication in all treatments (Fig 2). The vermi treatment generally had the highest minimum temperatures compared to the other treatments. The peak minimum temperatures were observed in the control treatment. The temperatures from the woodchips, compost, control and geotextile treatments were closely related, and differed from the vermi treatment, which showed the smallest variation in minimum temperature between days.

Daily maximum soil temperature from Nov 2009 to Feb 2010 at site 1 is shown in Fig 3. The vermi treatment showed the highest maximum daily temperatures, while the wood chip and control treatment showed the lowest temperatures, compared to the other treatments. The control and compost treatment were closely related, although the compost showed slightly higher maximum peaks compared to the control treatment. Wood chips showed the least variable maximum temperature on a day-to-day basis.

Daily maximum soil temperature from Nov 2009 to Feb 2010 at site 2 is shown in Fig 4. The control treatment showed the highest maximum temperature throughout the season, as well as very high peaks in temperatures (e.g. day 22 and day 31). The geotextile treatment showed a consistent and best-regulated maximum temperature throughout the season. All mulch treatments reduced the daily maximum soil temperatures compared to the control. The wood chips treatment was closely related to the control treatment, while the vermi and compost treatments were closely related to the geotextile treatment.

Hourly soil temperatures (1 to 4 Jan 2010) at site 1 clearly indicated that the wood chip treatment had the best ability to maintain a constant temperature throughout the day (Fig 5). This was the case for the first four days in January, representing typical summer conditions in the Western Cape. The control, vermi and compost treatments were closely related and showed more variable temperatures throughout the day, compared to the wood chips that showed little variability in the temperature range in these summer days.

Hourly soil temperatures at site 2 for four days (1 to 4 Jan 2010) during summer also indicated that the control treatment had the lowest ability to maintain a constant soil temperature (Fig 6). The geotextile treatment showed the least variation in temperature and reduced high (e.g. 1 Jan 2010: from 28 to 22.9 ^{o}C) and low temperature peaks effectively compared to the control treatment. All mulch treatments showed lower temperatures during the hottest times of the day

(14:00) compared to the control treatment. The vermi treatment temperatures were similar to those of the geotextile treatment and the wood chips and compost treatments were intermediate.

Autumn soil minimum (Fig 7) and maximum (Fig 9) temperatures at site 1 indicated that the wood chips treatment reduced maximum and minimum temperature peaks. The vermi treatment had the highest maximum temperatures and the control treatment had the lowest minimum temperatures.

Autumn soil minimum (Fig 8) and maximum (Fig 10) temperatures at site 2 indicated that the wood chips treatment had the highest maximum and geotextile the lowest maximum temperature, whereas all the mulch treatments had higher minimum soil temperatures compared to the control treatment. The vermi treatment had the highest minimum temperatures throughout this period.

Root distribution

The root distribution study conducted at site 1 in May 2010 (Fig 11) illustrated that the total number of roots in the control treatment did not differ between the compost and vermi treatments, whereas the total number of roots in the wood chips and geotextile treatments were noticeably higher. In the 1 m^3 area investigated, the wood chips treatment displayed the highest number of roots compared to the other treatments. The biggest contribution came from the roots < 2 mm (fine roots) in the 0-10 cm soil layer. In all treatments, most roots were present in the 0-10 cm soil layer as fine roots, except for the geotextile treatment where most fine roots were found in the 10-30 cm layer.

The total number of roots in each treatment at site 2 (Fig 12) indicated that the geotextile and wood chips treatments produced the highest number of roots, with the highest number in the geotextile treatment. The total number of roots in the control, compost and vermi treatments did not differ from each other, but was notably less than in the geotextile and wood chips treatments. The biggest contribution to total number of roots in the wood chips treatment derived from fine roots in the 0-10 cm soil layer. The same was true for the fine roots in the 0-10 cm soil layer in the geotextile treatment, but with two additional peaks of fine roots at the 10-30 cm and 50-80 cm. The biggest contribution of roots in the control, compost and vermi treatments occurred in two peaks of fine roots formed in the 0-10 cm and 50-80 cm layers.

Soil mineral analysis

From the mineral analyses (2009) of the compost (Table 8) and vermi compost (Table 9) material applied during October 2009, the compost contained a higher percentage of C, Ca, Na, Fe and Cu compared to the vermi compost with a higher percentage of H_2O, P, Mg, Mn, Zn and B. Both composts contained equal amounts of N and K with a similar pH. No analysis was done for the wood chips.

10 cm

There were significant differences between treatments in the soil mineral analysis (April 2010) at10 cm depth at site 1 (Table 10) after two treatment applications. The vermi and compost treatments both had significantly higher pH (KCl) values compared to the wood chips treatment, but did not differ significantly from the other two treatments. The vermi treatment resulted in a higher percentage of K compared to the other treatments, while the vermi, wood chips and compost treatments all contained a significantly higher K percentage compared to the control and geotextile treatments. The vermi treatment contained a significantly higher percentage of Zn and P compared to all the other treatments. The Mn percentage was significantly higher in the vermi treatment compared to the control, compost and wood chips treatments, but did not differ significantly from the geotextile treatment. A significant higher percentage of B was found in the vermi treatment compared to the other treatments. Wood chips and vermi treatments both had significantly higher percentages of B compared to the geotextile treatment, but did not differ significantly from the control and compost treatments.

K and Mg percentages differed significantly at 10 cm soil depth at site 2 (Table 11). The wood chips and vermi treatments contained significantly higher percentages of K compared to the other treatments. The percentage of Mg was also higher in the vermi treatment compared to the other treatments, although the vermi and wood chip treatments both contained a significantly higher percentage of Mg compared to the control and geotextile treatments, but did not differ significantly from the compost treatment.

30 cm

Results of the 30 cm soil mineral analysis at site 1 showed significant differences in Na, K, Ca, Mg, P and pH values (Table 12). The vermi and compost treatments had significantly higher pH values compared to the geotextile and wood chips treatments, but did not differ significantly from the control treatment. The wood chips and vermi treatments showed significantly higher Na percentages compared to the other treatments. The K percentage was also significantly higher in the vermi treatments compared to all other treatments. The wood chip and vermi treatments both had a significant higher K percentage compared to the other three treatments. Compost had a significantly higher Ca percentage compared to the wood chips and geotextile treatments, but did not differ significantly from the control and vermi treatments. All treatments had significantly higher Ca percentages compared to the wood chips treatment. Mg and P percentage were significantly higher in the vermi treatment compared to the other treatments.

Soil mineral analysis at 30 cm soil depth showed significant differences in Na, K and Mg percentage at site 2 (Table 13). The wood chips had a significant higher Na percentage compared to the control, compost and geotextile treatments, but did not differ significantly from the vermi treatment. The wood chips and vermi treatments both showed a significant higher Na percentage compared to the control and geotextile treatments, but did not differ significantly from the compost treatment. The K percentage was the highest in the vermi treatment and differed significantly from the control, compost and geotextile treatments, but not from the wood chips treatment. The wood chips treatment resulted in a significantly higher K percentage compared to the control and geotextile treatments, but did not differ significantly from the compost treatment. The vermi treatment had a significantly higher Mg percentage compared to the control, geotextile and wood chips treatments, but did not differ significantly from the compost treatment.

Discussion

Stem water potential

In this trial, significant differences in stem water potential measurements were not observed between treatments at either site. Throughout the trial, we generally observed that the soil in the upper part of the profile was well drained, whereas the lower subsoil areas where very wet at both sites, which may have attributed to the lack of response.

The increase in available soil water due to mulching found by other authors (Bronic and Lal 2005; Pinamonti et al. 1995; Trisdal 1989), can affect the uptake and redistribution of minerals (Shear 1980), as well as the nutrient cycling in the soil (Glover et al. 2000). This positive effect of mulching would still apply to the well-drained upper soil areas, where water shortages may occur. The stem water potential measurements may have not been sensitive enough to reveal the effect of more available water in the upper soil layers in the plant. This is in contrast to Choné et al. (2001), where it was used as a successful indication for irrigation scheduling in peach and plum orchards. Adaption to irrigation scheduling must follow when a mulch is added to an orchard, especially in heavier soil types (Simonne 2000). In this trial, the adaptation in irrigation scheduling will be effective as from October 2010.

As the thickness of the mulch influences its efficiency to reduce water loss (Brown and Tworkoski 2004), we speculate that the wood chips treatment will be more effective compared to the other organic applications after irrigation adaptations, due to the increased chips volume after the double application in October 2009. Due to the lower water holding capacity of a lighter soil, we speculate that the mulch treatments will be more effective to increase soil water availability in the sandy soil at site 2.

Soil temperature

At site 1, the wood chips and vermi treatments where the most effective in increasing minimum soil temperatures during spring and summer (Sept - Feb) and the first part of autumn (March –

May 15) and reducing diurnal variation. The wood chips treatment was the most effective treatment to regulate the soil temperatures in general – reducing maximum and minimum peaks and creating a more stable temperature range suitable for constant root growth (optimum 25 °C). However, all organic mulches resulted in slightly higher soil temperatures from time to time, compared to the bare surface of the control plot. Bussiére and Cellier (1994) explained that mulching can increase soil temperatures under very wet conditions - as was experienced in this trial from time to time (personal observations). This increase in temperatures under wet conditions occurs when a continuum is formed between the atmosphere and the soil by the preserved moisture in the mulch. They also found that, where the material used for mulching is able to lose water rapidly e.g. wood chips versus compost, it will limit water and heat transfer between the soil and the atmosphere. This may explain the difference between the wood chips treatment and the other organic materials.

Soil temperatures in the surface layers up to 5 cm can fluctuate widely (Pregitzer et al. 2000). At site 2, all mulch treatments resulted in lower maximum soil temperature peaks during summer. This was in line with findings of Trisdal (1989) (straw) and Pinamonti et al. (1995) (compost). The geotextile and vermi treatments resulted in the best temperature regulation throughout summer and the first part of autumn (2009/10).

At site 1, the vermi treatment showed the lowest ability to regulate soil temperatures and resulted in the even higher summer soil temperatures compared to the control. This is in contrast to site 2, where the vermi treatment showed a remarkable ability to regulate soil temperature. The lower water holding capacity of the sandy soil at site 2 will prevent the preserved water to form a continuum with the atmosphere, which will reduce the buffering effect of the mulch (Bussiére and Cellier, 1994). Tolk et al. (1999) found that the effectiveness of the mulch was correlated with textural properties of the soil type. This is in line with the results obtained in this trial, where the vermi treatments gave different results in the sandy loam versus heavier loam soils.

After adaptation of the trial irrigation scheduling planned for October 2010, we believe that the ability of the mulches to regulate the soil temperature should improve at site 1. As the wood chips layer is twice as thick as the other organic treatments, this treatment could result in the best option to reduce temperature variations by reducing evaporation and forming a buffering layer.

Root distribution

Most horticultural crops have a linear declining relationship between soil depth and the logarithm of rooting density (Atkinson and Wilson 1980). At both sites, the wood chips and geotextile treatments resulted in the largest root systems as reported by previous researchers (Forge et al. 2008; Pinamonti et al. 1995; Trisdal 1989). Top soils usually host more favourable conditions for root growth compared to sub soils, which partially explains the higher root density in the top 10 cm soil.

At site 1, the largest root system correlated with the best temperature regulation from the wood chips treatment. The vermi treatment at site 1 formed a poorer root system even though it was able to regulate soil temperature effectively. The root volume increased in the wood chips mulch, confirming work by Trisdal (1989), where the roots grew into the mulch, as it provided a well-aerated medium on top of the soil surface. This could further explain the larger root system formed by the wood chips (double medium volume) compared to the vermi treatment.

At site 2, the best temperature regulation was observed under the geotextile treatment, which again correlated with largest root system that is in line with previous research (Othieno 1971; Pregitzer et al. 2000; Trisdal 1989). In contrast, the wood chips treatment at site 2 formed a root system with a similar size to that of the geotextile treatment, even though it did not regulate temperature that well. The same observation as at site 1was made, where the roots grew into the thick wood chips medium which increased the rooting volume, and could partly explain the difference between the geotextile and wood chips treatment.

At site 1, with very few roots below 30 cm, undesirably wet conditions were observed from time to time in the sub soil areas (personal observation), although no signs of permanent water logging were found when the soil profiles were documented. In general, roots found in the deeper part of the soil profile were stunted and unbranched (personal observation).

At site 2, maximum soil temperatures were higher (on average 4°C) compared to site 1. The lower water holding capacity of the sandy loam soil together with high soil temperatures, can have severe negative implications on root formation. According to the root study, the trees at site 2 showed two distinct growth peaks at different soil depths. Number of roots in the deeper soil layers (50 – 80 cm) correlated well with the depth at which water would be frequently available in the sandy soil such as site 2. Another peak area of root growth was observed closer to the surface. All treatments showed similar root numbers at the 50 - 80 cm level, except for the wood chips treatment. The shallower and more proliferated root system formed by the thicker layer of wood chips (second season) may have resulted from the thicker layer of the medium, which would reduce evaporation more effectively and supplied a medium for root growth. More available water closer to the surface compared to the other treatments may have lead to higher root numbers in this closer to the surface layers.

Soil mineral analysis

In all treatments, at both sites, soil pH (KCl) was in the range of 5.0-7.5, which is suitable for apple root growth. At pH levels above 7.5, root growth is directly affected through inhibition of root elongation by ammonia toxicity. The same inhibition is found at pH levels below 5 due to aluminium toxicity (Marchner, 1995).

At site 1, the soil mineral analysis at 10 cm and 30 cm revealed that the vermi treatment had significantly more Mg and P. This did not correlate with the number of roots as found by Couts and Philipson (1980) and Marchner (1995). The mineral analyses from the vermi and compost indicated that the vermi contained a higher percentage of P and Mg, which might explain the origin of these minerals. At site 2, the vermi treatment also resulted in significantly higher values of Mg in the 10 cm and 30 cm soil depth, but again showed no correlation to the size of the root system.

In general, the soil analysis only provides some idea of the ability of the soil to buffer the soil solution and to provide minerals for plant uptake. To predict the effect of fertilization on plant nutrition, the chemical analysis on soil alone is inadequate, because it does not provide insight into the mobility of the nutrients in the soil solution. It also omits additional information like microbial activity and rhizosphere changes induced by the roots, which can be decisive for effective nutrient uptake under field conditions (Marchner 1995). Thus a leaf analysis will be used to determine the effect of the mulches on the uptake of nutrients by the plant (reported in paper 2).

At site 1, the vermi treatment resulted in a significantly higher percentage of K, Mg, Zn, Mn, B and P at the 10 cm soil depth and Na, K, Ca, Mg and P at 30 cm compared to the other treatments. At site 2, the vermi treatment significantly increased Mg (10 cm and 30 cm) together with K (30 cm).The vermi mineral analysis at application indicated that it contained higher levels of Mg, Zn, Mn, B and P compared the compost, whereas both contained the same percentage of K. From this, it is clear that the mulches were able to contribute to the soil mineral status, of which the vermi treatment was the most effective at both sites.

Minerals that accumulate in high concentrations in soil solution can indicate the high mobility of the nutrient for plant nutrition as well as the potential to leach out. The highest variation in these parameters usually occurs in the early summer, when the decrease in pH or oxidation and reduction (redox) potential will result in an increase in the concentrations of Cu, Zn, Fe and Mn (Marchner 1995). The low cation exchange capacity (CEC) of the sandy soil at site 2 will increase the chance of leaching. This can possibly explain why more significant differences were observed in the heavier soil at site 1.

Changes in the redox potential as reported by Marchner (1995) and chelation may partly explain the significant increase in the percentage micro nutrients in the leaves observed at site 2 (Data not shown in this paper). Due to the low micro nutrient requirement by plants compared to macro nutrients (White and Zasoski 1999), a change in micro nutrient levels in the plant after availability in the soil increased, is expected sooner than for macro nutrients.

At both sites, the wood chips and geotextile treatments resulted in the highest number of roots and feeder roots. At site 1, these treatments did not reflect an increased mineral uptake (data not shown in this paper). At site 2, significant differences were observed in the aerial parts of the wood chip treatment, but not in the geotextile treatment (data not shown in this paper). High root density creates competition for nutrients between the roots, caused by overlapping of depletion zones. This creates a non-linear relationship between the rate of uptake and root density. This factor should be reckoned with in attempts to correlate root density to soil horizons and layers (Marchner 1995).

As both the geotextile and wood chips treatment did not directly contribute any minerals to the soil, their mineral statuses are similar to that of the control treatment. As both sites were subjected to standard fertilization practices, we speculated that mulching with wood chips might address specific soil interactions and soil physical properties in a way that resulted in a positive effect on Ca uptake to the fruit (data not shown in this paper). At both sites the wood chips treatment resulted in the highest yield efficiency, even though it was only significant at site 1 (data not shown in this paper). This can be partly explained by the theory of Atkinson and White (1980) that soil disturbances and inter specific competition for minerals are affected by soil management systems. This effect on soil mineral availability in orchards is greater than the effect of fertilization with N, P and K. By affecting the distribution of the roots through soil management, the roots can interact with the resources in the soil. When the temperature and water potential is changed by soil management systems, it can produce differences in the mineral uptake, even in soils with high mineral content (Atkinson and White 1980).

The vermi treatment resulted in a significant increase of most of the mineral elements in the soil at site 1 and a few at site 2, whereas the compost treatment did not seem to supply nutrients to the soil at the same rate. Both these treatments resulted in similar sized root system compared to the control treatment at site 1. However, at site 2 the compost treatment resulted in a slightly smaller root system compared to the control and vermi treatment. As both these treatments resulted in a significant higher percentage of micro nutrient elements in the leaves at site 2 (data not shown in this paper), these treatments seemed to influence plant nutrition differently. The vermi treatment was able to supply the soil with a higher mineral solution, whereas results from the mycorrhizae analysis (data not shown in this paper) suggest that the compost treatment was more dependent on mycorrhizae to support plant mineral uptake.

Recommendations

Irrigation scheduling at both sites should be adapted (reduced) to the treatment requirements at the beginning of the new growing season in 2010 and soil moisture content documented.

According to Courts and Philipson (1980) and Marchner (1995), the effect of plant growth on soil fertility can be seen in enhanced root growth and a decrease in the root/shoot ratio in more fertile soils. Small trees with large root/shoot ratios will be the result of infertile conditions. At the end of the trial period, a full-scale root study should be conducted on both sites to quantify this aspect. The root/shoot ratio can be used as an indication of whether the mulch treatments were able to increase soil fertility in general over time.

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2008/2009

Table 1: Top 10 cm soil mineral analysis (Oct 2008) before trial commenced at site 1.

Treatment	pH (KCl)	C (%)	Na (%)	K (%)	Ca (%)	Mg (%)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	B (mg/kg)	P BrayII (mg/kg)
Control	5.73^{ns}	3.22^{ns}	0.13^{ns}	0.34^{ns}	10.47^{ns}	0.71^{a}	0.40^{ns}	4.05^{ns}	2.38^{ns}	0.57^{ns}	30.25^{ns}
Compost	5.58	3.68	0.12	0.27	9.87	0.60^{ab}	0.28	5.35	2.50	0.57	28.25
Polytex PT110 Woven Geotextile	5.45	3.81	0.13	0.32	8.99	0.57^{ab}	0.31	4.35	2.75	0.58	27.25
Woodchips	5.50	3.92	0.13	0.27	9.30	0.48^{b}	0.26	4.25	2.25	0.60	29.50
Vermi compost/ wood chips	5.43	3.51	0.09	0.29	8.52	0.42^{b}	0.34	4.95	2.43	0.55	27.75
P Value	0.5587	0.4009	0.2313	0.1923	0.3107	0.0373	0.7404	0.8675	0.6957	0.9603	0.8286
LSD	0.4208	0.7995	0.0437	0.0735	2.0267	0.1804	0.2538	3.008	0.765	0.1328	6.346

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 2: 10 cm soil mineral analysis (Oct 2008) before the trial commenced at site 2.

Treatment	pH (KCl)	C (%)	Na (%)	K (%)	Ca (%)	Mg (%)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	B (mg/kg)	P BrayII (mg/kg)
Control	5.95^{ns}	1.49^{ns}	0.15^{ns}	0.14^{ns}	6.55^{ns}	0.40^{ns}	2.16^{ns}	8.23^{ns}	5.30^{ns}	0.46^{ns}	58.25^{ns}
Compost	5.73	1.33	0.12	0.13	5.06	0.36	2.29	4.65	4.55	0.30	55.75
Polytex PT110 Woven Geotextile	5.85	1.19	0.15	0.16	5.11	0.37	3.30	6.18	5.90	0.41	64.00
Woodchips	5.83	1.10	0.13	0.12	5.03	0.28	3.31	6.75	6.38	0.35	60.25
Vermi compost/ wood chips	5.98	1.26	0.11	0.11	4.22	0.27	2.74	5.53	6.13	0.33	60.25
P Value	0.5982	0.4675	0.5639	0.6873	0.5455	0.7184	0.2671	0.4595	0.4064	0.8516	0.7504
LSD	0.3681	0.4599	0.0609	0.0755	2.9015	0.2512	1.3671	4.2106	2.1657	0.341	13.50

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 3: 10 cm – 30 cm soil mineral analysis (Oct 2008) before the trial commenced at site 1.

Treatment	pH (KCl)	Na (%)	K (%)	Ca (%)	Mg (%)	C (%)	P BrayII (mg/kg)
Control	5.58^{ns}	0.12^{ns}	0.23^{ns}	9.65^{ns}	0.62^{ns}	3.20^{ns}	27.8^{ns}
Compost	5.50	0.12	0.26	8.78	0.69	3.47	20.5
Polytex PT110 Woven Geotextile	5.20	0.12	0.37	7.58	0.58	3.58	25.3
Woodchips	5.13	0.13	0.25	7.12	0.50	4.02	26.5
Vermi compost/ wood chips	5.28	0.11	0.23	7.60	0.61	3.49	26.0
P Value	0.3573	0.1059	0.2525	0.4516	0.5067	0.6389	0.4429
LSD	0.5442	0.0136	0.1501	3.2292	0.2242	1.1428	275.21

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 4: 10 cm – 30 cm soil mineral analysis (Oct 2008) before the trial commenced at site 2.

Treatment	pH (KCl)	Na (%)	K (%)	Ca (%)	Mg (%)	C (%)	P BrayII (mg/kg)
Control	6.03^{ns}	0.12^{ns}	0.14^{ns}	6.35^{ns}	0.65^{ns}	1.43^{ns}	47.75^{ns}
Compost	5.70	0.12	0.15	4.87	0.42	1.24	51.75
Polytex PT110 Woven Geotextile	5.73	0.11	0.15	5.07	0.31	1.15	48.75
Woodchips	5.70	0.11	0.12	4.59	0.31	1.01	75.25
Vermi compost/ wood chips	5.80	0.11	0.15	5.00	0.40	1.16	50.50
P Value	0.3129	0.1840	0.7869	0.3301	0.3945	0.4573	0.6717
LSD	0.367	0.0136	0.0557	1.8511	0.4068	0.4804	46.00

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 5: 30 cm – 50 cm soil mineral analysis before trial commenced (Oct 2008) at site 1.

Treatment	pH (KCl)	Na (%)	K (%)	Ca (%)	Mg (%)	C (%)	P BrayII (mg/kg)
Control	5.50^{ns}	0.14^{ns}	0.33^{ns}	7.98^{ns}	0.62^{ns}	2.69^{ns}	23.75^{ns}
Compost	5.33	0.12	0.28	7.50	0.72	3.19	19.00
Polytex PT110 Woven Geotextile	5.10	0.12	0.24	6.52	0.58	3.36	21.50
Woodchips	5.13	0.12	0.26	6.96	0.59	3.74	22.25
Vermi compost/ wood chips	5.30	0.12	0.23	7.17	0.63	3.21	23.00
P Value	0.1786	0.2407	0.2827	0.6205	0.6525	0.1697	0.3984
LSD	0.367	0.0254	0.1059	2.0597	0.2205	0.8348	5.3499

Means with different letters differed significantly at $P < 0.05$. Means with "ns" was not significantly different.

Table 6: 30 cm – 50 cm soil mineral analysis before trial commenced (Oct 2008) at site 2.

Treatment	pH (KCl)	Na (%)	K (%)	Ca (%)	Mg (%)	C (%)	P BrayII (mg/kg)
Control	6.00^{ns}	0.11^{ns}	0.18^{ns}	5.45^{ns}	0.76^{ns}	1.20^{ns}	46.25^{ns}
Compost	5.73	0.11	0.15	4.75	0.55	1.14	50.50
Polytex PT110 Woven Geotextile	5.78	0.12	0.27	4.58	0.52	1.02	48.25
Woodchips	5.70	0.12	0.16	4.93	0.58	1.17	56.75
Vermi compost/ wood chips	5.60	0.11	0.14	3.95	0.46	0.96	39.75
P Value	0.1572	0.9608	0.5792	0.1415	0.3024	0.7418	0.9416
LSD	0.3229	0.0386	0.1843	1.1533	0.3024	0.4503	44.359

Means with different letters differed significantly at $P < 0.05$. Means with "ns" was not significantly different.

2009/2010

Table 7: Stem water potential measurements for at site 1 (19/02/2010) and site 2 (02/03/2010) after 60 min. of equilibration on a sunny day.

Treatment	Site 1 (Mpa)	Site 2 (Mpa)
Control	-1.21^{ns}	-0.97 ^{ns}
Compost	-1.26	-1.14
Polytex PT110 woven geotextile	-1.12	-1.10
Wood chips	-1.17	-1.08
Vermi compost/ wood chips	-1.19	-0.89
P Value	0.635	0.443
LSD	0.381	0.153

Means with different letters differed significantly at $P < 0.05$. Means with "ns" was not significantly different.

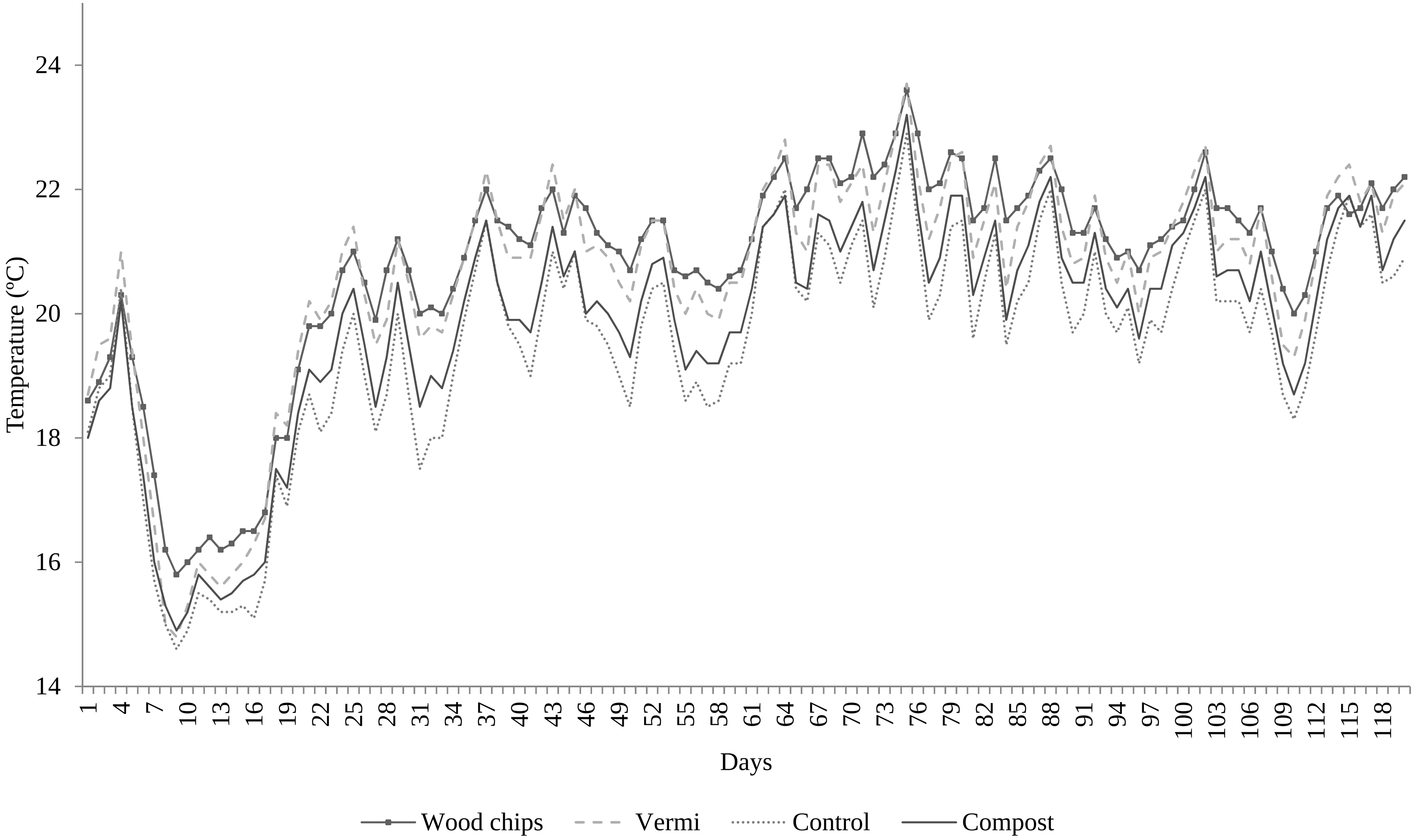

Fig 1: Daily minimum summer (Nov 2009 to Feb 2010) soil temperature for site 1 at 10 cm soil depth.

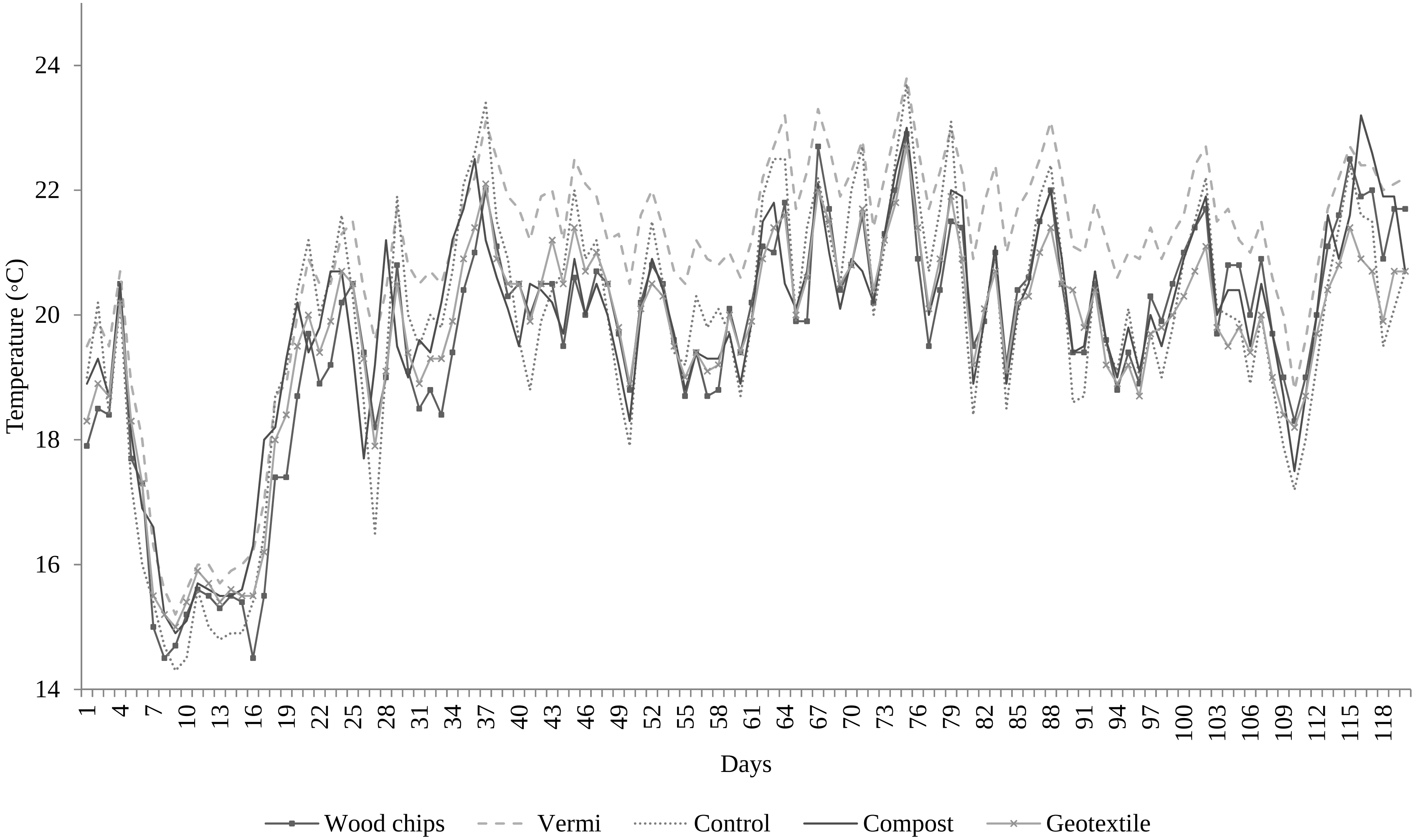

Fig 2: Daily minimum summer (Nov 2009 to Feb 2010) soil temperature for site 2 at 10 cm soil depth.

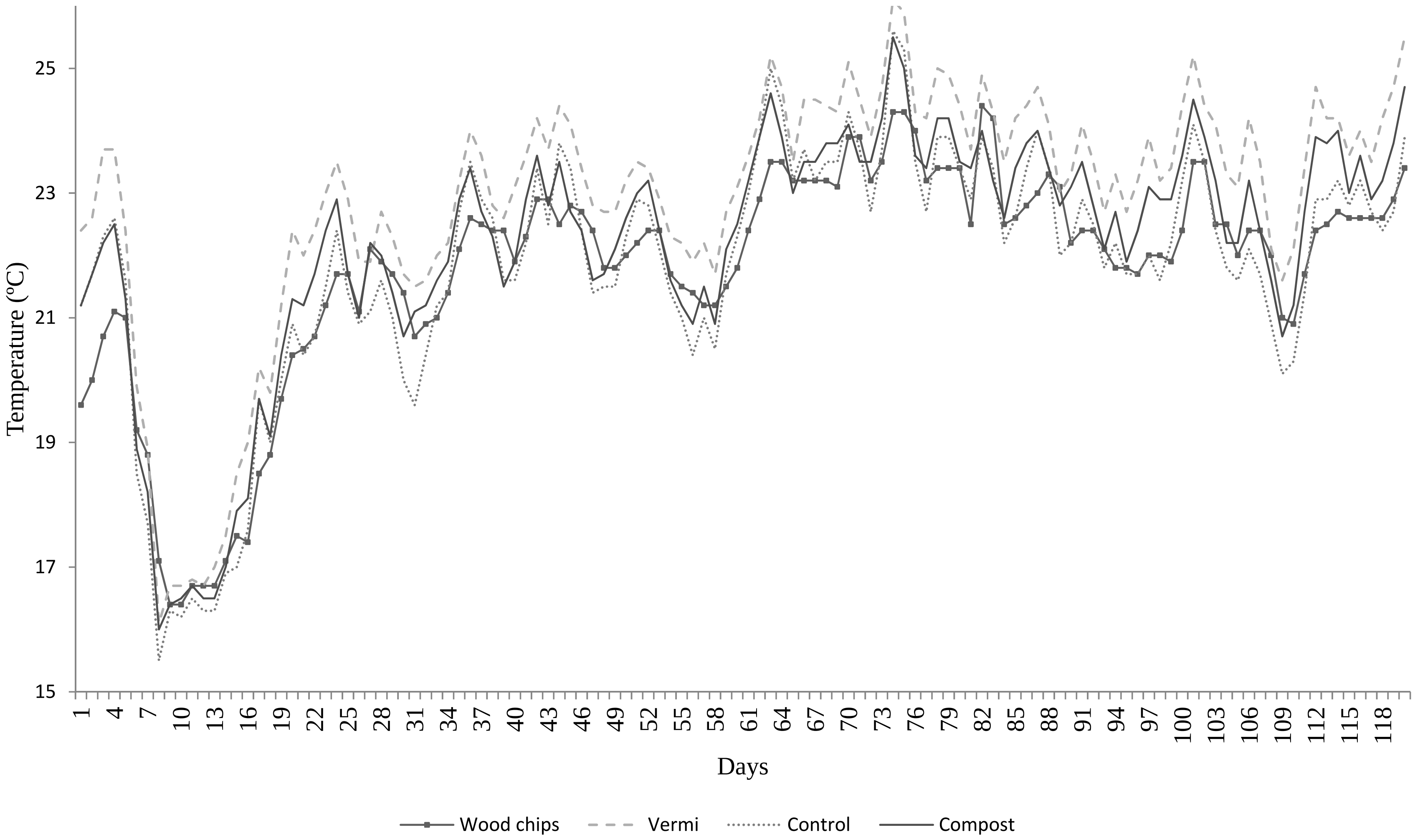

Fig 3: Daily maximum summer (Nov 2009 to Feb 2010) soil temperature for site 1 at 10 cm soil depth.

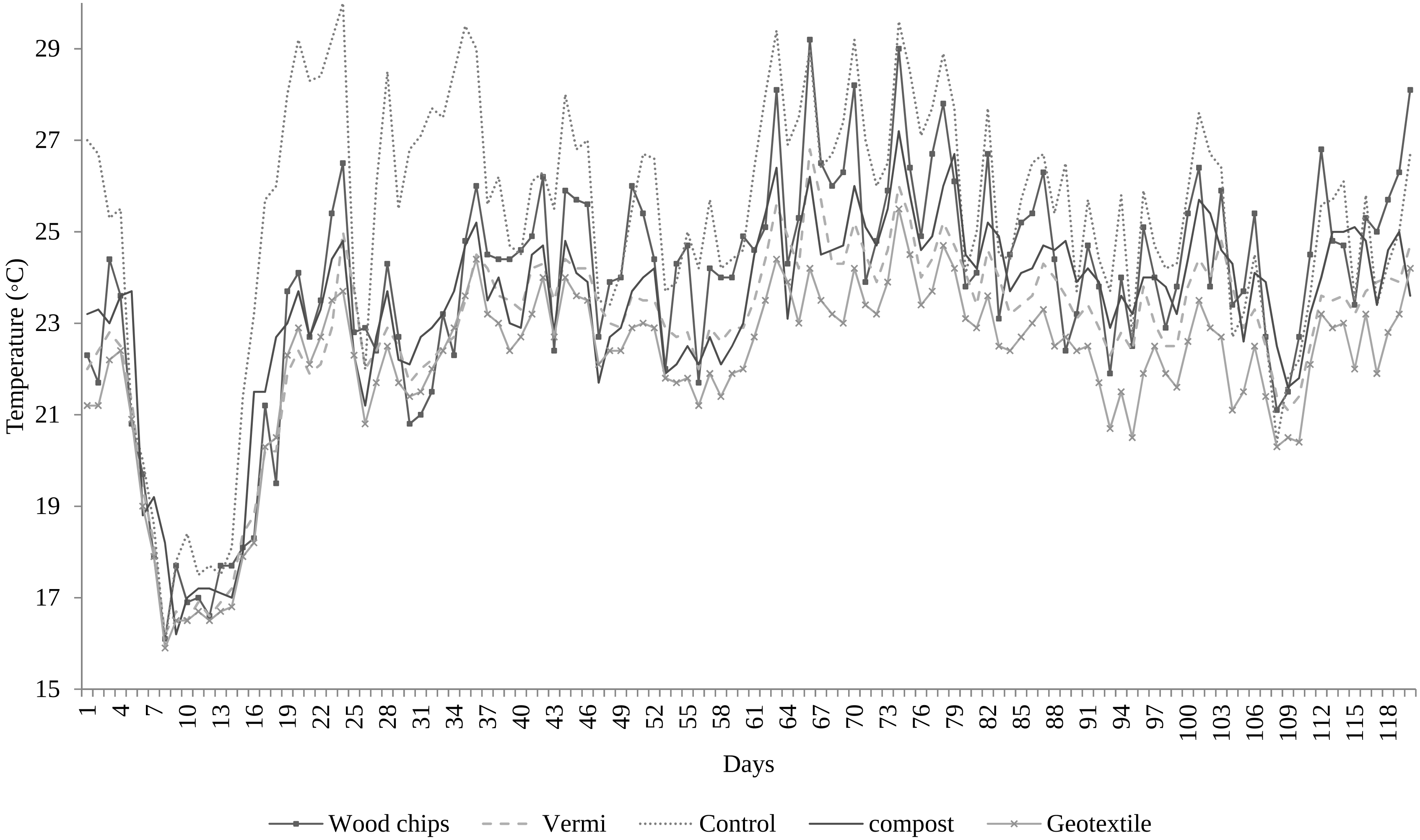

Fig 4: Daily maximum summer (Nov 2009 to Feb 2010) soil temperature for site 2 at 10 cm soil depth.

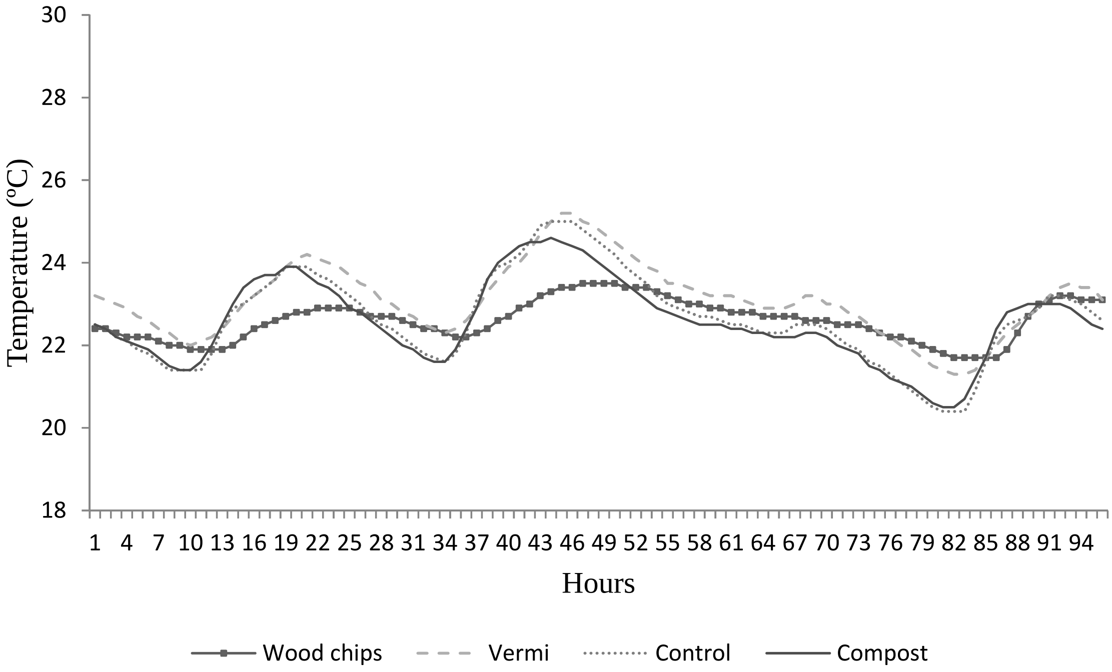

Fig 5: The hourly soil temperature from 1 (01h00) to 4 (23h00) Jan 2010 for site 1 at 10 cm soil depth.

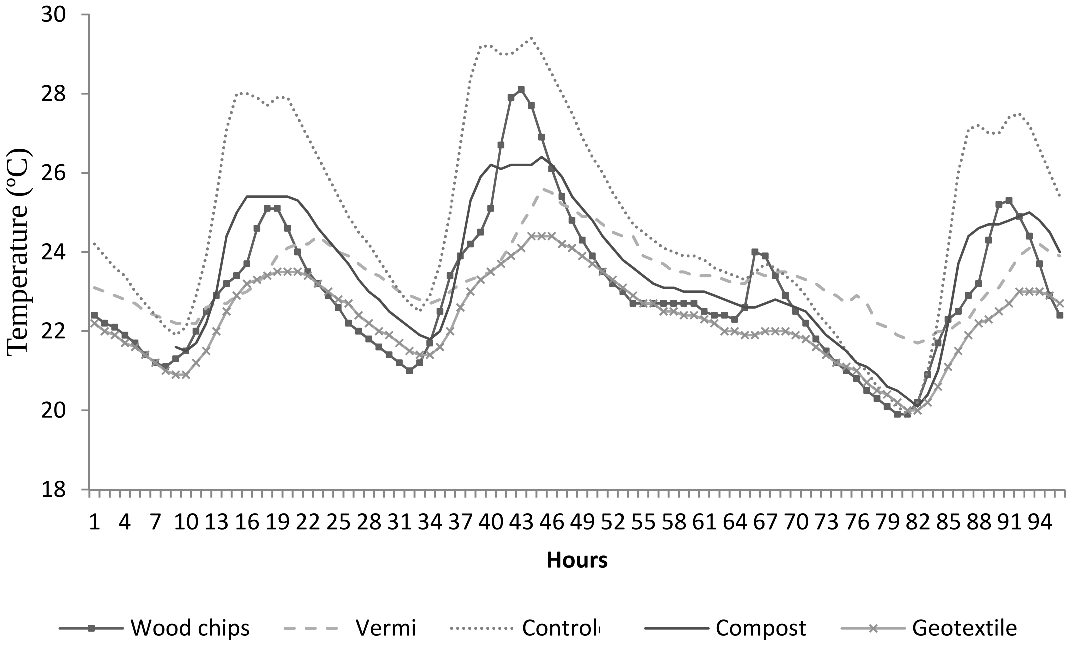

Fig 6: The hourly soil temperature from 1 (01h00) to 4 (23h00) Jan 2010 for site 2 at 10 cm soil depth.

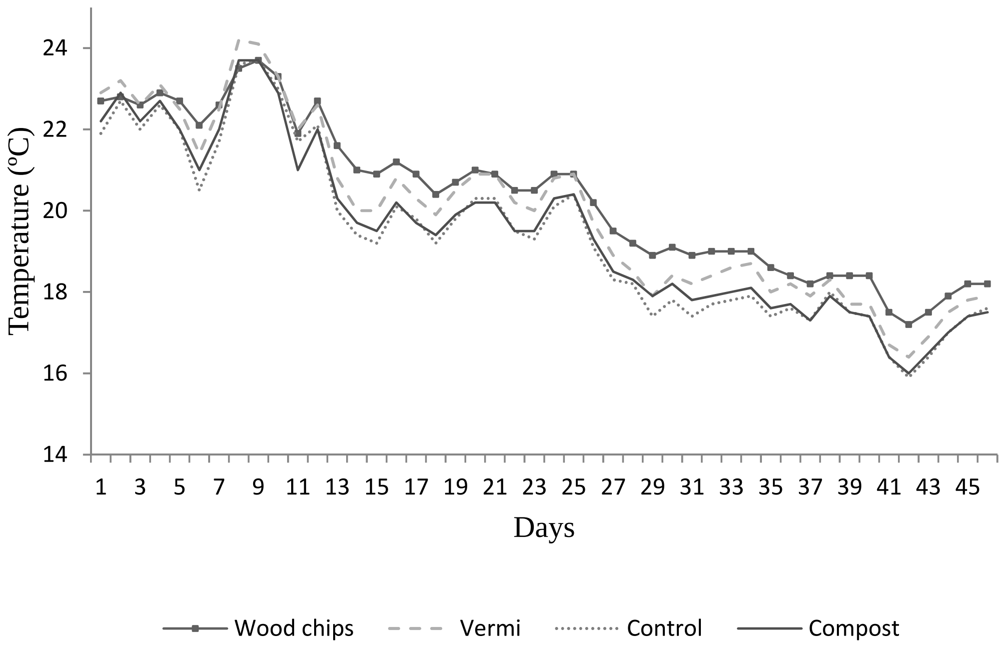

Fig 7: Daily minimum autumn (1 March to 15 Mei 2010) soil temperature for site 1 at 10 cm soil depth.

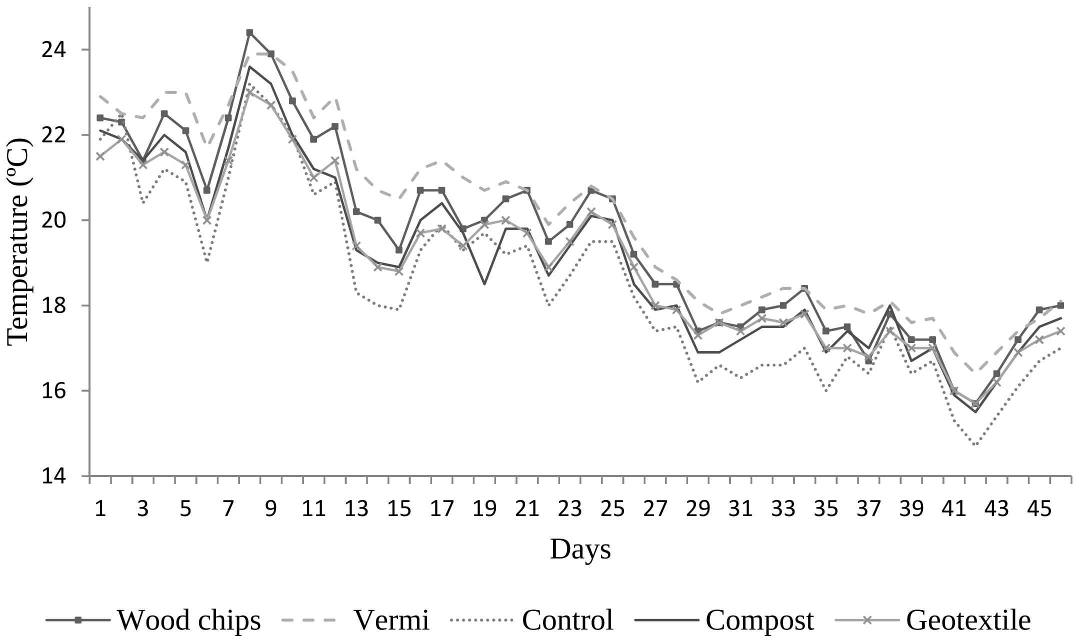

Fig 8: Daily minimum autumn (1 March to 15 Mei 2010) soil temperature for site 2 at 10 cm soil depth.

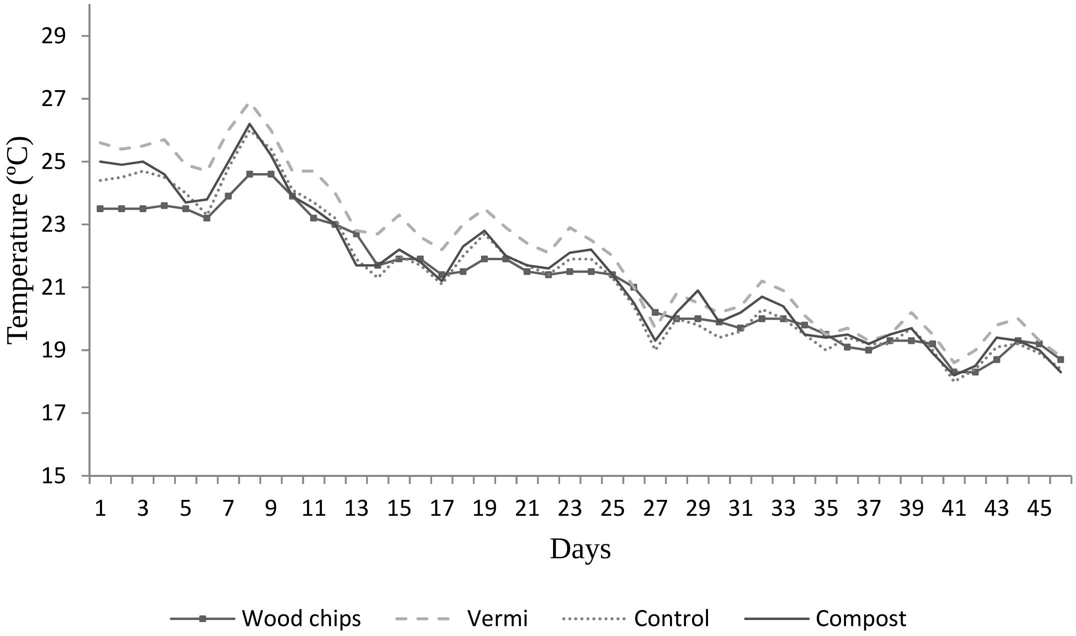

Fig 9: Daily maximum autumn (1 March to 15 Mei 2010) soil temperature for site 1 at 10 cm soil depth.

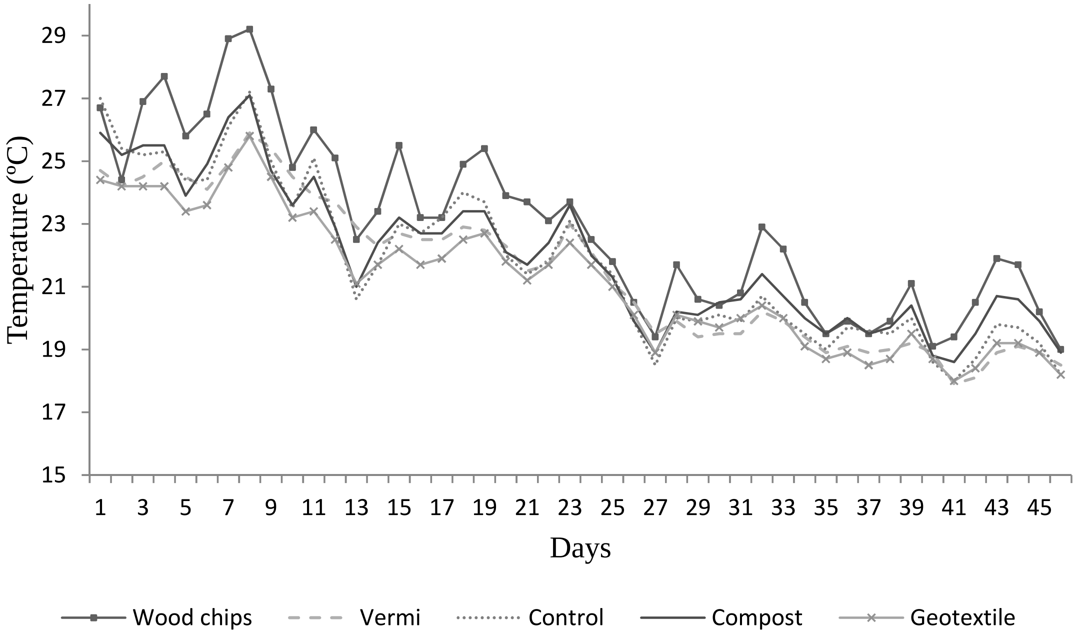

Fig 10: Daily maximum autumn (1 March to 15 Mei 2010) soil temperature for site 2 at 10 cm soil depth.

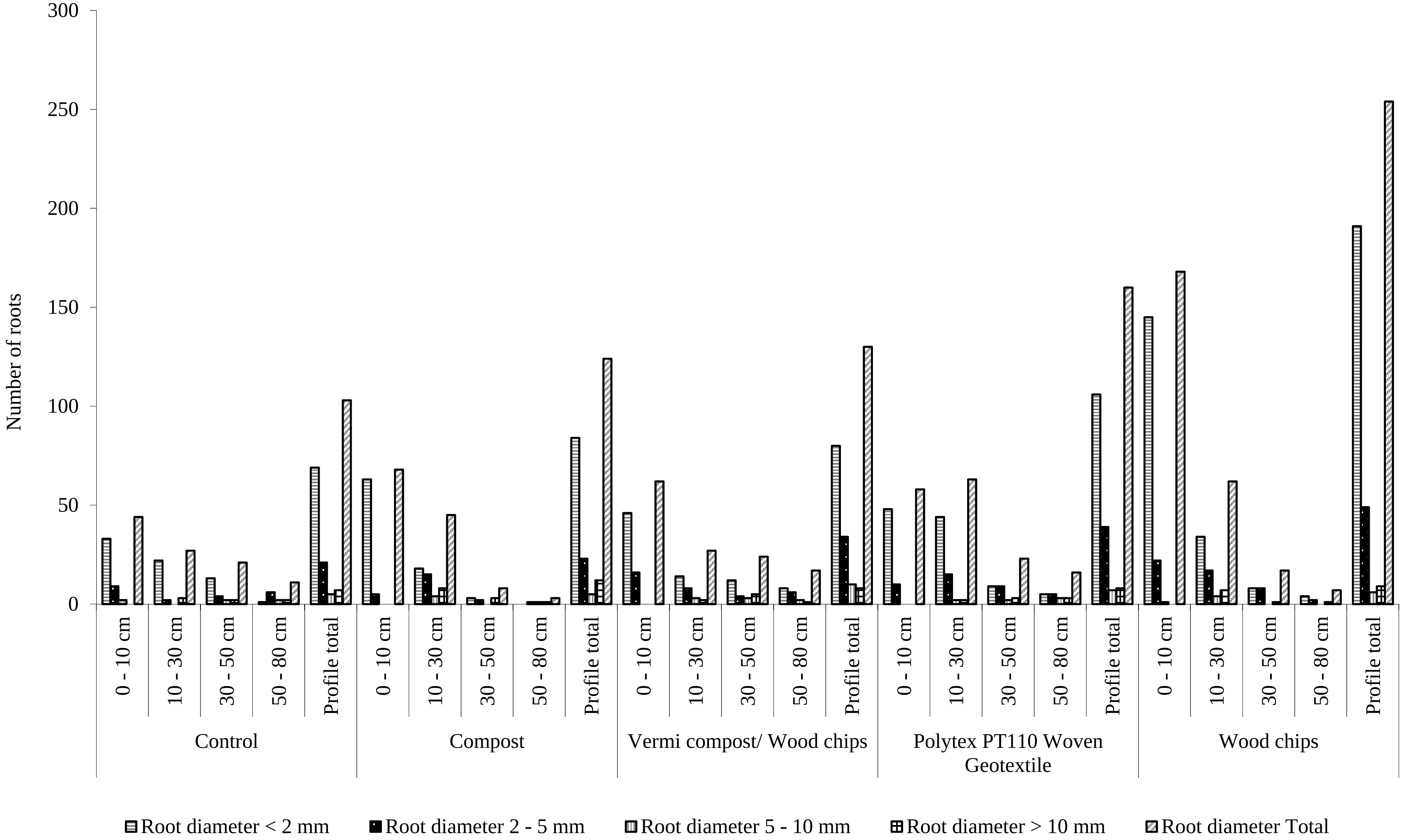

Fig 11: Root distribution of a single replication at site1 in May 2010.Roots were categorised according to their diameter at 10 cm intervals.

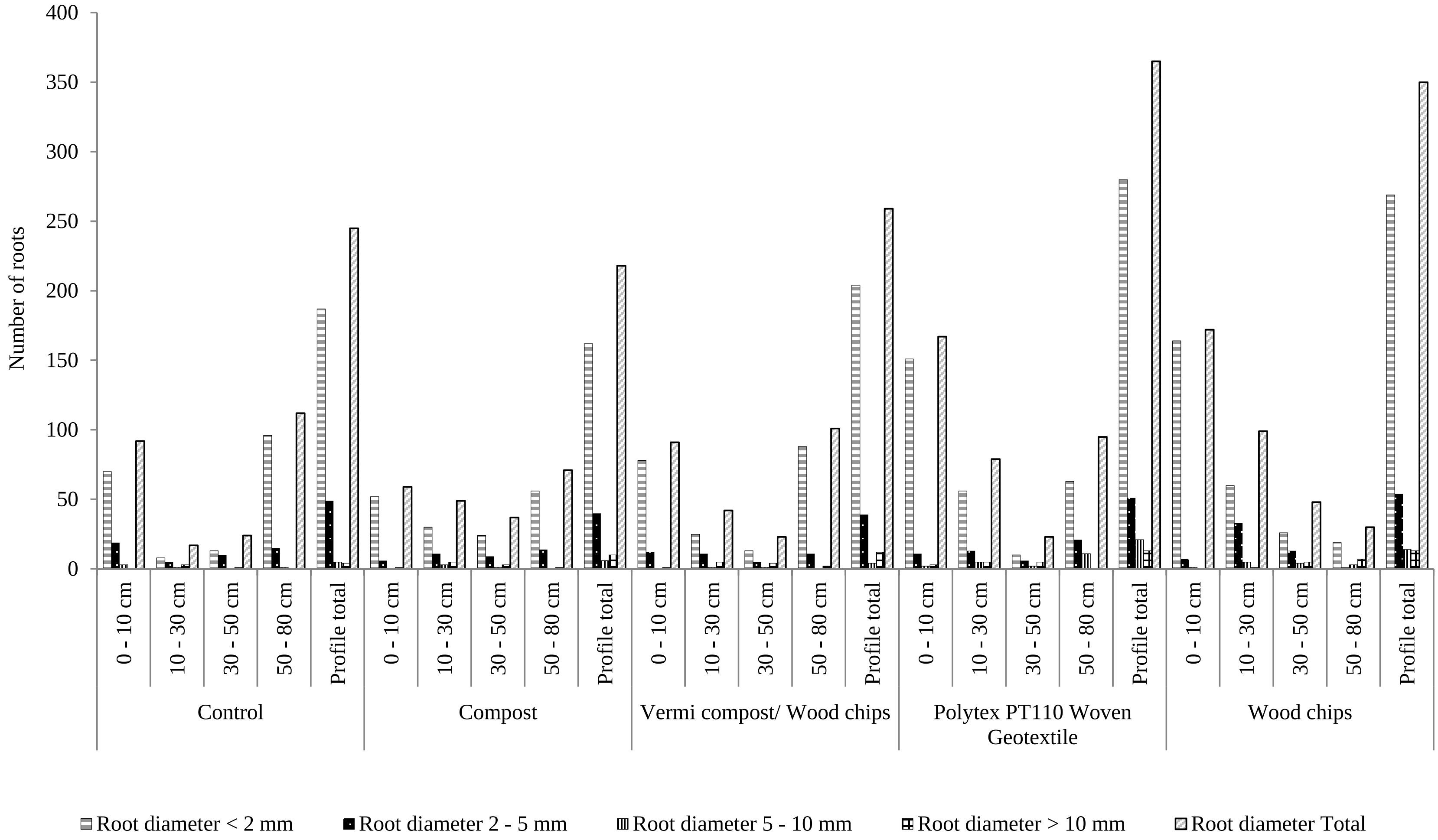

Fig 12: Root distribution of a single replication at site 2 in Sept 2009. Roots were categorised according to their diameter at 10 cm intervals.

Table 8: Mineral analyses results for compost applied during 2009.

Treatment	pH (KCl)	H2O (%)	C (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Compost	7.5	42.30	15.92	0.96	0.15	0.50	1.46	0.13	1312.74	67.42	890.01	8.23	86.33	7.68

Table 9: Mineral analyses results for vermi compost applied during 2009.

Treatment	pH (KCl)	H_2O (%)	C (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Vermi compost	7.6	48.10	12.78	0.93	0.37	0.53	1.05	0.28	1088.55	122.24	207.47	1.88	136.28	10.65

Table 10: Results of soil mineral analysis at10 cm depth in April 2010 at site 1.

Treatment	pH (KCl)	C (%)	Na (%)	K (%)	Ca (%)	Mg (%)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	B (mg/kg)	Fe (mg/kg)	P Bray (mg/kg)
Control	5.68^{ab}	3.51^{ns}	1.44^{ns}	2.31^{c}	80.94^{ns}	7.40^{b}	5.20^{ns}	3.58^{b}	3.37^{ns}	0.34^{bc}	33.98^{ns}	45.00^{b}
Compost	5.87^{a}	4.04	1.57	3.86^{b}	81.67	8.45^{b}	4.00	3.48^{b}	2.42	0.40^{bc}	35.22	39.83^{b}
Polytex PT110 Woven Geotextile	5.75^{ab}	3.57	1.27	2.13^{c}	82.59	6.83^{b}	4.02	2.88^{b}	3.47	0.28^{c}	26.65	25.67^{b}
Wood chips	5.47^{b}	3.41	1.62	4.99^{b}	71.95	8.61^{b}	3.01	2.17^{b}	2.65	0.43^{b}	31.61	27.83^{b}
Vermi compost/ Wood chips	6.03^{a}	4.01	1.79	6.94^{a}	72.58	14.17^{a}	4.65	8.50^{a}	5.53	0.58^{a}	33.80	158.33^{a}
P Value	0.0372	0.1004	0.3925	<0.0001	0.2560	0.0002	0.1543	0.0007	0.0518	0.0034	0.2499	0.0020
LSD	0.3994	0.5823	0.5509	1.3727	8.2481	2.8174	1.7557	2.6984	2.1549	0.138	8.2588	66.185

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 11: Results of soil mineral analysis at 10 cm depth in April 2010 at site 2.

Treatment	pH (KCl)	C (%)	Na (%)	K (%)	Ca (%)	Mg (%)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	B (mg/kg)	Fe (mg/kg)	P Bray (mg/kg)
Control	5.88^{ns}	1.73^{ns}	1.07^{ns}	2.07^{b}	80.16^{ns}	7.42^{c}	5.72^{ns}	5.85^{ns}	7.53^{ns}	0.16^{ns}	47.43^{ns}	104.17^{ns}
Compost	6.25	1.60	0.96	2.30^{b}	84.35	9.64^{bc}	5.47	5.53	7.15	0.16	47.63	108.50
Polytex PT110 Woven Geotextile	5.67	1.55	1.27	1.95^{b}	75.01	7.76^{c}	6.31	6.43	8.47	0.12	39.62	99.17
Wood chips	5.07	1.75	1.43	5.42^{a}	75.37	12.23^{b}	7.23	6.63	10.27	0.23	57.83	156.67
Vermi compost/ Wood chips	6.30	1.68	1.27	5.17^{a}	76.79	16.77^{a}	6.72	7.10	7.48	0.19	57.31	184.00
P Value	0.0622	0.9319	0.2154	0.0008	0.1015	0.0005	0.2666	0.9088	0.6071	0.2977	0.1261	0.2613
LSD	0.4744	0.5411	0.4355	1.9109	7.7577	4.0043	1.8027	3.7143	4.491	0.1106	15.79	93.246

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 12: Results of soil mineral analysis at 30 cm depth in April 2010 site 1.

Treatment	pH (KCl)	C (%)	Na (%)	K (%)	Ca (%)	Mg (%)	P Bray (mg/kg)
Control	5.43^{ab}	3.10^{ns}	1.27^{b}	2.15^{c}	76.48^{ab}	7.34^{b}	33.67^{b}
Compost	5.63^{a}	3.71	1.45^{b}	3.13^{c}	79.17^{a}	7.65^{b}	33.17^{b}
Polytex PT110 Woven Geotextile	5.23^{bc}	3.83	1.36^{b}	2.40^{c}	69.32^{b}	6.89^{b}	19.50^{b}
Wood chips	5.07^{c}	3.17	1.81^{a}	4.37^{b}	61.09^{c}	7.21^{b}	17.83^{b}
Vermi compost/ Wood chips	5.62^{a}	3.50	1.85^{a}	6.21^{a}	72.35^{ab}	10.38^{a}	63.00^{a}
P Value	0.0011	0.4898	0.0008	<0.0001	0.0013	0.0013	0.0051
LSD	0.2736	1.0052	0.2863	1.062	7.994	1.6111	23.557

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 13: Results of soil mineral analysis at 30 cm depth in April 2010 at site 2.

Treatment	pH (KCl)	C (%)	Na (%)	K (%)	Ca (%)	Mg (%)	P Bray (mg/kg)
Control	5.68^{ns}	1.41^{ns}	0.99^{c}	2.60^{c}	76.81^{ns}	7.058^{b}	63.33^{ns}
Compost	5.90	1.25	1.14^{bc}	3.92^{bc}	79.42	8.39^{ab}	72.50
Polytex PT110 Woven Geotextile	5.68	1.40	1.11^{c}	2.32^{c}	76.48	7.13^{b}	63.17
Wood chips	5.75	1.27	1.74^{a}	5.13^{ab}	73.21	8.12^{b}	70.67
Vermi compost/ Wood chips	5.92	1.43	1.60^{ab}	6.13^{a}	73.23	11.05^{a}	103.33
P Value	0.3611	0.9306	0.0080	0.0006	0.4674	0.0416	0.2512
LSD	0.3147	0.5394	0.4559	1.7239	8.0892	2.7431	40.527

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Paper 2

The effect of mulching on yield and nutrient uptake to the leaves and fruit of apples on two different soil types

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Abstract

A field trail was designed to evaluate the effect of mulching on fruit quality, yield and mineral uptake in apples. Four different mulches: compost, wood chips, vermi compost topped with a wood chip layer and a polytex geotextile, were used as treatments on two different soil types (heavy silt loam and sandy loam). The vermi compost/wood chips and wood chips significantly increased yield efficiency after two years, at the heavy silt loam site. At the sandy loam site, the yield efficiency was increased by the polytex geotextile and wood chips treatments, however not significantly. At both sites, the compost treatment reduced the yield efficiency compared to the control treatment, whereas the woodchips treatment resulted in the highest yield efficiency at both sites. Treatment differences in fruit and leaf minerals were only significant at the sandy loam soil. Wood chips significantly increased fruit calcium at the sandy loam site. Leaf mineral uptake at the sandy loam soil was significantly increased as follows: compost and geotextile treatments (manganese), control treatment (iron), compost treatment (zink) and vermi, wood chips and geotextile (boron).

Introduction

According to Faust (1989), nutrition is one of the best ways to improve fruit tree productivity. However, nutritionists are faced with new challenges regarding the supply of nutrients to fruit trees. Due to our demand on the mineral status of certain organs of fruit trees, it is not sufficient to only supply the soil with nutrients and to ensure their uptake, but we have to manipulate the physiology of the plant to ensure that certain minerals elements reach the target organs in specified quantities. There is a strong correlation between apple yield and the leaf mineral concentrations of nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg) (Nurzynski *et al.*, 1990). While soil mineral analysis provides information on the soil's nutrient status, leaf and fruit mineral analysis will provide a cumulative insight on factors influencing nutrient availability and uptake by the plant (Faust, 1989).

A study on the accumulation of nutrients into the leaves and fruit of pears (Buwalda and Meekings, 1990) and young, bearing apple trees (Kanqueehi, 2008) indicated the differences between these organs. Fruits served as major sinks for P, K, boron (B) and copper (Cu) (Buwalda and Meekings, 1990; Kanqueehi, 2008), while leaves served as major sinks for calcium (Ca), manganese (Mn), (Buwalda & Meekings, 1990) and zink (Zn) (Kanqueehi, 2008). Both leaves and fruit contain moderate amounts of iron (Fe) (Buwalda and Meekings, 1990; Kanqueehi, 2008), Mg and N (Kanqueehi, 2008).

Understanding the variation in the mineral demand of the plant during the growing season in terms of timing and quantity is essential for manipulation of optimal fruit quality, storage and yield (Clark and Smith, 1998). Ions are further utilized by plant organs according to the physiology of the tree (Faust, 1980).

Uptake of nutrients by apple roots usually starts in late spring and reaches a maximum near mid summer (Nurzynski *et al.*, 1990). N, P, Ca, Mg and B are taken up actively during three different phenological stages in the season (Terblanche, 1972): 1) shoot extension growth, 2) six to nine weeks before leaf senescence, and 3) leaf drop. These trials were performed on 'Golden Delicious' in pots. Kanqueehi (2008) agreed with the uptake of N, P, Ca and Mg, but differed in that no B uptake was found before mid summer, even after shoot growth terminated. According to Kanqueehi (2008), postharvest uptake made the largest contribution to the total tree N, P and Ca, whereas pre-harvest uptake made the largest contribution towards the total tree Mg and B. these trials were performed on commercial 'Royal Gala' trees. K is actively absorbed during two different stages in apple trees: extension growth and leaf drop. The biggest contribution towards total tree K occurs during shoot growth extension (Terblanche, 1972; Kanqueehi, 2008).

In pears, Cu, Zn and Mn uptake is extremely low until shoot growth terminates, thereafter uptake is evident at two stages: first, when shoot growth terminates up to leaf senescence and second, during leaf drop (Terblanche, 1972). Results from Kanqueehi (2008) confirmed the findings of Terblanche (1972) on Zn uptake, but differed for Cu and Mn. No Cu uptake was found before mid summer and the largest contribution to the total tree Mn occurred from spring to mid summer.

In pears, Fe uptake is similar to that of Cu, Zn and Mn, except for the period of shoot extension, when no Fe is taken up (Terblanche, 1972; Kanqueehi, (2008). The biggest contribution towards Fe uptake was made post harvest.

The mineral content of the fruit at harvest will affect the storage life of fruit, as well as its quality (Bramlage, 1993; Tomala, 1997). Therefore, management practices during the growing season will affect fruit quality through management of the mineral content (Bramlage, 1993). By improving soil physical aspects such as porosity and water availability, plant mineral absorption can be enhanced (Pinamonti *et al.*, 1995). A sawdust mulch reduced physiological disorders in apple fruit and increased the Ca and K concentrations in the leaves (Lang *et al*., 2001). Furthermore, a combination of a compost mulch and fertilizer resulted in an overall higher concentration of minerals in the leaves (Brown and Tworkoski, 2004), whereas a bio-solid mulch, created more suitable conditions for the uptake of P (Neilsen *et al*., 2003).

Various organic materials mulches in orchards were effective in reducing evaporative water loss and controlling weeds (Forge *et al*., 2003). A paper mulch effectively increased growth and yield in high density apple orchards (Forge *et al*., 2003). According to Neilsen *et al*. (2004), some organic materials (different bio-solids covered by shredded paper and alfalfa straw) used as mulches were also able to increase available soil minerals and enhance the microbial activity, as well as root development. This had a positive effect on growth and yield in apples (Neilsen *et al*., 2004). Szewczuk and Gudarowska (2004) found that organic - and inorganic mulches in apple orchards increased yield and fruit size. Despite the large fruit size, apples from mulched treatments were firmer after harvest and had a higher Ca content. Compared to the mulched trees, fruit from herbicide strip trees showed a bigger weight loss during storage. A black, poly-ethylene mulch topped with sawdust increased Ca uptake in apple leaves and fruit, resulting in an increase in fruit storage quality, while the incidence of bitter pit was reduced significantly (Lang *et al*., 2001).

Mathews *et al*. (2002) found that both a peat moss and manure compost mulch application in newly planted apple orchards increased the growth and bloom rate, together with yield (Brown and Tworkoski, 2004). Newly planted apple trees, which will benefit from rapid growth (trunk cross-sectional area (TCA)) due to the positive correlation between trunk diameter and future yield (Mathews *et al*., 2002), increased their TCA with 50 percent when mulched with paper compared to no mulching (Neilsen *et al*., 2004). Using five different mulches (bio-solids, shredded paper, alfalfa straw, woven polypropylene, and bio-solids covered with shredded paper) in a semi arid region, Neilsen *et al*. (2003) also showed that, despite the optimum supply of water and minerals to all treatments, mulches further increased the yield in dwarf apple trees. Compared to a herbicide strip in an apple orchard, the cumulative yield over four years increased with the use of a mulch (Neilsen *et al*., 2004). In contrast, a green mulch like permanent sod, competes for minerals and water in the same root zone, resulting in less crop roots in the topsoil and a smaller soil volume for the crop to utilize. This reduced the crop yield (Trisdal, 1989).

Few mulch studies have been published on research conducted in South Africa. A six-year trial by Van Schoor (2009) revealed no differences in nutrient uptake between straw mulched and non mulched plots in a pear orchard, but fruit were firmer. Applying compost to the planting hole and as a mulch showed some changes in the soil chemistry, however these did not correlate with nutrient uptake in the trees (Van Schoor, 2009). Kotzé and Joubert (1992) reported no effect on the soil, fruit or foliar chemical composition after application of a rooibos tea waste mulch to newly planted apricot trees in a sandy soil. However, trees that were mulched showed an increase in size and yield, which was ascribed to optimized irrigation water utilization, due to reduced evaporative water losses.

These results contrasted positive reports in the rest of the world. Therefore, the efficiency of four mulches, other than straw, and their ability to influence nutrient uptake in apple trees, were re-evaluated in two commercial apple orchards. We hypothesized that, if we could change some physical, biological or chemical soil characteristics to more favorable conditions through mulching, the trees should react to these changes and respond with an increase in mineral uptake as reported in literature.

Materials and methods

In October 2008, the trial commenced on a commercial site, Lourensford Estate, Somerset West, Western Cape, South Africa (-34° 2' 31.29", +18° 55' 16.20"). Two high density orchards, adjacent to one another, were planted in 1998 with ‘Cripps` Pink’ apple cultivar on M793 rootstock. The soil types at the two orchards differed, orchard one being a heavy silt loam soil orchard two, a sandy loam soil. Both orchards were under the same management and were irrigated by means of micro sprinklers (5 mm/h for 3 hours twice a week during summer). A level surface in both orchards ensured no water runoff and no need for buffer rows. The inter row cover crop was managed by frequent mowing and the tree rows were managed by herbicide application.

Three organic mulches were applied: compost, wood chips, and vermi compost topped with wood chips (vermi). These were compared to an inorganic mulch, polytex PT110 woven geotextile (geotextile), and the commercial control (no mulch treatment). A randomized complete block design was used as the trial lay out, with six replications of four tree plots and two buffer trees between plots.

Mulches were re-applied on an annual basis to maintain an organic mulch of approximately 5 cm for the vermi and compost treatments. The first year, each of the vermi compost, compost and wood chip blocks received a total of approximately 72 L per 6 m^2. To conform to industry practices, the amount of wood chips applied was doubled from 2009 on the wood chip treatment only, to create a mulch of approximately 10 mm.

Fruit and leaf mineral analysis

Leaf samples (10 leaves / replication) were taken annually at the end of January according to standard procedure. Due to financial constrains, in January 2009 only four replicates were used, but in January 2010, six replicates were used for leaf mineral analysis.

A sample of 20 fruit of similar size was randomly sampled per block, at the main harvest, for mineral analyses. The pips and the fruit core were not included in the mineral analysis, but the peel was included. Both leaf - and fruit mineral analyses were done by a commercial laboratory (Bemlab Pty Ltd, Strand, South Africa).

Fruit yield and maturity

Fruit were harvested during April and May. Multiple harvests occurred due to the maturing character of Cripps' Pink. The total yield of each block was correlated with the trunk circumference to determine the yield efficiency per treatment.

From each block, two samples of 20 fruit of similar size were randomly selected for fruit quality assessment: one for evaluation at harvest and the other, after cold storage of eight weeks at -0.5°C. Evaluation was done by the Department of Horticultural Science, Stellenbosch University.

Fruit size was measured with an EFM (Electronic Fruit Size Measure) and fruit firmness was determined with a FTA (Fruit Texture analyser), using a 7.9 mm tip, on opposite fruit sides. Both instruments are from GÜSS Manufacturing (Pty) Ltd, Strand, South Africa. Fruit mass was determined with an electronic scale.

Fruit colour was determined for background colour and pink over colour (the intensity of the red and the percentage of the fruit covered). This was done by visual inspections and ratings according to colour charts (Background: Unifruco Research Service (PTY) Ltd. Colour chart for apples and pears. 0.5 = Green and 5 = Yellow), (Pink: Pink Lady colour chart, 1 = Green and 12 = Pink). Starch break down was visually assessed according to a colour chart (Unifruco Research Service (PTY) Ltd.) for pome fruit (circular types), after the fruit was cut in half, painted with an iodine solution (1%) and allowed to dry for one minute.

The total soluble solids (TSS) and titratable acidity were measured from juice made of wedges from all 20 fruit. TSS was measured with a digital refractometer (ATAGO CO.LTD, ATAGO model: PR-32) and the acidity via titration with NaOH (0.1 mol.L^{-1}) in a Metrohm 760 sample changer.

Shoot growth

Shoot growth was measured from the length of two one-year-old lateral shoots at each block after two growing seasons (15/ 04/ 2010).

Statistical analysis

Data was analyzed with the Statistical Analysing System (SAS) programme (SAS Institute Inc, 2004, Cary, NC) by means of a general Linear Model (GLM). The least square means and standard errors were calculated for treatments. Variance was considered significant at a 5% level.

Results

2008/2009

Fruit maturity and quality

Except for malic acid, there were no significant differences in any of the parameters regarding fruit maturity between treatments on site 1. The wood chips and vermi treatments had significantly higher malic acid values than the control and geotextile treatments, but did not differ from the compost treatment (Table 1).

At site 2, no significant differences were found among any of the treatments for the fruit maturity parameters at harvest (Table 2).

The fruit quality evaluation after cold storage only showed significant differences in red colour intensity at site 1. The wood chips and vermi treatments had significantly higher values in red intensity compared to the compost treatment, but did not differ significantly from the control and geotextile treatments (Table 3).

At site 2, no significant differences were found between any of the treatments for fruit quality after cold storage (Table 4).

Yield

At site 1, the weight of fruit picked during the main harvest (harvest 2) was significantly lower for the compost compared to the other treatments (Table 5). The yield efficiency of the total harvest was significantly higher for the wood chips compared to the control and compost treatments, but did not differ significantly from the geotextile and vermi treatments (Table 5).

No significant differences were found between treatments for yield at site 2 (Table 6).

Fruit and leaf mineral analysis

Fruit mineral analysis did not show any significant differences between treatments at either site (Tables 7 and 8). At site 1, leaf mineral analysis resulted in significantly higher N levels at the vermi treatment compared to the wood chips, compost, and control treatments, but did not differ significantly from the geotextile treatment. None of the other elements showed any significant differences (Table 9). At site 2, leaf mineral analyses did not show any significant differences between treatments (Table 10).

2009/2010

Fruit maturity and quality

No significant differences were found for fruit evaluations at harvest at either site 1 (Table 11) or site 2 (Table 12), or after storage, for site 1 (Table 13) or site 2 (Table 14).

Yield

At site 1, the weight of fruit harvested from the first harvest (main harvest) for the compost treatment was significantly lower compared to the other treatments. During the second harvest, the percentage fruit harvested from the wood chips treatment was significantly higher compared to the compost treatment, but not from the control, geotextile, and vermi treatments (Table 15). The yield for the vermi treatment was significantly higher than the control, compost and geotextile treatments, but did not differ significantly from the wood chips treatment. The total yield for the vermi, wood chips, geotextile and control treatments were all significantly higher than the compost treatment (Table 15). The yield efficiency for the wood chips and vermi treatments were significantly higher than all the other treatments at site 1 (Table 15).

At site 2, neither yield, nor yield efficiency showed any significant differences between treatments (Table 16).

Fruit and leaf mineral analysis

At site 1, fruit mineral analysis did not indicate significant differences between treatments (Table 17), but at site 2, significant differences were found in the Ca percentage of fruit between treatments (Table 18). The wood chips treatment had a significantly higher Ca percentage compared to the control, compost and vermi treatments, but not the geotextile treatment.

At site 1 (Table 19), the leaf mineral analysis did not show any significant differences between treatments, but at site 2, significant differences were found for some micro elements in the leaf mineral analysis (Table 20). The compost treatment had a significantly higher Mn concentration compared to the wood chip, control and vermi treatments, but did not differ significantly from the geotextile treatment. Both the compost and geotextile treatments had significantly higher Mn concentrations compared to the control and vermi treatments, but did not differ significantly from the wood chips treatment (Table 20). The control treatment showed a significant increase in Fe concentration compared to the geotextile, wood chips and vermi treatments, but not for the compost treatment. The Zn concentration was significantly higher in the leaves of compost treatment compared to the other treatments. The B concentration was the highest in the vermi treatment and differed significantly from the control and compost treatments, but did not differ significantly from the geotextile and wood chip treatments. The vermi, wood chips and geotextile treatments all had significantly higher concentration of B compared to the control treatment, but did not differ significantly from the compost treatment (Table 20).

There were no significant differences between treatments for shoot growth at either of the sites (Table 21).

Discussion

2008/2009

Fruit maturity and quality

At site 1, the wood chips and vermi treatments showed significant higher values for malic acid at harvest. These results were not observed after cold storage. According to Casero *et al*. (2004), K and P, in both the fruit and leaves, are well correlated with fruit acidity. Nevertheless, these elements showed no significant differences in fruit or leaf analyses for these treatments. Both the vermi and wood chips treatments significantly increased the red colour of fruit after cold storage compared to the compost treatment. This was despite the significant higher leaf N found in the vermi treatment. These results did not occur again during the second season.

Although only significant at site 1, the wood chips treatment increased yield efficiency, whereas the compost treatment resulted in the lowest yield efficiency at both sites. This may be partly due to the higher percentage of plant parasitic nematodes at site 1 (data not shown in this paper) and smaller root systems at site 2 (data not shown in this paper), observed in the compost treatments.

2009/2010

Yield

At site 1, the vermi and wood chips treatments significantly increased the yield efficiency. The wood chips and geotextile treatments also resulted in the highest yield efficiencies at site 2, although differences were not significant. This is in line with previous research in various parts of the world, where mulching increased yield efficiency on various crops (Barzegar *et al.*, 2002; Baxter, 1970; Forge *et al.*, 2003; Merwin and Brown, 2009; Neilsen *et al.*, 2004). In a mulching (rooibos tea waste) trial under South Africa conditions by Kotzé and Joubert (1992), they also reported a significant increase in growth and yield of young apricot trees after mulching. However, their mulch did not affect the chemical properties of the soil, but rather increased the effective use of the irrigation water which led to the increase in yield and growth. Van Schoor

(2009) agreed with their findings and reported that, even after six years, a wheat straw mulch had little effect on the soil chemistry.

In our trial, in the case of the wood chips treatment at both sites and geotextile treatment at site 2, little changes in the soil chemical properties were noticed after two seasons, but these treatments did result in the largest root systems (data shown in paper 1) which could have contributed towards the increase in yield compared to the control treatment. In the vermi - treatment at site 1, changes in the soil nutrient status were observed. Elements such as P and Zn, of which both were significantly increased in the soil with the vermi treatment (data shown in paper 1), have the ability to increase yield efficiency (Neilsen and Neilsen, 1997; Fallahi *et al*., 2010) and may partly explain the increases we found in yield efficiency for this treatment, compared to the control.

In contrast to the vermi, wood chip and geotextile treatments, the compost treatment resulted in a trend where it reduced the yield efficiency at both sites compared to the control treatment, even though it was not significant. This was in line with other mulching trials, using compost (Ghuman and Sur, 2001; Hartley and Rahman, 1998). At site 1, the yield efficiency of the compost and geotextile treatments could have been influenced by the presence of nematodes. The nematode analyses indicated that the compost and geotextile treatment contained high numbers of *Pratylenchus* (data not shown). These nematodes are known to reduce root system volumes which can result in a reduction in yield (Forge *et al*., 2008; Forge and Kempler, 2009).

At both sites, the yields for 2009/2010 season were lower than in 2008/2009. Despite this decrease in yield, fruit size did not change. The effect of the treatments on return bloom will be monitored in the 2010/2011 season to determine if this could be the cause for the lower yield.

Fruit mineral analysis

Analyses of the fruit mineral content only showed significant differences for site 2 (sandy loam soil), where the wood chips treatment resulted in an increased fruit Ca percentage, even though significant differences between treatments were not detected in the soil mineral analysis (data shown in paper 1). A general increase in nutrient uptake in the fruit due to mulching has also been reported before (Barzegar *et al*., 2002, Lang *et al*., 2001; Szewczuk and Gudarowska, 2004). Regarding Ca, the wood chip treatment resulted in the biggest root system of all treatments (data shown in paper 1), of which the biggest percentage was represented by fine roots (0.5 – 2 mm in diameter). As Ca is taken up at the tips of active growing young roots, the presence of a large volume of active growing roots is more important in Ca uptake compared to P and K (Faust, 1980). Additionally, Trisdal (1989) explained that root growth is favored in conditions where the soil temperature is more regulated. During mid summer, the wood chips treatment was very effective in regulating soil temperature and, during autumn, resulted in slightly higher soil temperatures compared to the other treatments at site 2 (Data shown in paper 1), which was also conducive to root growth. Therefore, the root architecture and volume in the wood chips treatment can partially explain the increased Ca uptake in the tree without an addition of Ca to the soil.

While root studies were carried out in this trial (data shown in paper 1), wet soil conditions after irrigation were observed at deeper levels for both sites. The subsoil of site 1 was wetter compared to the sandy soil of site 2 (personal observation). This was expected due to the heavier, silt soil type of site 1. On average, the trees at site 2 contained 133 more roots per treatment compared to that of site 1 (data shown in paper 1). These suboptimal environmental conditions could offer a possible explanation for differences only observed at site 2 at this time. During the 2010/2011 season, the irrigation will be adapted to the requirements at each site that will decrease excess moisture and possibly increase fruit mineral uptake, especially at site 1.

Leaf mineral concentration

The soil mineral analysis at site 1 (heavy silt loam soil), indicated significant differences between treatments in the levels of Na, Ca, K, Mg, Zn, Mn, B, and P (data shown in paper 1), but none of these were reflected in the leaf mineral analysis. This is in line with previous research where organic amendments changed the level of nutrients in the soil, but were not reflected in the leaves (Kotzé and Joubert 1992; Pinamonti *et al*., 1995; Van Schoor, 2009). According to Van Schoor (2009), trees may react to these situations over time as nutrients become more available to the plant. As our trial has only been running for two seasons, and heavier soils tends to lag behind lighter soils in reaction to changes, the reaction to these changes in site 1 are expected in the near future.

The vermi treatment significantly increased most of the soil minerals (P, K, Mg, Na, Zn, Mn and B (data shown in paper 1). This confirms results from Kale *et al.* (1992) and Sinha *et al.* (2010), where the application of vermi together with fertilizer increased both nutrient uptake and yield. The vermi treatment increased the soil P to very high levels at both sites (153.33 mg/kg at site 1 and 184.0 mg/kg at site 2) (data shown in paper 1). High soil P levels can reduce K uptake (Van Schoor, 2009), but leaf K levels were above the minimum industry requirements (Kotzé, 2001) at both sites. This should be monitored to prevent problems in the future.

In contrast to the results at site 1, the leaf mineral analysis at site 2 (sandy loam site) resulted in significant differences between treatments in the levels of Mn, Zn, Fe and B, whereas significant difference between treatments for Na, K and Mg where observed in the soil mineral analysis. The increases in Mn and Zn uptake can be ascribed to an extent to the higher concentrations found in the organic mulches. The mineral analysis for the compost and vermi material used in this trial indicated that the vermi contained about twice as much Mn compared to the compost (data shown in paper 1), but the compost treatment resulted in the highest Mn uptake into the leaves. The same was found with Zn, where the much lower concentration in the compost again resulted in a more effective uptake.

The compost treatment resulted in a root system that was even smaller than that of the control treatments (Forge and Kempler, 2009). The mycorrhizal analysis indicated a higher (4 – 5 %) root colonization at the compost treatment compared to the vermi treatment (data shown in paper 3). The smaller root system of the compost treatment may show a greater dependence on mycorrhizal contribution towards nutrient uptake (Carrenho et al., 2007), and since mycorrhiza is known to enhance the uptake of Mn (Linderman, 1988) and Zn (Atkinson, 1983; Lakatos *et al*., 2001), it offers an explanation as to why the compost treatment resulted in a significantly higher uptake of these nutrients compared to the vermi treatment. The fact that the leaves serve as greater sinks for Mn and Zn (Kanqueehi, 2008) may explain why differences were only observed in the leaves and not the fruit at this stage.

Both the compost and vermi mulches contained high levels of Fe (data shown in paper 1), but nevertheless the control treatment resulted in a significantly higher Fe concentration in the leaves compared to the geotextile, wood chips and vermi treatments. This cannot be explained at present. The compost and vermi material contained equally high amounts of B (data shown in paper 1), but only the vermi treatment increased the concentration in the leaves significantly. Increased leaf B concentrations have been reported in previous mulching trials using composts (Hartley and Rahman, 1998). Due to the complexity of micronutrient availability to plants, it is not linearly correlated to the total amount in the soil. Furthermore, a combination of plant and soil inability to supply micronutrients in the correct form can also cause differences in assimilation by plants (White and Zasoski, 1999). This can contribute to the lack of correlation between the results of the leaf analyses and specific levels of microelements in the compost and vermi - mulches in this trial. Terblanche (1972) came to a similar conclusion regarding uptake of a mineral nutrient and the role of the plant’s physiological need and the minerals’ availability in the soil.

Although limited literature is available on the direct effect of temperature regulation on specific micro elements, both Trisdal (1989) and Pinamonti *et al.* (1955) reported that temperature control through mulching resulted in a more stable environment for root activity and increased mineral uptake. During summer and autumn 2009/2010, maximum soil temperatures of the vermi and compost treatments where closely related, and both mulches regulated soil temperatures more effectively compared to the wood chips and the control treatments (data shown in paper 1). The most important time of Cu, Zn, Fe and Mn uptake occurs from shoot growth termination (end January) until leaf drop (around April/May) (Terblanche, 1972). As the soil conditions in the vermi and compost treatments during this time seemed to be more favourable for root activity, it could have resulted in the reported differential nutrient uptake.

The low nutrient holding capacity (CEC) of the sandy soil at site 2 may partly explain why significant differences were only observed in the heavier soil type at site 1. Coarse textured soils, such as at site 2, are more likely to lose mineral elements via leaching, especially in the high rainfall regions or heavily irrigated conditions, such as in this trial (Kotze, 2001). As the CEC at site 2 will probably increases over time due to the mulch application (Pinamonti *et al.*, 1995; Trisdal, 1989), we would expect that the treatments will result in an even higher mineral uptake and transport to the leaves.

Shoot growth

Increased shoot (Baxter, 1970) and TCA (Neilsen *et al*., 2003; Neilsen *et al*., 2004) growth due to mulch applications have been reported previously on newly planted orchards or dry land conditions. This is in contrast to the results obtained from this trial, but in agreement with expectations in a bearing, mature apple orchard with balanced vigor and low stress conditions.

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2008/2009

Table 1: Fruit maturity analysis at harvest (07/05/2009) at site 1.

Treatment	Background (green)	Red (intensity)	Red (%)	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TSS (^{o}Brix)	TA
Control	3.18^{ns}	6.17^{ns}	51.08^{ns}	61.83^{ns}	8.77^{ns}	66.50^{ns}	129.50^{ns}	14.02^{ns}	0.53^{b}
Compost	3.20	5.97	51.13	57.33	8.90	64.70	123.15	13.97	0.55^{ab}
Polytex PT110 woven geotextile	3.25	5.66	48.04	65.33	8.90	64.81	122.63	13.92	0.53^{b}
Wood chips	3.28	6.38	53.67	64.46	8.93	64.48	120.11	13.93	0.57^{a}
Vermi compost/ wood chips	3.35	7.16	57.42	64.42	8.96	64.47	120.48	13.85	0.57^{a}
P Value	0.6058	0.0742	0.1008	0.4538	0.7118	0.3051	0.5331	0.9204	0.0163
LSD	0.2381	1.0524	6.8979	9.8467	0.2966	2.2187	12.364	0.3824	0.0312

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 2: Fruit maturity analysis at harvest (07/05/2009) at site 2.

Treatment	Background green	Red intensity	Red (%)	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TSS (^{o}Brix)	TA
Control	3.33^{ns}	7.23^{ns}	59.17^{ns}	75.75^{ns}	9.07^{ns}	65.30^{ns}	124.47^{ns}	13.43^{ns}	0.57^{ns}
Compost	3.33	7.68	61.83	71.83	9.14	64.84	121.81	13.88	0.69
Polytex PT110 woven geotextile	3.31	7.03	56.9	75.42	9.06	66.14	127.54	14.02	0.61
Wood chips	3.34	7.55	59.9	80.92	9.09	64.72	120.64	14.45	0.65
Vermi compost/ wood chips	3.39	7.08	57.75	77.33	8.96	65.59	124.87	13.65	0.63
P Value	0.9906	0.3971	0.4076	0.1455	0.7198	0.5348	0.6871	0.4989	0.0781
LSD	0.2133	0.832	5.5302	7.0032	0.2677	1.9073	10.608	1.2204	0.0825

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 3: Fruit quality evaluation after cold storage for 8 weeks (07/07/09) at site 1.

Treatment	Background green	Red (%)	Red intensity	Greasiness (%)	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TSS (^{o}Brix)	TA
Control	3.74^{ns}	54.83^{ns}	6.40^{ab}	0.63^{ns}	93.58^{ns}	7.63^{ns}	66.19^{ns}	129.08^{ns}	14.23^{ns}	0.60^{ns}
Compost	3.68	54.67	5.73^{b}	0.79	96.50	7.69	66.50	130.39	13.97	0.58
Polytex PT110 woven geotextile	3.75	54.75	6.36^{ab}	0.42	92.83	7.72	66.48	129.83	14.10	0.58
Wood chips	3.63	57.33	6.68^{a}	0.97	95.00	7.79	66.73	130.07	14.27	0.59
Vermi compost/ wood chips	3.67	57.02	7.05^{a}	0.89	97.08	7.86	66.93	132.55	14.53	0.60
P Value	0.3116	0.8577	0.0477	0.2240	0.396	0.6316	0.836	0.892	0.8906	0.9614
LSD	0.1054	6.9021	0.8380	0.5215	5.1916	0.3299	1.3752	7.3679	1.1902	0.0666

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 4: Fruit quality evaluation after cold storage for 8 weeks (07/07/09) at site 2.

Treatment	Background green	Red (%)	Red intensity	Greasiness (%)	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TSS (^{o}Brix)	TA
Control	3.64^{ns}	47.83^{ns}	5.47^{ns}	0.14^{ns}	79.92^{ns}	7.63^{ns}	66.19^{ns}	129.08^{ns}	14.27^{ns}	0.49^{ns}
Compost	3.72	51.17	5.88	0.10	86.67	7.69	66.50	130.39	14.23	0.51
Polytex PT110 woven geotextile	3.72	51.08	5.83	0.15	81.17	7.72	66.48	129.83	13.93	0.49
Wood chips	3.66	49.75	5.63	0.17	80.17	7.79	66.73	130.08	13.90	0.48
Vermi compost/ wood chips	3.66	46.25	5.15	0.12	84.50	7.86	66.93	132.55	13.97	0.48
P Value	0.1580	0.2080	0.1200	0.9631	0.6943	0.6316	0.8368	0.8927	0.1351	0.5621
LSD	0.0821	4.9538	0.6046	0.2061	11.704	0.3299	1.3752	7.3697	0.3670	0.0409

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 5: The 2009 yield as recorded over the three harvesting days (1: 23/04/2009) (2: 05/05/2009) (3:13/05/2009) at site 1.

Treatment	Harvest 1 (kg)	Harvest 2 (kg)	Harvest 3 (kg)	Total yield (kg)	Yield efficiency (kg. cm^{-1})
Control	31.65^{ns}	84.63^{a}	2.01^{ns}	118.29^{ns}	1.20^{b}
Compost	40.30	60.04^{b}	4.16	104.50	1.08^{b}
Polytex PT110 woven geotextile	36.94	76.53^{a}	7.80	121.27	1.29^{ab}
Wood chips	45.18	80.88^{a}	6.36	132.43	1.52^{a}
Vermi compost/ wood chips	38.52	80.82^{a}	3.77	123.10	1.29^{ab}
P Value	0.2486	0.03770	0.3639	0.1739	0.0293
LSD	12.4980	16.1510	6.2672	22.3970	0.2590

Means with different letters differed significantly at $P < 0.05$. Means with "ns" was not significantly different.

Table 6: The 2009 yield as recorded over the three harvesting days (1: 23/04/2009) (2: 05/05/2009) (3:13/05/2009) at site 2.

Treatment	Harvest 1 (kg)	Harvest 2 (kg)	Harvest 3 (kg)	Total yield (kg)	Yield efficiency (kg. cm^{-1})
Control	57.22^{ns}	50.45^{ns}	20.70^{ns}	128.36^{ns}	1.27^{ns}
Compost	48.82	40.81	18.61	108.24	1.16
Polytex PT110 woven geotextile	58.06	45.98	24.36	128.40	1.40
Wood chips	61.88	42.49	27.69	132.35	1.45
Vermi compost/ wood chips	49.97	48.67	18.71	117.35	1.25
P Value	0.4132	0.6278	0.5450	0.2656	0.1453
LSD	16.1930	14.7270	13.0010	24.4840	0.2498

Means with different letters differed significantly at $P < 0.05$. Means with "ns" was not significantly different.

Table 7: Fruit mineral analysis of macro elements at harvest 2009 at site 1.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Water (%)
Control	37.00^{ns}	8.07^{ns}	130.33^{ns}	8.43^{ns}	6.20^{ns}	80.89^{ns}
Compost	35.83	6.11	115.83	7.07	5.95	80.90
Polytex PT110 woven geotextile	32.83	6.32	119.50	7.15	5.87	80.79
Wood chips	31.83	6.01	125.67	7.47	5.83	80.58
Vermi compost/ wood chips	35.50	8.12	132.67	7.32	6.35	80.47
P Value	0.2062	0.0861	0.3953	0.4627	0.5770	0.9874
LSD	5.0208	2.0470	20.2110	1.6875	0.7727	1.9892

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 8: Fruit mineral analysis of macro elements at harvest 2009 at site 2.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Water (%)
Control	35.33^{ns}	5.55^{ns}	121.67^{ns}	10.25^{ns}	6.20^{ns}	79.46^{ns}
Compost	37.83	5.50	130.50	9.88	6.48	79.36
Polytex PT110 woven geotextile	35.67	5.45	121.33	8.70	6.05	80.23
Wood chips	37.83	6.64	124.00	9.62	6.65	79.88
Vermi compost/ wood chips	36.50	5.19	119.67	8.62	5.95	80.25
P Value	0.8133	0.2902	0.3912	0.3879	0.1878	0.1042
LSD	5.5508	1.4394	16.656	2.0495	0.6635	0.8439

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 9: Leaf mineral analysis (Feb 2009) at site 1.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	2.35^{b}	0.10^{ns}	1.47^{ns}	1.18^{ns}	0.29^{ns}	254.00^{ns}	279.50^{ns}	87.25^{ns}	6.00^{ns}	142.75^{ns}	36.00^{ns}
Compost	2.36^{b}	0.11	1.41	1.23	0.30	229.00	261.50	88.75	6.25	131.50	36.75
Polytex PT110 woven geotextile	2.42^{ab}	0.11	1.42	1.20	0.28	232.75	276.50	91.00	7.00	139.75	38.00
Wood chips	2.39^{b}	0.10	1.39	1.13	0.25	237.00	327.00	84.25	5.75	168.25	34.50
Vermi compost/ wood chips	2.47^{a}	0.11	1.51	1.13	0.28	249.00	298.50	101.75	6.50	152.00	37.75
P Value	0.0321	0.0806	0.7063	0.8809	0.1256	0.5589	0.1089	0.1693	1.5580	0.3095	0.3314
LSD	0.0775	0.0091	0.2078	0.2475	0.03300	37.356	50.0470	14.8400	1.0430	37.273	3.8696

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 10: Leaf mineral analysis (Feb 2009) at site 2.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	2.39^{ns}	0.12^{ns}	1.53^{ns}	0.92^{ns}	0.30^{ns}	214.75^{ns}	318.75^{ns}	95.50^{ns}	4.00^{ns}	143.50^{ns}	42.00^{ns}
Compost	2.40	0.13	1.76	1.06	0.31	241.00	307.25	124.50	5.00	139.25	37.25
Polytex PT110 woven geotextile	2.30	0.11	1.49	1.01	0.29	239.25	273.75	118.25	4.50	124.25	32.50
Woodchips	2.39	0.12	1.53	1.05	0.33	239.25	279.75	123.00	4.50	121.75	31.75
Vermi compost/ wood chips	2.39	0.14	1.64	1.09	0.32	230.25	271.00	118.25	4.75	122.00	37.25
P Value	0.5651	0.2380	0.1781	0.2989	0.4928	0.3339	0.0582	0.4362	0.4724	0.3049	0.4492
LSD	0.1501	0.0291	0.2537	0.1756	0.0517	30.003	37.792	35.847	1.1767	27.489	12.886

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

2009/2010

Table 11: Fruit maturity analysis at harvest (22/04/2010) at site 1.

Treatment	Background Green	Red intensity	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TSS (^{o}Brix)	TA
Control	2.91^{ns}	7.99^{ns}	41.00^{ns}	8.75^{ns}	64.59^{ns}	117.06^{ns}	13.32^{ns}	0.56^{ns}
Compost	3.12	8.13	38.65	8.78	64.46	117.27	12.93	0.55
Polytex PT110 woven geotextile	2.87	7.78	45.17	9.06	65.13	120.90	12.73	0.55
Woodchips	2.86	7.98	42.96	8.79	65.04	119.89	13.08	0.56
Vermi compost/ wood chips	2.87	8.78	45.38	8.75	64.01	125.04	13.60	0.56
P Value	0.5769	0.6000	0.4240	0.2233	0.6520	0.6395	0.6606	0.9952
LSD	0.3772	1.3528	8.3614	0.3115	1.7053	11.987	1.273	0.063

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 12: Fruit maturity analysis at harvest (22/04/2010) at site 2.

Treatment	Background green	Red intensity	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TSS (^{o}Brix)	TA
Control	3.02^{ns}	5.90^{ns}	58.75^{ns}	8.33^{ns}	65.22^{ns}	125.92^{ns}	14.23^{ns}	0.56^{ns}
Compost	3.04	6.47	55.00	8.22	64.92	124.92	14.15	0.62
Polytex PT110 woven geotextile	3.00	6.58	44.25	8.21	64.38	121.39	13.72	0.59
Woodchips	3.00	6.68	48.32	8.15	64.13	118.88	13.87	0.56
Vermi compost/ wood chips	3.03	6.28	52.18	8.08	64.87	129.00	13.95	0.59
P Value	0.6624	0.7143	0.4032	0.5533	0.7101	0.1960	0.4093	0.5405
LSD	0.0626	1.2432	16.215	0.3114	1.7629	9.0224	0.6057	0.0871

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 13: Fruit quality evaluation after cold storage for 8 weeks (24/06/2010) at site 1.

Treatment	Background green	Red (%)	Red intensity	Greasiness (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TA
Control	3.50^{ns}	58.42^{ns}	6.99^{ns}	0.22^{ns}	7.44^{ns}	62.35^{ns}	111.02^{ns}	0.47^{ns}
Compost	3.55	59.83	7.27	0.41	7.44	63.09	114.38	0.48
Polytex PT110 woven geotextile	3.83	56.17	6.78	0.28	7.77	63.36	114.61	0.44
Woodchips	3.52	57.92	6.88	0.29	7.54	62.68	111.60	0.45
Vermi compost/ wood chips	3.47	54.25	6.52	0.18	7.55	62.34	109.58	0.47
P Value	0.3229	0.5418	0.4771	0.3096	0.3402	0.5996	0.6003	0.5897
LSD	0.3807	7.1362	0.8537	0.225	0.3633	1.5964	7.7046	0.0483

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 14: Fruit quality evaluation after cold storage for 8 weeks (24/06/2010) at site 2.

Treatment	Background green	Red (%)	Red intensity	Greasiness (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TA
Control	3.51^{ns}	48.48^{ns}	5.82^{ns}	0.03^{ns}	7.16^{ns}	64.53^{ns}	120.67^{ns}	0.44^{ns}
Compost	3.43	43.78	5.50	0.03	7.21	64.01	117.73	0.45
Polytex PT110 woven geotextile	3.45	51.92	6.35	0.02	7.17	63.78	116.58	0.43
Woodchips	3.50	48.78	5.99	0.13	7.02	63.11	112.69	0.46
Vermi compost/ wood chips	3.76	48.30	5.83	0.04	7.20	65.00	112.76	0.48
P Value	0.2408	0.4940	0.5893	0.2025	0.6503	0.2727	0.3651	0.1630
LSD	0.3215	9.1464	1.0776	0.1029	0.2866	1.8089	10.685	0.0433

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 15: The 2010 yield as recorded over the two harvesting days (1: 21/04/2010) (2: 28/04/2010) at site 1.

Treatment	Harvest 1 (kg)	Harvest 2 (kg)	Total yield (kg)	Yield efficiency (kg. cm^{-1})
Control	39.37^{a}	19.85^{ab}	79.00^{b}	0.75^{b}
Compost	25.50^{b}	16.79^{b}	63.53^{c}	0.45^{b}
Polytex PT110 woven geotextile	37.33^{a}	19.61^{ab}	79.73^{b}	0.57^{b}
Woodchips	38.99^{a}	31.59^{a}	89.58^{ab}	0.75^{a}
Vermi compost/ wood chips	45.02^{a}	29.39^{ab}	96.93^{a}	0.72^{a}
P Value	0.0228	0.1402	0.0029	0.0020
LSD	11.158	13.897	15.815	0.1457

Means with different letters differed significantly at P < 0.05. Means with “ns” was not significantly different.

Table 16: The 2010 yield as recorded over the two harvesting days (1: 22/04/2010) (2: 03/05/2010) at site 2.

Treatment	Harvest 1 (kg)	Harvest 2 (kg)	Total yield (kg)	Yield efficiency (kg. cm^{-1})
Control	57.12^{ns}	41.03^{ns}	115.34^{ns}	0.84^{ns}
Compost	47.34	37.28	102.14	0.78
Polytex PT110 woven geotextile	58.27	44.62	121.22	0.96
Woodchips	70.46	38.80	127.45	1.03
Vermi compost/ wood chips	49.72	35.95	103.74	0.83
P Value	0.2766	0.8849	0.3071	0.2477
LSD	22.753	18.873	28.469	0.2429

Means with different letters differed significantly at P < 0.05. Means with “ns” was not significantly different.

Table 17: Fruit mineral analysis at harvest 2010 at site 1.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	57.00^{ns}	5.35^{ns}	120.83^{ns}	6.93^{ns}	5.95^{ns}	12.07^{ns}	1.40^{ns}	2.43^{ns}	0.30^{ns}	0.42^{ns}	4.75^{ns}
Compost	61.00	9.08	107.33	6.43	6.13	11.90	1.38	2.75	0.25	0.85	4.03
Polytex PT110 woven geotextile	54.33	5.61	121.17	7.17	6.05	12.90	1.32	2.15	0.32	0.38	4.82
Woodchips	55.67	6.31	117.17	7.30	5.88	11.45	1.33	2.60	0.32	0.40	4.55
Vermi compost/ wood chips	56.50	5.58	119.00	7.21	6.00	13.07	1.35	1.93	0.30	0.42	4.40
P Value	0.5786	0.2238	0.8071	0.5558	0.9574	0.7379	0.8872	0.4811	0.3089	0.4477	0.5161
LSD	8.6153	3.6574	26.574	1.1744	0.7087	2.9107	0.1926	1.0302	0.0712	0.5998	1.0084

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 18: Fruit mineral analysis at harvest 2010 at site 2.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	46.50^{ns}	6.98^{ns}	109.33^{ns}	5.40^{b}	5.52^{ns}	9.22^{ns}	1.03^{ns}	2.87^{ns}	0.22^{ns}	0.70^{ns}	3.33^{ns}
Compost	47.17	6.62	111.50	5.63^{b}	5.55	10.05	1.03	2.88	0.20	0.52	3.02
Polytex PT110 woven geotextile	50.17	6.35	105.50	5.92^{ab}	5.47	11.05	1.08	2.97	0.25	0.60	2.97
Woodchips	49.00	5.92	107.00	6.57^{a}	5.45	10.77	10.7	3.82	0.18	0.52	2.48
Vermi compost/ wood chips	50.50	6.15	114.83	5.20^{b}	5.50	11.97	1.05	3.05	0.20	0.50	3.02
P Value	0.9547	0.6523	0.7896	0.0298	0.9950	0.2565	0.9311	0.5414	0.3170	0.7314	0.2945
LSD	13.007	1.5508	16.746	0.8581	0.5265	2.5499	0.1406	1.3158	0.0663	0.3488	0.7823

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 19: Leaf mineral analysis (Feb 2010) at site 1.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	2.37^{ns}	0.21^{ns}	1.71^{ns}	1.41^{ns}	0.30^{ns}	137.67^{ns}	253.50^{ns}	172.00^{ns}	5.50^{ns}	91.17^{ns}	40.17^{ns}
Compost	2.41	0.22	1.70	1.44	0.31	149.17	270.17	174.00	5.67	96.83	39.33
Polytex PT110 woven geotextile	2.39	0.23	1.68	1.47	0.27	161.17	299.50	183.00	5.83	108.50	38.83
Wood chips	2.36	0.20	1.56	1.48	0.31	146.67	242.17	177.00	5.50	88.83	37.50
Vermicompost/ wood chips	2.39	0.18	1.50	1.49	0.31	151.00	254.00	180.00	5.67	94.50	37.33
P Value	0.9384	0.6332	0.2587	0.9178	0.7010	0.3197	0.2844	0.9733	0.8433	0.4642	0.4340
LSD	0.1188	0.0661	0.2306	0.2021	0.0619	22.249	56.43	31.014	0.6988	23.338	3.5814

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 20: Leaf mineral analysis (Feb 2010) at site 2.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	2.47^{ns}	0.20^{ns}	1.48^{ns}	1.41^{ns}	0.38^{ns}	161.83^{ns}	192.33^{c}	236.83^{a}	4.67^{ns}	71.17^{b}	30.33^{c}
Compost	2.52	0.21	1.42	1.59	0.36	149.67	300.17^{a}	207.50^{ab}	4.33	103.33^{a}	32.50^{bc}
Polytex PT110 woven geotextile	2.56	0.27	1.47	1.49	0.37	127.00	262.83^{ab}	188.83^{b}	4.67	82.67^{b}	35.17^{ab}
Wood chips	2.48	0.21	1.38	1.41	0.42	135.83	230.17^{bc}	182.17^{b}	3.67	77.50^{b}	37.00^{ab}
Vermi compost/ wood chips	2.53	0.23	1.64	1.30	0.38	133.67	188.33^{c}	173.83^{b}	4.17	64.67^{b}	38.67^{a}
P Value	0.4443	0.2011	0.2721	0.3199	0.1592	0.0655	0.0017	0.0293	0.1313	0.0096	0.0104
LSD	0.1133	0.0492	0.2121	0.2175	0.0532	25.504	55.431	38.213	0.8629	20.587	4.7287

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Table 21: The average shoot growth of one year old lateral shoots measured at 15/ 04/ 2010.

Treatment	Site 1 (cm)	Site 2 (cm)
Control	37.74^{ns}	52.41^{ns}
Compost	36.04	44.26
Polytex PT110 woven geotextile	28.98	46.39
Wood chips	33.20	37.38
Vermi compost/ wood chips	24.50	46.85
P Value	0.3079	0.5158
LSD	14.28	18.057

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Paper 3

The effect of mulching on the populations of soil fauna and microflora in mature apple orchards

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Abstract

Soil biota plays a central role in the fertility of soil, even though it forms the smallest portion in the soil. A field trial was conducted to assess the influence of different mulches on the soil fauna, including mycorrhiza, nematodes, earthworms and other mesofauna. Two different soil types (sandy loam and heavy silt loam) planted with apples where used to indicate the effect of soil type on the results. Treatments included mulches with compost, vermi compost, wood chips and polytex geotextile, which were compared to an unmulched surface in a randomized complete block design. All mulches increased mycorrhizal colonization compared to the control treatment,

even though it was only significant at the sandy loam site. All organic mulches showed a potential to decrease the percentage of pathogenic nematodes after two seasons, with the exception of compost at the heavy silt loam site. The wood chips mulch proved to be the most effective. The polytex geotextile mulch increased the percentage pathogenic nematodes at both sites. Earthworm and mesofauna numbers were too low to analyse.

1. Introduction

Soil organisms play an important role in modern agriculture in terms of plant nutrition and soil fertility (Dick, 1997; Van Schoor, 2009). Mineralization, immobilization and nutrient cycling are all important microbial functions in the process of decomposition through which they are able to influence plant nutrition (Dick, 1992).

Depending on size, soil organisms can be divided into different taxa. Bacteria and fungi are known as microflora, while microfauna include nematodes and protozoa (Brussaard, 1997). Nematodes are further divided into five functional groups, depending on their feeding types and morphology: plant parasites, bacterivores, fungivores, omnivores and predators (Brussaard, 1997). Springtails and mites are classified as mesofauna, whereas earthworms and ants form part of the macrofauna (Fu et al., 2009).

Decomposing plant material or living plant roots are the two main forms that act as a food source in the soil food web. Primary decomposition of organic material is performed by the soil fungi and bacteria (Mulder et al., 2003), while plant parasitic nematodes (herbivores) and symbiotic fungi (Mycorrhiza) are classified as primary consumers of living plant material

(Bulluck et al., 2002). Depending on the food source input, a rapid increase in the number of micro floral decomposers or primary consumers of plant material will follow.

Fungal and bacterial feeding nematodes, together with a few other mesofauna invertebrates, are classified as secondary consumers that graze on the decomposer fungi and bacteria (Mathews et al., 2002). These mesofauna and nematodes also serve as prey for other generalist predators in the soil food web (Mathews et al., 2002). Bacterial numbers tend to increase sharply with the addition of organic material with a low carbon: nitrogen (C: N) ratio, resulting in a high number of bacterial feeding nematodes. Fungal mass is less variable over time and breaks down more complex substrates with a high C: N ratio (Ferris et al., 2001). The rapid bacterial decomposition pathway is bound to water availability, whereas the slower fungal pathway is less dependent on water availability (Powell, 2007).

As the soil food web is driven by organic C inputs, agricultural practices can also influence the rates at which the soil food web operates, as well as the functionality through its effect on the structural succession at higher trophic levels (Brusaard et al., 2007). Tillage reduces soil carbon mainly due to the oxidation of organic C which serves as a food source to this fauna (Trisdal, 1989). These shortages in C inputs will have a severe effect on the higher level of feeding groups as they require a constant flow of energy to support their abundance (Ferris & Bongers, 2006). Soil tillage can reduce the abundance of soil macrofauna with as much as 50% (Mathews et al., 2002).

Other key factors performed by the soil food web that are also beneficial to agricultural systems include N fixation, detoxification, disease suppression and the production of compounds that promote plant growth (Bonkwski et al., 2000; Bronic & Lal, 2005; Van Schoor, 2009). With the addition of inorganic fertilizers in the absence of a carbon source, only a small amount is released directly back to the soil solution due to bacterial immobilization (Bonkwski et al., 2000). In addition, the rate of nutrient cycling and decomposition are determined by the soil organisms which graze on the fungi and bacteria such as fungivorous and bacterivorous nematodes as well as protozoa (Whiteford et al., 1988, Mulder et al., 2003). Forge et al. (2003) stated that, when microbivorous protozoa and nematodes graze on the microbial biomass, it enhanced N mineralisation and turn over.

Tertiary and higher order consumers are considered to be the omnivorous and predatory nematodes (Bulluck et al., 2002) together with other larger arthropods, mites and Collembolans (Powell, 2007). These general predators prey on all the other consumers in the soil food web and link the energy flow within the soil food web. An increase in abundance of these higher trophic level nematodes will exert a high level of predation on lower level opportunistic nematode species such as the plant parasites, which responds quickly to newly available resources (Ferris & Bongers, 2006).

Agricultural soil management practice can affect the soil food web by influencing the amount of linkages between the different trophic feeding types, therefore the biodiversity (Forge & Kempler, 2009). In general, biodiversity is increased with low input- and decreased in high input agriculture (Bronic & Lal, 2004). High input unsustainable mono agriculture systems decrease soil biodiversity to an extinct stage where they completely rely on the addition of inorganic fertilizers, together with herbicides and pesticides, to maintain high yields (Giller et al., 1997). Having a well-structured and diverse soil food web would ensure more linkages to the higher order feeding groups, which can prevent specific groups, such as opportunistic species, from becoming dominant (Giller et al., 1997).

Due to the complexity of all the species involved in a diverse soil food web, researchers developed functional classes (groups with the same function in the soil food web) to generalize changes in the soil food web (Lacroix & Abbadie, 1998). Nematodes are central to these functional groups and form a part of the decomposing soil food web at different trophic levels (Ferris & Bongers, 2006; Forge et al., 2008). Changes in the structure of the microbial community will be mirrored by the same changes in the nematode community structure (Forge et al., 2003). Therefore, the analysis of the nematode community structure will give some indication on the status of the soil food web (Forge et al., 2003; Forge et al., 2008).

Synthetic or organic materials used as mulches are seen as an alternative method for orchard understory management (Mathews et al., 2002). According to Walsh et al. (1996), organic mulching can be defined as any organic material forming a protective layer on the soil surface, provides management that increase organic matter into the soil, enhance soil aeration and preserve soil moisture (Pinamonti et al., 1995). Compared to tillage and herbicide use, mulching reduces disturbance to the soil environment and preserves the soil biological activity (Merwin & Brown, 2009).

Forge et al. (2003) indicated that, shredded paper and sawdust mulch decomposition will result in N immobilisation, due to the greater C:N ratio’s. Forge et al. (2008) commented that previous research indicating that plant roots and microbial biomass compete for nutrients may not be accurate, because they did not consider a system in which nutrient cycling will increase along with an increase in C rich material. Forge et al. (2003) found that the abundance of bacterivorous and fungivorous nematodes can increase under different organic mulches. When a paper mulch was added to the soil surface, an increased number of protozoa and various nematodes trophic groups were found (Forge et al., 2003). Applying a manure mulch to the surface increased the number of nitrification- and cellulose degrading bacteria in the soil (Lakatos et al., 2001). Neilsen et al. (2004) found increased influxes of N and phosphate (P) turnover by the microbial biomass even though no N or P was added to the soil by the shredded paper mulch.

Plant growth can also be enhanced by bacterivorous nematodes by mechanisms other than mineralisation (Forge et al., 2003). Adding a paper mulch to the soil decreased the numbers of *Pratylenchus penetrans* effectively (Forge et al., 2008). *P. penetrans* is known as the root lesion nematode that causes fine feeder roots to become necrotic and die back when fed on. Bongers & Bongers (1998) described indexes to use the nematode community structure as an indication of structural and trophic succession at higher feeding orders that provide an overall status of the soil food web. However, these indexes cannot be used under South African conditions yet, due to a lack of identification of feeding types of the free-living nematodes (personal communication, S. Storey).

The application of compost mulches can also help with the suppression of some soil borne plant diseases (Brown & Tworkoski, 2004) and proves to be effective in reducing fungal and arthropod pests in orchards (St. Laurent et al., 2008). Derkowska et al. (2008) found that compost mulches decreased the number of roots colonized by arbascular mycorrhizal (AM), whereas a peat mulch had a positive effect on the frequency of colonized roots. According to Atkinson (1983), a root system with high root density and a large amount of lateral roots have a higher potential for colonization due to contact with mycorrhiza hyphae. Under herbicide strips, apple root density is low, which explains the lower rate of colonization (Atkinson & White, 1980). The application of a straw mulch to the soil surface increased the amount of earthworms (Cockroft & Trisdal, 1978). Earthworms are referred to as engineers of the ecosystem due to their ability to transform the physical state of materials (Abbott & Murphy, 2003), ability to mix organic matter and residues with the soil (Cockroft & Trisdal, 1978) and improve water infiltration and soil aeration (Trisdal, 1989).

An increase of organic matter (living plant roots or plant litter (mulch)) in the soil has been reported to increase the efficiency of nutrient uptake and water holding capacity of soil by activation of the soil biological sphere (Ferris & Bongers, 2006; Forge et al., 2008). Thereafter the food web becomes more structured as the opportunists are replaced by more specialized feeding groups, which exerts a top-down regulation effect on the numbers of opportunists (Ferris & Bongers, 2006; Forge et al., 2008). Based on this, we hypothesised that organic mulches can supply the existing depleted soil food web in our trial with a carbon source and thereby create a well-structured food web, compared to no mulch and inorganic mulch areas. If so, we can increase the fertility of the soil with an organic mulch and thus also increase fruit quality with an increase in nutrient uptake. As mycorrhizae are a primary consumer in the soil food web, the first changes associated with the treatments may be detected in the root colonization percentage – therefore it can be used to monitor and quantify changes in the soil biology. In addition, we propose to use differences in the ratio of plant parasitic to free-living nematodes as an indication of a top down regulation on proximal enrichment species.

2. Materials and methods

2.1 *Trial layout*

The trial commenced in October 2008 at Lourensford Estate, Somerset West, Western Cape, South Africa (-34° 2' 31.29", +18° 55' 16.20"). We used two apple orchards, adjacent to one another, planted with 'Cripps` Pink' on M793 rootstock in 1998. The orchards differed in soil type: orchard 1 consisted of a heavier silt loam soil type (Site 1), whereas orchard 2 had a light sandy loam soil type (Site 2). The inter row cover crops were managed by frequent mowing. Both orchards were managed similarly and irrigation was by means of micro sprinklers (5 mm/h for 3 hours twice a week) during the growing season. Herbicides, mainly glyphosate, were used on all treatments, twice during the season. Nemacure was applied in the past before the trial commenced for nematode control.

The two orchards were evaluated separately in their responses to the 4 different mulches. A randomized complete block design was used as the trial lay out with six replications of four tree plots and two buffer trees between plots. The three organic mulches were compost, wood chips, and vermi-compost (vermi) topped with wood chips. These were compared to an inorganic mulch, pollytex PT110 woven geotextile (geotextile), and the commercial control (no mulch treatment). The first year (2009), each of the vermi, compost and wood chip plots (6 m^2) received approximately 72 L of material. To conform to industry practices, the amount of wood chips applied was dubbled in 2009 for the wood chip treatments to cover the area with an approximately 10 cm mulch layer.

2.2 Mycorrhizae

The method from Giovanetti & Mosse (1979) was used as a staining protocol for mycorrhizae analysis. A composite root sample, consisting of four subsamples per plot, was taken at 15 cm depth. Fine roots, about 1 mm in diameter, were cut into 1 cm pieces and a subsample of 40 segments was used in the staining. The subsample was cleared in 10% w/v KOH in an autoclave at 121 ºC for 15 minutes. Roots were rinsed with water and then covered in 0.5% NH_4OH for 5 minutes. Afterwards roots were stained for 15 minutes at 121 ºC in the autoclave using 0.05 % w/v Alinine blue. Thereafter roots were de-stained in 50% glycerol.

A compound light microscope at 200 X magnification was used to examine 10 root pieces from each plot. The microscope slide containing the segments was fitted onto a hairline and the interactions were observed for the presence or absence of mycorrhiza. A colonization % was calculated for each plot at both sites.

2.3 Nematodes

Nematodes were analyzed on an annual basis in April. Two subsamples per plot were pooled to create a composite sample. Samples were taken at 0 – 15 cm depth and 15 – 30 cm depth. A sample containing 250 cm^3 soil was used in the centrifugal-flotation extraction method (Jenkins, 1964) to separate the nematodes from the soil. The suspension was reduced to 20 ml after 1 hour settlement. A compound microscope was used to identify the number of nematodes in 2 x 1 ml extractions. Plant parasitic nematodes were identified to genus level and the non parasitic nematodes were lumped together as free living nematodes.

2.4 Other mesofauna (Springtails and Collembola)

A pilot study was done at site 2 regarding the presence and composition of meso-fauna after two seasons of treatment. The Berlese-Tullgren funnel method (Gobat et al., 2004) was used to evaluate approximately 300 ml of soil from the top 15 cm during April 2010.

2.5 Statistical analysis

Data was analyzed using the Statistical Analysing System (SAS) programme (SAS Institute Inc, 2004, Cary, NC). A general Linear Model (GLM) procedure was used for the analysis of variance. Standard errors and least square means were calculated for treatments. Data was significant at a 5 % level.

3. Results

3.1 Mycorrhizae

No significant differences were found between treatments at site 1 (heavy silt loam soil) (Table 1). At site 2 (sandy loam soil) (Table 1), all mulch treatments increased the percentage of roots colonized by mycorrhizae significantly compared to the control treatment. The wood chips treatment resulted in the highest colonization percentage (96.67), while the percentage of colonized roots were higher in all the organic mulches compared the geotextile treatment (88.33). However, there were no significant differences between the mulch treatments.

3.2 Nematodes

During 2009, there were no significant differences between treatments at site 1 (Table 2). At site 2 in 2009 (Table 3), treatments differed significantly in their number of *Pratylenchus* nematodes in the 0 – 15 cm soil layer, where the geotextile treatment contained significantly higher numbers compared to the control, wood chips and vermi- treatments, but did not differ significantly from the compost treatment.

In the 2010 analysis, at site 1 (Table 4), treatments differed significantly for free-living (0 – 15 cm and 15 – 30 cm) and *Pratylenchus* (0 – 15 cm) nematodes. In the 0 – 15 cm ssoil layer, the compost and wood chips treatments contained significantly higher numbers of free-living nematodes compared to the other treatments. The geotextile treatment contained significantly higher numbers of *Pratylenchus* nematodes compared to the control, wood chips and vermi treatments in the 0 – 15 cm soil layer, but did not differ significantly from the compost treatment. At the 15 – 30 cm soil layer, the number of free-living nematodes was significantly higher at the compost treatment compared to the control and geotextile treatments, but did not differ significantly from the wood chips and vermi treatments. No significant differences were found in the 2010 analysis at site 2 (Table 5).

At site 1, treatments did not differ significantly in the percentage of plant parasitic and free living nematodes in either of 2009 of 2010 seasons in the upper 15 cm soil layer (Fig 1). The percentage of plant parasitic nematodes decreased, and the percentage of free-living nematodes increased at the control, wood chips and vermi- treatments from 2009 to 2010. In contrast, the compost and geotextile treatments increased the percentage of plant parasitic nematodes and decreased the percentage of free-living nematodes from 2009 to 2010 in the upper 15 cm soil at site 1.

In the 15 – 30 cm soil layer at site 1, treatments differed significantly in the percentage of plant parasitic and free-living nematodes in 2010 (Fig 2). The geotextile treatment contained a significantly higher percentage of plant parasitic nematodes compared to the compost and wood chips treatments, but did not differ significantly from the other treatments. Both the geotextile and control treatments contain a significantly higher percentage of plant parasitic nematodes compared to the wood chips treatment, but did not differ significantly from the other treatments. The wood chips treatment contained a significantly higher percentage of free-living nematodes compared to the control and geotextile treatments, but did not differ significantly from the other treatments. Both the wood chips and the compost contained a significantly higher percentage of free-living nematodes compared to the geotextile treatment, but did not differ significantly from the other treatments. All organic mulch treatments (compost, wood chips and vermi-) increased the percentage of free-living nematodes from 2009 to 2010, whereas the control and geotextile treatments decreased the percentage.

At site 2, treatments showed no significant differences in the percentage of plant parasitic and free-living nematodes at the upper 0 - 15 cm soil layer in 2009 and 2010 (Fig 3). In the control, compost and wood chips treatments, a decrease in the percentage plant parasitic nematodes and increase in the percentage of free-living nematodes from 2009 to 2010 was observed. The nematode composition in both the geotextile and the vermi - treatments remained relatively constant from 2009 to 2010.

In the 15 – 30 cm soil layer at site 2 (Fig 4), treatments showed significant differences during 2010 in the percentage of free-living and plant parasitic nematodes. The geotextile treatment contained a significantly higher percentage of plant parasitic nematodes compared to all the other treatments. The wood chips treatment significantly reduced the percentage of plant parasitic nematodes compared to the control and geotextile treatments, but did not differ significantly from the other two treatments. The control, compost, wood chips and vermi- treatments contained a significantly higher percentage of free-living nematodes (75.46, 80.28, 87.82, 77.60) compared geotextile treatment (59.41). In the control and geotextile treatments, there was a decrease in the percentage of free-living nematodes, whereas in the compost and woodchips treatments, an increase the percentage of free-living nematodes from 2009 to 2010 was observed. The vermi- treatment remained relatively unaffected from 2009 to 2010.

3.3 Mesofauna arthropods

The number of springtails and other arthropod mesofauna were so low that no analysis of any data was possible (data not show). It was therefore decided to postpone the next sampling.

4. Discussion

4.1 Mycorrhizae

At site 1 (heavy silt loam soil), treatments did not differ significantly in the percentage of roots colonized by mycorrhiza as found at site 2 (sandy loam soil). However, at both sites, all mulch treatments still resulted in a higher percentage root colonization compared to the control treatment. This is in line with the findings of Derkowska et al. (2008), where mulching increased the frequency of colonized roots. At both sites, the wood chips treatment resulted in the highest percentage root colonization. Derkowska et al. (2008) reported that different organic mulches varied in their ability to increase colonization – thus explaining this result.

According to Atkinson & White (1980), root-to-root infection due to high root density is one of the most effective methods to increase root systems colonized by mycorrhiza. In this trial, the root studies (data shown in paper 1) indicated that the wood chips treatment resulted in the largest roots system at site 1. The bigger root volume could partly explain the higher mycorrhizal colonization of the wood chips treatment. At site 2, both the geotextile and wood chips treatments resulted in the largest root systems (data shown in paper 1), but only the wood chips treatment showed a strong correlation with the percentage of roots colonized. Thus, another factor other than the root volume, is involved in colonization. According to Derkowska et al. (2008), root hairs and fine roots that form under highly proliferated, mulched root systems are more easily penetrated by fungi. Even though the number of root hairs and fine roots were not quantified in this study, we observed that the root system branching patterns of the treatments differed considerably (personal observation). At both sites, the geotextile treatment formed longer, less branched roots compared to the organic mulches (personal observation) and this may further explain the lower colonization compared to the wood chip treatment. The compost and vermi- treatments did not increase the size of the root system compared to the control treatment in either site (data shown in paper 1) however, they formed more branched root systems with finer roots (as observed in the wood chips treatment), which may account for the increased percentage of colonization (Atkinson, 1983) compared to the control.

At both sites, the compost treatment resulted in a higher percentage (+/- 5 %) roots colonized by mycorrhiza. According to the findings of both Lakatos et al. (2001) and Bronic & Lal, (2004), there is a negative correlation between high soil P levels and the mycorrhizal colonization rate. The vermi- treatment resulted in extremely high levels of soil P compared to the other treatments at both sites, even though it was only significant at site 1 (data shown in paper 1). At neither site, there was a clear relationship between high soil P levels and the colonization rate, as the vermi treatment resulted in a higher percentage of colonized roots, compared to the control and geotextile treatments. This agrees with Kale et al. (1992), where the application of vermi increased mycorrhizal colonization, even though it increased soil P levels as well.

Adding organic materials with high nutritional levels to the soil may reduce root colonization due to the effect from the different minerals (Carrenho et al., 2007). Since mycorrhiza is sensitive to high levels of P (Lakatos et al., 2001) and Zn (Miller et al., 1985), the coherent effect of the higher mineral status of the soil of the vermi- treatment could have suppressed colonization compared to the compost treatment (Carrenho et al., 2007) resulting in a lower colonization percentage.

5.2 Nematodes

5.2.1 Number of nematodes

There were no consistent significant effects of mulching on the number of the different nematodes over two years at either site. The compost and wood chips treatments significantly increased the number of free-living nematodes in the 0 - 15 cm soil at site 1 in 2010. The geotextile treatment resulted in a significantly higher number of *Pratylenchus* nematodes in 0 - 15 cm at site 2 (2009) and site 1 (2010).

During 2010 at site 1, where the geotextile resulted in the lowest (not significant compared to the control and vermi treatments) number of free-living nematodes, it also resulted in a significantly higher number of *Pratylenchus*. In this case, it is possible that the reduced number of general predators (free-living nematodes) instigated an increase in the number of opportunistic plant parasites, due to a lack of predation. In contrast, the compost treatment resulted in a significantly higher number of free-living nematodes, but did not reduce the number of *Pratylenchus* significantly compared to the geotextile treatment. With the compost treatment at site 1, there was a general increase in nematode numbers of both the free-living and plant parasitic groups. This agrees with results from Forge and Kempler (2009), showing that the effect of organic mulch applications are more specific, depending on the type of organic material, as opposed to the general idea of biological activity stimulated by organic material applications.

Pratylenchus nematodes reduce fine roots due to their feeding which causes the roots to become necrotic, resulting in meagre and un-branched root systems (Forge et *al*., 2008). This was in agreement with observations at both sites, where the root system in the geotextile treatment was less branched and contained fewer fine roots compared to the other mulched treatments (personal observation). The root system of the compost treatment at site 1 also resulted in the smallest root system compared to the other treatments (data shown in paper 1), which confirms the same observations made by Forge and Kempler (2009)

5.2.2 *Percentage free living and plant parasitic nematodes*

Differences between treatments were not always significant where the percentages of free-living and plant parasitic nematodes were analysed, however some general trends were observed. In the compost treatment, there was an increase in the percentage plant parasitic nematodes and a decrease in the percentage free-living nematodes from 2009 to 2010 at site 1(0 - 15 cm), but the opposite was found at site 2. With the vermi- treatment, the percentage of plant parasitic and free-living nematodes remained relatively unaffected at site 2 (15 cm and 15 - 30 cm), whereas the percentages decreased and increased at site 1 respectively for 0 - 15 cm and 15 - 30 cm. This trend was also reported by Forge & Kempler (2009) who found that, depending on factors such as soil type or the presence of different weeds involved as alternative hosts, the same organic mulch can give variable results.

Compost and vermi treatments, which contain high N organic material, are generally dominated by bacterial decomposition, characterized by a rapid response in bacterial feeding nematodes (Forge et al., 2005). Bacterial activity is limited to water availability and decreases sharply when the source becomes limited (Bullock et al., 2002). Furthermore, the bacterivorous nematodes release a smaller portion of their assimilated C to the general predators and other free-living nematodes when grazed on (Ferris and Bongers, 2006). Such shortages in resources to the higher trophic levels free-living nematodes could result in lower levels of predation pressure (Ferris and Bongers, 2006). In our trial, a lower ability to retain moisture and the high N organic material in the compost and vermi treatments could have reduced the inherent capability of these mulches to facilitate increases in the percentage free-living nematodes and suppressing the percentage plant parasites as effectively as the wood chips treatment.

The geotextile treatment increased the percentage of plant parasitic nematodes and decreased the percentage of free-living nematodes from 2009 to 2010 at both sites in the upper 15 cm and 15 - 30 cm layer, and significantly reduced the percentage of free-living nematodes at 15 – 30 cm. As the nematode analysis is a reflection on the supply side of the food chain (Ferris and Bongers, 2006), it is possible that the geotextile treatment only supplied the soil food web with living plant roots, due to its inorganic nature. Thus, the primary consumers, plant parasitic nematodes, increased as the source (plant roots) increased (Powel, 2007). In such a system with limited bacteria and fungi, it results in a situation with a limited food sources to the higher order free-living nematodes (Ferris and Bongers, 2006).

The wood chips treatment (mainly consisting of cellulose) decreased the percentage of plant parasitic nematodes and increased the percentage of free-living nematodes from 2009 to 2010 at both sites, however 2009 was not statistically compared to 2010. At both sites, the wood chips were the most effective treatment to decrease the percentage pathogenic nematodes and increase free-living numbers. These results are in line with previous research (Forge et al., 2003; Forge et al., 2008; Forge and Kempler, 2009), where paper mulches (mainly cellulose) reduced the numbers of pathogenic nematodes. When organic matter with high C:N ratios are applied to the soil, it is dominated by fungal decomposition. In this slower decomposition process, there would be a constant availability of resources to support the free-living nematodes (Ferris et al., 2001), which might suppress the numbers of the plant parasitic nematodes (Forge and Kempler, 2009).

In this trial, where a high percentage of mycorrhizae colonization was present, the wood chips treatment might have had an advantage compared to the other treatments concerning the soil food web, as mycorrhizae also serves as a food source to fungivorous nematodes. Thus, the soil food web might have already been partly developed to a fugal dominated pathway. According to Ferris and Bongers (2006), the already present soil organisms which fed on the mycorrhizae would only be supplied with an additional fungi source in the fungal dominated wood chips decomposition.

Over time, decomposition changes the state of the organic material to where both the fungal and bacterial pathways are used to decompose the different substrates (Powel, 2007). This will be mirrored by a succession in the soil food web (Ferris and Bongers, 2006). Since the data presented are only representative of two growing seasons, results from the compost and vermi-treatments may change in the future.

One advantage of the faster decomposing pathways by bacteria (compost and vermi-treatments), is the enhanced mineralization process that can supply the plant with more readily available minerals. This was observed at site 2, where both the vermi- and compost treatments resulted in a significant increase in some of the microelements in the leaves (data shown in paper 2). One the other hand, in a fungal dominated pathway (wood chips) where the high C:N ratio could lead to immobilization, the system can be managed with the application of inorganic fertilizer (Ferris and Bongers, 2006). The geotextile treatment represents a carbon-limited food web, in which more soil minerals are intercepted by microbial immobilization due to a slower recycling rate (Wardle, 1992).

The application of organic material to the soil surface poses a dilemma where the decomposition is restricted to a small zone of interaction on the soil surface. However, by applying the material to the soil surface, it reduces the disturbance to the soil environment and preserves the soil biological structure (Merwin & Brown, 2009). Enrichment further down the soil profile will be increased by fungal networks and other borrowing organisms such as earthworms (Abbott & Murphy, 2003; Cockroft & Trisdal, 1978; Trisdal, 1989; Van Schoor, 2009) and arthropods (Leroy et al., 2007; Mathews et al., 2002). During this trial, we observed very few earthworms (personal observation) and the mesofauna arthropods assessment resulted in almost none present. The application of nematicides three years preceding the trial, together with regular applications of herbicides and pesticides, could have reduced the numbers considerably. Thus, the two seasons' treatment, even in an undisturbed environment, may have still been too short to develop a sustainable soil food web to facilitate sufficient levels where these organisms and systems develop (Ferris & Bongers, 2006). However, even though we were not able to use the indexes described by Bongers & Bongers (2006), we still observed some changes in the soil biology by evaluating the free-living nematodes, which indicated that the surface application successfully influenced the soil biology.

5. Conclusion

All mulch types had a positive effect on mycorrhizal colonization compared to the control treatment, even though it was only significant at site 2. The higher colonization under the mulched conditions can be ascribed to the higher root-to-root infections, which was the highest at the more proliferated root system formed by the wood chips treatment.

Organic mulch treatments showed promising results in reducing pathogenic nematodes and increasing free-living nematodes. The wood chips treatment proved to be the most effective of the three organic treatments, however this was only over a short period of two seasons. The geotextile treatment increased the percentage of pathogenic nematodes. Since this treatment lacked the organic input of the other mulch treatments, it appears to have resulted in a situation where the food source (only plant roots) was a one sided supply.

Mycorrhizal colonization and the decomposition mineralization effect of the mulches already resulted in selected changes in plant mineral uptake and yield efficiency (data shown in paper 2). This indicates the important role of the soil biota in plant nutrition and production for future commercial agricultural practises. Agricultural intensification methods overlooked the effect of the soil biota on the continuous supply of nutrients and their contribution to root efficiency, which proves to be vital in modern agriculture.

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Results

Table 1: Percentage roots colonized by mycorrhiza at the site 1 and 2 in 2010.

Treatment	Site 1 Colonization %	Site 2
Control	81.67^{ns}	75.00^{b}
Compost	90.00	95.00^{a}
Polytex PT110 woven geotextile	90.00	88.33^{a}
Wood chips	98.33	96.67^{a}
Vermi-compost/ wood chips	85.00	91.67^{a}
P Value	0.4389	0.0016
LSD	18.75	9.98

Means with different letters differed significantly at $P < 0.05$. Means with "ns" was not significantly different.

Table 2: Analysis of the number of nematodes per 250 cm^3 soil at site 1 in 2009.

Depth	0 – 15 cm				15 – 30 cm			
Treatment	Free living	Prat	Xiph	Trich	Free living	Prat	Xiph	Trich
Control	483.3^{ns}	53.33^{ns}	91.7^{ns}	60.00^{ns}	441.7^{ns}	56.67^{ns}	58.3^{ns}	90.00^{ns}
Compost	678.3	31.67	188.3	18.33	463.3	18.33	100.0	140.00
Polytex PT110 woven geotextile	405.0	20.0	115.0	46.67	595.0	5.00	68.3	88.33
Wood chips	513.3	38.33	550.0	85.00	588.3	36.67	271.7	148.33
Vermi compost/ wood chips	543.3	33.33	105.0	63.33	490.0	30.00	46.7	158.33
P Value	0.5014	0.7531	0.3416	0.1719	0.5949	0.4206	0.2690	0.4071
LSD	317.52	51.749	521.72	54.204	250.38	56.817	231.79	96.068

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Prat = Pratylenchus

Xiph = Xiphinema

Trich = Trichoderma

Table 3: Analysis of the number of nematodes per 250 cm^3 soil at site 2 in 2009

Depth	0 – 15 cm				15 – 30 cm			
Treatment	Free living	Prat	Xiph	Trich	Free living	Prat	Xiph	Trich
Control	423.3^{ns}	25.00^{b}	61.67^{ns}	11.67^{ns}	633.3^{ns}	21.67^{ns}	111.67^{ns}	46.67^{ns}
Compost	456.7	65.00^{ab}	26.67	13.33	651.7	21.67	86.67	91.67
Polytex PT110 woven geotextile	760.0	116.67^{a}	131.67	10.00	895.0	28.33	168.33	35.00
Wood chips	563.3	1.67^{b}	73.33	1.67	810.0	45.00	155.00	10.00
Vermi compost/ wood chips	458.3	3.33^{b}	36.67	16.67	553.3	6.67	76.67	36.67
P Value	0.1323	0.0422	0.4267	0.4987	0.2085	0.5333	0.6124	0.1186
LSD	286.82	82.772	121.07	17.714	323.83	45.436	145.27	60.804

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Prat = Pratylenchus

Xiph = Xiphinema

Trich = Trichoderma

Table 4: Analysis of the number of nematodes per 250 cm^3 soil at site 1 in 2010.

Depth	0 – 15 cm				15 – 30 cm			
Treatment	Free living	Prat	Xiph	Trich	Free living	Prat	Xiph	Trich
Control	438.30^{b}	5.00^{b}	138.33^{ns}	6.67^{ns}	336.70^{b}	10.00^{ns}	115.00^{ns}	93.33^{ns}
Compost	775.00^{a}	45.00^{ab}	141.67	10.00	673.30^{a}	15.00	165.00	78.33
Polytex PT110 woven geotextile	401.70^{b}	85.00^{a}	180.00	26.67	365.00^{b}	50.00	158.33	75.00
Wood chips	758.30^{a}	23.33^{b}	50.00	33.33	583.00^{ab}	6.67	66.67	78.33
Vermi compost/ wood chips	513.30^{b}	13.33^{b}	110.00	13.33	550.00^{ab}	23.33	146.67	45.00
P Value	0.0069	0.0482	0.5382	0.1617	0.0415	0.0909	0.7097	0.6122
LSD	238.33	55.491	159.06	24.935	232.10	33.578	162.69	63.202

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Prat = Pratylenchus

Xiph = Xiphinema

Trich = Trichoderma

Table 5: Analysis of the number of nematodes per 250 cm^3 soil at site 2 in 2010.

Depth	0 – 15 cm				15 – 30 cm			
Treatment	Free living	Prat	Xiph	Trich	Free living	Prat	Xiph	Trich
Control	370.00^{ns}	6.67^{ns}	15.00^{ns}	15.00^{ns}	343.30^{ns}	1.67^{ns}	71.67^{ns}	26.67^{ns}
Compost	526.67	8.33	51.67	6.67	550.00	6.67	250.00	5.00
Polytex PT110 woven geotextile	326.67	6.67	115.00	8.33	470.00	8.33	233.33	70.00
Wood chips	531.67	1.67	8.33	5.00	503.30	1.67	76.67	11.67
Vermi compost/ wood chips	481.67	5.00	30.00	5.00	636.70	8.33	133.33	40.00
P Value	0.1452	0.7957	0.1543	0.7041	0.0973	0.3866	0.0573	0.1127
LSD	199.13	11.572	92.72	16.571	211.27	9.6347	153.73	52.038

Means with different letters differed significantly at $P < 0.05$. Means with “ns” was not significantly different.

Prat = Pratylenchus

Xiph = Xiphinema

Trich = Trichoderma

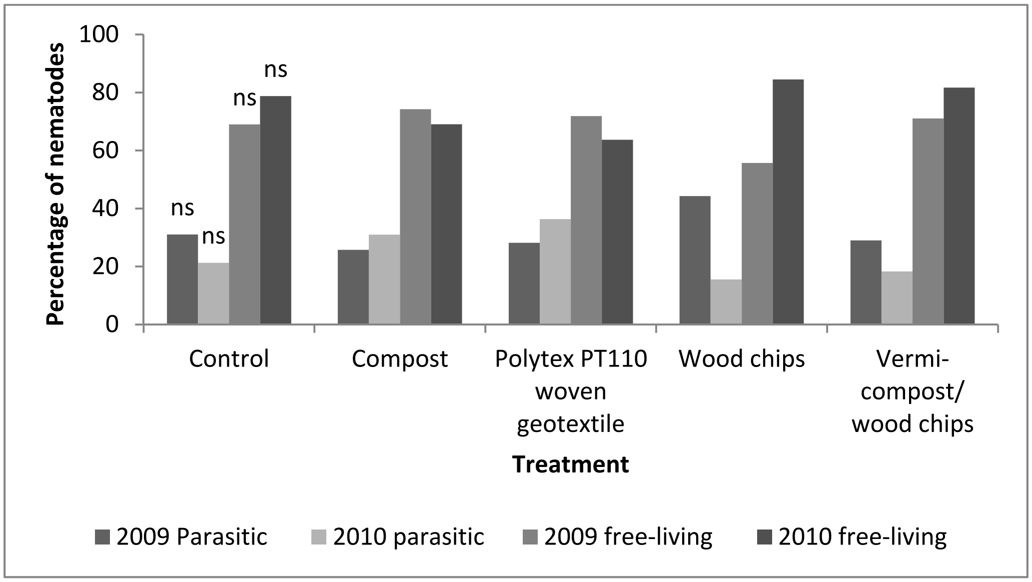

Fig. 1: Percentage plant parasitic and free-living nematodes at 0 – 15 cm soil depth in 2009 and 2010 at site 1.

Means with different letters differed significantly at $P < 0.05$. Means with "ns" was not significantly different.

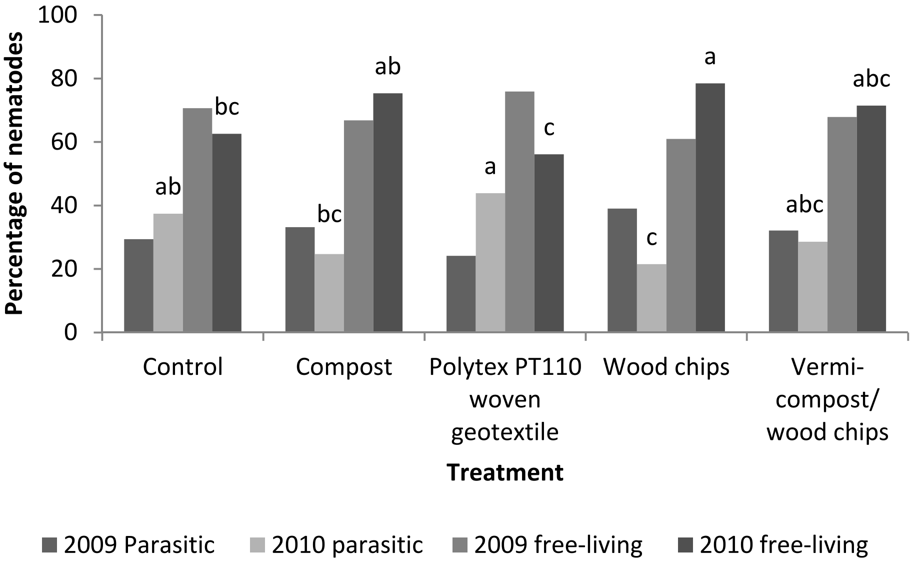

Fig. 2. Percentage plant parasitic and free-living nematodes at 15 - 30 cm soil depth in 2009 and 2010 at site 1.

Means with different letters differed significantly at $P < 0.05$. Means with "ns" was not significantly different.

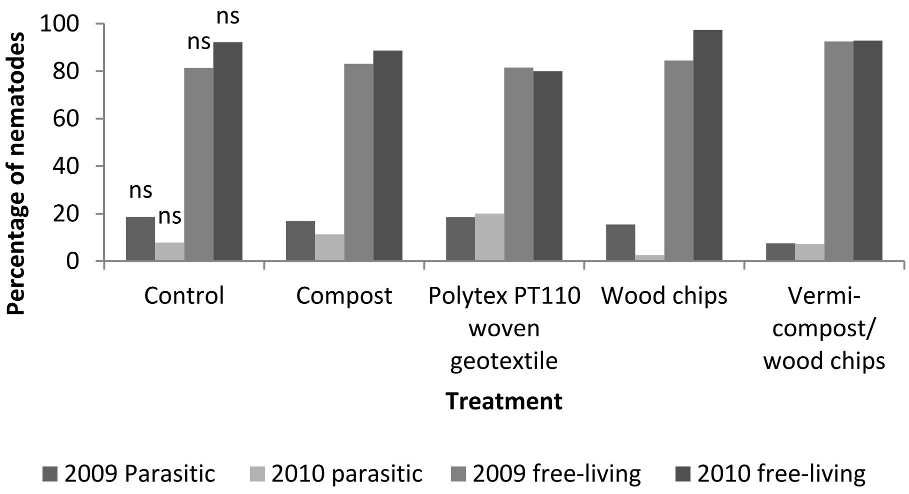

Fig. 3. Percentage plant parasitic and free-living nematodes at 0 – 15 cm soil depth in 2009 and 2010 at site 2.

Means with different letters differed significantly at P < 0.05. Means with “ns” was not significantly different.

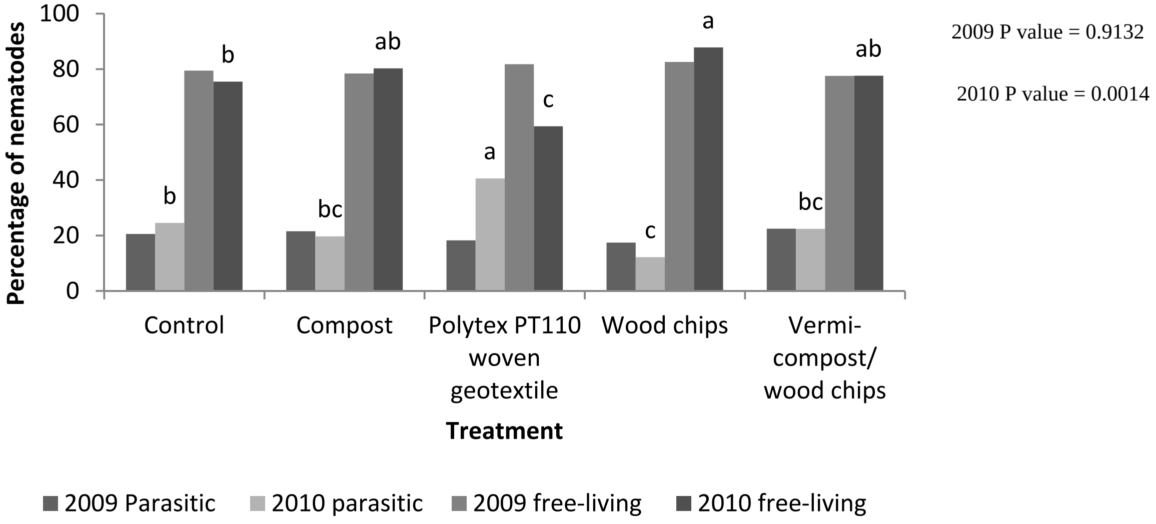

Fig. 4. Percentage plant parasitic and free-living nematodes at 15 - 30 cm soil depth in 2009 and 2010 at site 2.

Means with different letters differed significantly at P < 0.05. Means with “ns” was not significantly different.

Paper 4

The Ability of a Compost and Straw Mulch to Sustain Nutrient Uptake, Yield and Tree Performance in an Organic 'Cripps` Pink' Orchard.

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Subject Category: Crop production: Temperate fruit & Tree Nuts

The Ability of a Compost and Straw Mulch to Sustain Nutrient Uptake, Yield and Tree Performance in an Organic 'Cripps` Pink' Orchard.

Additional index words. Apples, Cover crop, Compost tea, Pink Lady^{R}, South Africa

Abstract. A field trail was initiated to investigate the efficiency of a combination of different mulch and ground cover systems to sustain high apple yields in a commercial orchard. The main treatment types in the tree rows were, an un-mulched chemical control that received inorganic fertilizer which was compared to two types of organically fertilized treatments: 1) compost and straw mulch and 2), a compost and straw mulch together with regular applications of compost tea. Both the compost/ mulch and compost/ mulch with compost tea treatments significantly increased the soil cation exchange capacity and soil carbon percentage. Furthermore, both treatments significantly contributed to the soil mineral content. However, only phosphorus (P) uptake was significantly increased in fruit and leaf samples where enhanced P soil levels occurred. All the mulch treatments significantly increased mycorrhizal colonization and affected soil microbial activity positively. Despite these positive effects of the mulching treatments on the soil chemistry and biology, both mulching treatment types significantly reduced the fruit nitrogen (N) concentration as well as yield, which resulted in vigorous vegetative growth. The addition of compost tea failed to show significant differences from the compost/ mulch treatment in as far as its contribution to soil minerals, fruit quality, leaf mineral uptake or yield over a period of eight years are concerned.

Introduction

Organic matter application to the soil can influence plant growth in various ways: through plant nutrient availability, total mineral addition to the soil, microbial mineralization rates and the formation of chelating agents which maintains mineral elements in a soluble state for plant uptake (Pinamonti, 1998). Addition of organic matter can also enhance soil physical aspects such as structural stability and porosity, which has a positive effect on root growth and hence further increases plant mineral uptake (Oliveira and Mervin, 2001).

According to Shiralipour et al. (1992), improved soil physical condition is the major benefit from organic matter applications, as compost application supplies mineral nutrients in limited quantities and can result in crop losses due to deficient plant levels if it the plant is not supplied with additional nutrients (Evanylo et al., 2008; Shiralipour et al., 1992). The microbial decomposition of organic material in the soil with high carbon: nitrogen (C:N) ratios such a compost, results in N mineralization, whereas the decomposition of N limited materials such as hay or straw, results in N immobilization (Forge *et al.*, 2003). Furthermore, if organic material is to be successfully incorporated into soil organic matter to enhance soil structure, the system should be N limited and the C source should be supplied at a constant, slow rate to support microbial life. Therefore, the rate of immobilization and mineralization should be in balance to support crop demands and uphold the organic matter content (Haynes, 1980).

In contrast, agricultural systems can benefit from the additive mineral effect of decomposing organic materials, as it would reduce the total requirement of inorganic fertilizer (Evanylo et al., 2008). Tiquia et al. (2002) reported that, mulching with composted yard waste increased the total microbial biomass together with the soil cation exchange capacity (CEC), nutrient levels ((P), potassium (K), calcium (Ca)) and soil organic matter when compared to bare surfaces. In addition, applying inorganic fertilizer resulted in a significant higher level of soil N compared to the composted yard waste mulch application. In contrast, Pinamonti (1998) found that compost (municipal solid waste and yard waste) mulches were able to increase soil N, P and K compared to inorganic fertilizer treatments. However, the leaf mineral analyses indicated that the mulches only increased K levels, whereas it resulted in lower N and P levels compared to the inorganic amendments, despite the composts' higher soil nutrient levels.

With complete organic production systems, the applications of manure and composts are seen as the only source of N and other nutrients, and are therefore applied at high rates in order to support crop growth and demand (Evanylo et al., 2008). Hadas et al. (2004) also found very high rates of compost application to be adequate for the production of wheat. In most agronomical situations such high application becomes uneconomical. However, organic producers often demand a premium for organically grown crops, thereby justifying the practice as more economically sustainable.

The addition of organic material to the soil surface as a mulch has further shown to regulate soil temperature and decrease weed growth together with evaporative water loss, promoting more favourable conditions for root growth and nutrient uptake (Haynes, 1980). According to Merwin and Brown (2009), mulch applications are less disruptive to the soil structure, more preservative to the soil biology and non-destructive to the tree roots in established orchards.

This report forms a part of a much bigger trial carried out by the ARC Infruitec-Nietvoorbij, Stellenbosch (DFPT Project 282010, Evaluation of soil surface and mulching practices for organic production of deciduous fruit). Our emphasis was focussed on the possible contribution of the mulches to fruit quality and only compared the two last seasons of the trial period.

We hypothesised that a compost mulch application in an apple orchard could stimulate and uphold the soil biology over time and in addition, regulate the balance between nutrient mineralization and immobilization to support the tree demand. Furthermore, mulching could create more favourable growing conditions in the upper soil layers, which would promote root proliferation with a higher possibility for the effective uptake of mineralized nutrients by the tree.

Materials and methods

The trial commenced in 2003 at the Elgin experimental farm in Grabouw, on a clay loam soil type. Four-year-old ‘Cripps` Pink’ apple trees on M7 rootstocks were used for seven tree plots (9 m^2).

Treatments consisted of mulching, mulching with compost tea and the unmulched chemical control in the tree row, which were combined with different combinations of weed control in the work row to create the different treatments. Treatments were replicated four times in a randomized block design. The mulch (50 mm thick) consisted of a compost layer topped with straw spread over the whole plot (1.5 m wide), which was reapplied on an annual basis.

The eight different treatments were as follow:

1. Chemical control of the weeds in the tree row, combined with weeds being slashed during the year in the work row (chemical - slash weeds).
2. Chemical control of weeds in the tree row, combined with a cover crop during the winter in the work row that was chemically controlled in the spring, with continuous chemical control during the rest of the growing season (chemical - cover crop & chemical).

3. Mulch in the tree row combined with a cover crop during the winter in the work row that was chemically controlled in the spring, with continuous chemical control during the rest of the growing season (mulch - cover crop & chemical).
4. The application of a mulch over the entire area (mulch - mulch).
5. Mulch in the tree row combined with a cover crop during the winter in the work row that was flattened in spring using a roller (mulch - cover crop & roller).
6. Mulch in the tree row with regular application of compost tea during the growing season combined with a cover crop during the winter in the work row that was flattened at spring using a roller (mulch & compost tea - cover crop & roller).
7. Mulch in the tree row, combined with weeds being slashed during the year in the work row (mulch - slash weeds).
8. Mulch in the tree row with regular application of compost tea during the growing season combined with combined with weeds being slashed during the year in the work row (mulch & compost tea - slash weeds)

In the unmulched treatments (treatments 1 and 2), fertilizer was supplied at a rate of 65 kg N. ha^{-1} at full bloom and in autumn. In the mulch treatments (treatments 3 to 8) where compost was applied, a single application was equivalent to 75 kg N. ha^{-1}, 20.8 kg P. ha^{-1} and 50 kg K. ha^{-1}. From 2003 until 2007, the compost/ mulch treatments received a compost application during spring and autumn; however, at the end of 2007 the trees were girdled to reduce vigorous vegetative growth. In 2008, no compost was applied in spring, however, a double application was made in autumn.

In treatments where a cover crop was used, legumes and wheat were rotated on an annual basis. Pest and disease management was conducted using organically acceptable methods.

Where symptoms of mineral deficiencies occurred, it was addressed using organically acceptable fertilizing practices.

In this paper we focused on the main effect of the treatments in the tree row. Treatments 1 and 2 (chemical control) are seen as the control treatments which are compared to mulch applications (treatments 3, 4, 5 and 7), and mulch application together with compost tea (treatments 6 and 8).

Soil mineral analysis. In 2010, a composite soil sample was taken at 5, 15, 30 and 45 cm soil depth at each plot. The mineral analysis was done by a commercial laboratory (Bemlab Pty Ltd, Strand, South Africa).

Leaf and fruit mineral analysis. Leaf samples (10 leaves / treatment plot) were taken annually at the end of January according to standard procedure. A sample of twenty fruit of similar size was randomly taken from each treatment plot, at the main harvest, for mineral analyses. The peel was included in the mineral analysis, however, the pips and the fruit core were removed. Both leaf - and fruit mineral analyses were done by a commercial laboratory (Bemlab Pty Ltd, Strand, South Africa).

Fruit maturity and quality. Fruit were harvested during April and May in 2009 and 2010. Multiple harvests occurred due to the specific maturation of ‘Cripps’ Pink’.

During 2009 and 2010, two samples of 20 fruit were used for fruit quality assessment from each treatment plot: one for evaluation at harvest and the other for storage quality assessment after cold storage for eight weeks at - 0.5°C. The samples were randomly taken from the main harvest. Evaluation was done by the Department of Horticultural Science, Stellenbosch University.

Fruit size was measured with an EFM (Electronic Fruit Size Measure) and fruit firmness was determined with a FTA (Fruit Texture analyser), using a 7.9 mm tip, on opposite peeled sides of the fruit (GÜSS Manufacturing (Pty) Ltd, Strand, South Africa). Fruit mass was determined with an electronic balance.

Fruit colour was determined for background colour and pink over colour (the intensity of the red and the percentage of the fruit covered). This was done by visual inspections and ratings according to colour charts (Background: Unifruco Research Service (PTY) Ltd. Colour chart for apples and pears. 0.5 = green and 5 = yellow), (Pink: ‘Pink Lady’ colour chart, 1 = green and 12 = pink). Starch break down was visually assessed according to a colour chart (Unifruco Research Service (PTY) Ltd, Starch conversion chart (Pome fruit) circular types), after the fruit was cut in half, painted with an iodine solution (1%) and allowed to dry for one minute.

The total soluble solids (TSS) and titratable acidity (TA) were measured from juice made of wedges from all 20 fruit. TSS was measured with a digital refractometer (ATAGO CO. LTD, ATAGO model: PR-32) and the TA via titration with NaOH (0.1 mol.L^{-1}) in a Metrohm 760 sample changer.

Statistical analysis. Data were analyzed with the Statistical Analysing System (SAS) programme (SAS Institute Inc, 2004, Cary, NC) by means of a general Linear Model (GLM). The least square means and standard errors were calculated for treatments. Variance was considered significant at a 5% level.

Results

Soil minerals

The 2010 soil mineral analysis at 5 cm soil depth (Table 1) showed that the pH was significantly more acidic in the control treatments (1 and 2) compared to both the mulch (3, 4, 5 and 7) and mulch + compost tea (6 and 8) treatments. Furthermore, the carbon (C) percentage was significantly lower in the control treatments compared to all other treatments, whereas the phosphate (P) and potassium (K) concentrations were only significantly lower compared to treatments 3, 4, 5 and 6. Sodium (Na) was also significantly lower in the control treatments compared to all treatments, except treatment 8. Both the mulch and mulch + compost tea treatments resulted in significantly higher calcium (Ca) and magnesium (Mg) concentrations compared to the control treatments.

At 15 cm soil depth (Table 2), the pH, C (not significant different from treatment 3), P, Ca and Mg concentrations were significantly lower at the control treatments compared to the other treatments. Treatments 4 and 6 resulted in a significantly higher Na concentration compared to treatment 1, 2, 3, 7 and 8, but did not differ significantly from treatment 5. Treatments 4 and 6 also contained a significantly higher K concentration compared the control treatments, but did not differ significantly from the other treatments.

At 30 cm soil depth (Table 3), the pH, C, Ca and Mg were significantly lower at the control treatments compared to other treatments. The P concentration was also significantly lower at the control treatments compared to all the other treatments, except for treatment 3. The Na concentration was only significantly higher at treatments 4, 5, 6 and 7 compared to the control treatments. Treatments 3, 4 and 6 contained significantly higher levels of K compared to the control treatments, but did not differ significantly from the other treatments.

At 60 cm soil depth (Table 4), the pH, Ca and Mg were significantly lower at the control treatments compared to the other treatments. Treatments 4, 5, 6 and 8 contained significantly higher concentration of P compared to treatments 1, 2 and 3. Furthermore, treatments 3, 4 and 6 contained a significantly higher concentration of K compared to the control treatments, whereas treatments 4, 5, 6 and 7 contained a significantly higher Na concentration compared to the control treatments.

Leaf and fruit minerals

Leaf mineral analysis in 2009 (Table 5) indicated that, treatments 1, 2, 3 and 6 contained significantly higher N percentages compared to treatments 5, 7 and 8. However, they did not differ significantly from treatment 4. The control treatments contained a significantly lower leaf P percentage compared to the other treatments. Treatments 1 and 4 contained a significantly higher leaf K percentages compared to treatments 5, 7 and 8. Treatments 1, 2, 7 and 8 contained significantly lower Mg percentages compared to 3, 5 and 6. Na was significantly higher in treatment 1 compared to treatments 5, 6 and 7, but did not differ significantly from the other treatments. However, Na was significantly higher in treatments 1, 2, 3, 4 and 8 compared to treatment 7. Manganese (Mn) was significantly higher in the control treatments compared to treatments 4, 6, 7 and 8. Copper (Cu) was significantly higher in treatment 6 compared to all the other treatments. Treatments did not differ significantly in terms of Ca, Fe, Zn and B.

The leaf mineral analysis in 2010 (Table 6) indicated that treatments 7 and 8 contained a significantly lower N percentage compared to all the other treatments. Treatments 1, 2, 3 and 4 all contained a significantly lower P percentage compared to treatments 7 and 8. The K percentage was also significantly higher in treatments 7 and 8 compared to the other treatments. The control treatments contained a significantly higher Cu concentration compared to the other treatments, whereas treatments 7 and 8 contained a significantly higher boron (B) concentration compared to the control treatments. However B was also significantly higher in treatment 7 compared to treatments 1, 2, 3, 4, 5 and 8.

The fruit mineral analysis in 2009 (Table 7) indicated that treatments 4, 6, 7 and 8 contained significantly higher P levels compared to the other treatments. No significant differences were found between treatments for Na, K, Ca and Mg.

Fruit mineral analysis in 2010 (Table 8) indicated significant differences in N, P, Mg, iron (Fe) and zinc (Zn). The control treatments contained significantly higher N and Zn concentrations compared to the other treatments. Treatments 7 and 8 contained a significantly higher P percentage compared to treatments 1, 2 and 6, but did not differ significantly from the rest. Treatment 6 contained a significantly lower percentage of Mg compared to all other treatments, except treatment 8. The control treatments contained a significantly higher concentration of Mn compared to the other treatments, except for treatments 4 and 7. Fe was significantly higher in treatments 2 compared to all the other treatments. However treatments 2 and 3 both contained a significantly higher Fe compared to treatments 6, 7 and 8. However, they did not differ significantly from the rest of the treatments.

Fruit maturity and quality

Fruit maturity results were inconsistent during the 2009 (Table 9) and 2010 (Table 10) evaluations. In 2009, the starch breakdown percentage was significantly higher in treatment 3 compared to treatments 1 and 8, where starch breakdown in treatment 1 was significantly lower compared to all other treatments. In 2009, treatment 2 resulted in a significantly higher TSS compared to the other treatments. In 2010, TA was significantly lower in treatments 2 and 3 compared to treatments 6, 7 and 8. In 2010, fruit from treatments 7 and 8 were significantly firmer compared to treatments 1, 2, 3, 4 and 5. However, treatment 7 was also significantly firmer compared to treatment 6.

Treatment differences in fruit quality analyses were inconsistent during 2009 (Table 11) and 2010 (Table 12). In 2009,Tss was significantly higher in treatment 7 compared to treatments 2, 3, 4 and 5, but did not differ significantly from the other treatments. However, TSS in treatments 1, 7 and 8 were all significantly higher compared to treatments 3 and 5, but did not differ significantly from treatments 2, 4 and 6. In 2010, background colour was significantly greener at treatment 8 compared to treatments 1, 2, 3, 4, 5 and 6 furthermore. Both treatments 7 and 8 were significantly firmer compared to treatments 2, 4 and 6.

Discussion

The higher soil C levels observed at the mulch treatments (3 to 8) compared to the unmulched control treatments (1 and 2) in 2010 was also observed in both 2005 and 2008 (DFPT Project 282010). As the addition of C to the soil is known to improve its physical and chemical properties (Mathews et al. 2002; Merwin and Brown, 2009), it could explain the higher CEC values obtained at the mulch treatments in both 2007 and 2008 (DFPT Project

282010). These changes in the soil characteristics, together with the mineral additive effect of the compost mineralization, can be seen as the main contributing factors which led to increased levels of Ca, Mg, Na and K at the compost/ mulch treatments in the 2010 soil analysis confirming findings of Pinamonti et al. (1995).

Furthermore, the soil pH was significantly lower in the control treatments (treatment 1 (average pH 4.42) and treatment 2 (average pH 4.63) at all depths. At low pH levels (around 4.5), the availability of most minerals (except Fe and especially P) for absorption from the soil, decrease (Evanylo et al., 2008). However, Fe uptake, which is favoured at low pH levels (Evanylo et al., 2008), showed no clear trends in the fruit and leaf mineral analysis for both 2009 and 2010.

The application of municipal solid waste composts to acidic soils has shown to increase the pH (Shiralipour et al., 1992), which might partly explain the higher pH in the mulch treatments (3 to 8). The high soil P levels in the mulch treatments could have resulted from an additive effect of the high P containing compost used in this trail (DFPT Project 282010).

In contrast to the cations which showed no clear trends, the higher soil P levels at mulch treatments resulted in increased levels of P uptake in both the leaves and the fruit in 2009 and 2010. As organic material application is also known to reduce soil P sorption, making it more available for plant uptake (Palm et al., 1997), it is likely that the cumulative effect of P addition and P solubility could in part explain the higher uptake to the leaves and fruit.

Furthermore, the 2007 analyses (DFPT Progress report 2007/8 - 280019) indicated that the percentage mycorrhizal colonized roots were significantly higher at the mulched compared to the unmulched treatments (except for treatment 3). As mycorrhizal fungi is known to assist in P uptake (Atkinson, 1983; Lakatos et al., 2001), it could further contribute to the increased uptake observed at the compost/ mulched treatments.

Only in 2010 did all mulched treatments result in significantly lower fruit N levels. However, this was the general trend from 2007 onwards, especially with treatments 3, 6, 7 and 8 (DFPT Progress report 2007/8 - 280019). This did not correspond with leaf N, as no clear trends could be identified in 2009 or 2010. According to Faust (1989), these differences in N uptake between the leaves and fruit provide some indication on the time of N availability.

Analyses in 2007 indicated that the unmulched treatments contained a significantly higher number of microbes during spring time compared to the mulched treatments (DFPT Progress report 2007/8 - 282010). Since composts are stabilized organic residues, microbial degradation is needed to mineralize the organic N (Hadas et al., 2004). However, suboptimal soil conditions experienced in spring due to mulching would reduce the microbial respiration rate (Keith et al., 1997; Walter et al., 1989), resulting in deficient N uptake in spring to secure fruit set (Ernani and Dias, 1999), which might explain the low yields obtained from the compost/ mulched treatments from 2007 to 2010. A combination of inorganic fertilizer with organic material (farm yard manure) produced the highest yield over a four year period compared to each applied separately (Palm et al., 1997). According to Palm et al. (1997), the immediate availability of N from the inorganic application synchronised better with crop demand.

In contrast to the spring analyses, bait lamina analysis during summer indicated that microbial activity was the lowest at the unmulched control treatments (DFPT Progress report 2007/8 – 282010). Mulching characteristics, which favours microbial activity, such as more regulated soil temperature and moisture availability is known to increase the mineralization rate, which would result in plant available N (Keith et al., 1997). High levels of N uptake during summer will increase the period of shoot extension growth (Terblanche, 1972), which may in part explain the higher rates of tree growth observed at all the mulched treatments from 2003 to 2008 (Data not shown). According to Kotzé (2001), this vigorous vegetative growth will result in poor fruit set and reduced yields. This is in line with results from Hartley and Rahman (1998), where apple yields was reduced with the application of a 10 cm thick compost mulch. Despite the lower yields produced by all the mulched treatments in this trial, fruits size and quality remained unaffected in 2009 and 2010 due to treatments. Furthermore, the M7 vigorous rootstock used in this trial has a known potential for relative vigorous trees. According to Weibel et al. (2007), an organic system requires a less vigorous system where the initial vegetative growth is transformed to more generative growth after 3 years to ensure good fruit set and high yield.

In treatments 6 and 8, where compost tea was added in addition to the compost/ mulch, no clear trends were found in terms of mineral uptake to the leaves or fruit. Furthermore, no distinguishable trends were evident in terms of soil biota, tree growth, yield (DFPT Progress report 2007/8 and 2009/10 - 282010) or fruit quality throughout this trial period. This is in line with (Kangueehi, 2008), where the addition of compost tea to apple trees failed to increase yield or tree performance.

In contradiction to this trial, integrated practices use techniques such a mulching to facilitate a more effective uptake of the nutrients supplied in an inorganic form. The combination of favourable effects rendered from the mulch application contributes to sustained availability of the applied inorganic nutrients. Results from Lourensford Estates trials (Paper 2) showed that the application of a 10 cm thick wood chips mulch to two different ‘Cripps’ Pink’ apple orchards, significantly increased yield efficiency after two years.

Conclusion

In this field trial mulching was able to contribute to soil chemistry in terms of pH, C and several minerals. Of these there were no clear trends evident over several consecutive years. However in 2010, increased soil mineral levels of Ca, Mg, Na, K and P observed at the mulched treatments. Of these only P was able to result in a significant higher rate of uptake to both the leaves and fruit in 2009 and 2010.

At the treatments were compost tea was added to aid the mulch application, it showed no significant contributions to tree performance of yield.

With exception to fruit N, no clear trends could be identified in the fruit and leaf mineral analysis. From 2007 onwards, the fruit mineral N content of the mulch treatments was consistently less compared to the unmulched treatments (not significant in 2009). This corresponded with the lowest yields produced by the mulch treatments from 2007 onwards. The impaired balance between the inadequate N availability early in the season and the high plant demand to secure fruit set is seen as the main reason for the low yields observed. In addition, the extensive mineralization of N from the vast quantities of compost during the summer months, together with the vigorous M7 rootstock, resulted in unfavourable tree growth. Accordingly the sustainability of the compost mulch is compromised by the low yields it produced despite the other positive effects on the soil and tree.

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Table 1: Soil mineral analysis at 5 cm soil depth in Elgin clay-loam site 2010.

Treatment	pH (KCl)	C (%)	P Bray II (mg/kg)	K (mg/kg)	Na (cmol(+)/kg)	Ca (cmol(+)/kg)	Mg (cmol(+)/kg)
1	4.43^{c}	1.83^{c}	20.50^{e}	188.75^{d}	0.14^{c}	2.38^{c}	0.53^{d}
2	4.89^{b}	2.07^{c}	50.50^{de}	209.75^{cd}	0.14^{c}	4.07^{c}	0.78^{d}
3	6.18^{a}	3.56^{b}	157.50^{bc}	364.50^{ab}	024^{b}	12.18^{b}	2.31^{bc}
4	6.08^{a}	4.27^{ab}	234.00^{abc}	386.75^{ab}	0.39^{a}	13.37^{ab}	2.69^{ab}
5	6.33^{a}	4.40^{a}	300.25^{a}	356.50^{abc}	0.37^{a}	15.52^{a}	2.64^{abc}
6	6.43^{a}	4.57^{a}	255.25^{ab}	454.75^{a}	0.39^{a}	16.14^{a}	2.96^{a}
7	6.43^{a}	4.50^{a}	154.25^{bcd}	316.00^{abcd}	0.24^{b}	14.21^{ab}	2.68^{ab}
8	6.45^{a}	4.01^{ab}	143.25^{cd}	285.25^{bcd}	0.20^{bc}	12.15^{b}	2.14^{c}
P Value	< 0.0001	< 0.0001	0.0002	0.0219	< 0.0001	< 0.0001	< 0.0001
LSD	0.3866	0.8036	104.94	151.02	0.0965	2.1958	0.5418

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 2: Soil mineral analysis at 15 cm soil depth in Elgin clay-loam site 2010.

Treatment	pH (KCl)	C (%)	P Bray II (mg/kg)	K (mg/kg)	Na (cmol(+)/kg)	Ca (cmol(+)/kg)	Mg (cmol(+)/kg)
1	4.43^{c}	1.84^{d}	17.25^{d}	209.25^{b}	0.14^{d}	2.46^{d}	0.55^{d}
2	4.55^{c}	1.79^{d}	47.25^{d}	218.50^{b}	0.16^{cd}	3.10^{d}	0.63^{d}
3	6.08^{b}	2.67^{dc}	124.25^{c}	320.50^{ab}	0.22^{bcd}	10.67^{c}	1.94^{bc}
4	6.20^{ab}	3.44^{bc}	211.50^{ab}	367.75^{a}	0.37^{a}	12.80^{abc}	2.35^{ab}
5	6.23^{ab}	3.95^{ab}	269.25^{a}	304.75^{ab}	0.32^{ab}	13.83^{ab}	2.28^{abc}
6	6.50^{a}	4.21^{a}	252.75^{a}	417.00^{a}	0.37^{a}	14.96^{a}	2.61^{a}
7	6.30^{ab}	4.05^{a}	148.75^{bc}	328.00^{ab}	0.24^{bc}	12.74^{abc}	2.38^{a}
8	6.38^{ab}	2.98^{bc}	130.75^{b}	317.00^{ab}	0.20^{cd}	11.47^{bc}	1.90^{c}
P Value	< 0.0001	< 0.0001	< 0.0001	0.0369	0.0004	< 0.0001	< 0.0001
LSD	0.4067	0.9852	63.853	124.50	0.1048	2.4929	0.4199

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 3: Soil mineral analysis at 30 cm soil depth in Elgin clay-loam site 2010.

Treatment	pH (KCl)	C (%)	P Bray II (mg/kg)	K (mg/kg)	Na (cmol(+)/kg)	Ca (cmol(+)/kg)	Mg (cmol(+)/kg)
1	4.38^{b}	1.46^{b}	15.00^{d}	184.75^{d}	0.13^{c}	2.16^{b}	0.43^{b}
2	4.58^{b}	1.55^{b}	30.25^{cd}	230.00^{cd}	0.15^{c}	3.01^{b}	0.60^{b}
3	6.05^{a}	2.66^{a}	104.25^{bc}	349.50^{ab}	0.22^{bc}	9.90^{a}	1.88^{a}
4	5.95^{a}	2.59^{a}	152.50^{ab}	347.50^{ab}	0.35^{a}	9.71^{a}	1.90^{a}
5	6.10^{a}	2.97^{a}	208.00^{a}	274.50^{bcd}	0.31^{ab}	11.61^{a}	1.96^{a}
6	6.28^{a}	2.81^{a}	169.50^{ab}	426.75^{a}	0.35^{a}	11.35^{a}	1.98^{a}
7	6.30^{a}	3.14^{a}	116.00^{b}	298.00^{bcd}	0.27^{ab}	10.50^{a}	1.87^{a}
8	6.28^{a}	2.84^{a}	122.75^{b}	310.00^{abc}	0.21^{bc}	10.04^{a}	1.71^{a}
P Value	< 0.0001	0.0012	0.0005	0.0106	0.004	< 0.0001	< 0.0001
LSD	0.388	0.808	77.818	116.780	0.119	2.767	0.374

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 4: Soil mineral analysis at 60 cm soil depth in Elgin clay-loam site 2010.

Treatment	pH (KCl)	C (%)	P Bray II (mg/kg)	K (mg/kg)	Na (cmol(+)/kg)	Ca (cmol(+)/kg)	Mg (cmol(+)/kg)
1	4.45^{c}	1.53^{c}	13.75^{d}	194.50^{c}	0.15^{b}	2.42^{c}	0.45^{c}
2	4.53^{c}	1.49^{c}	30.75^{cd}	229.50^{bc}	0.16^{b}	2.73^{c}	0.54^{c}
3	5.80^{b}	1.96^{bc}	64.25^{cd}	322.00^{b}	0.22^{ab}	7.16^{b}	1.44^{b}
4	6.08^{ab}	2.55^{a}	128.00^{ab}	315.25^{b}	0.33^{a}	9.44^{ab}	1.73^{ab}
5	6.08^{ab}	2.54^{a}	143.50^{a}	270.25^{bc}	0.29^{a}	10.01^{a}	1.70^{ab}
6	6.10^{ab}	2.28^{ab}	135.25^{ab}	430.75^{a}	0.32^{a}	9.70^{a}	1.76^{a}
7	6.10^{ab}	2.62^{a}	83.00^{bc}	291.50^{bc}	0.29^{a}	9.15^{ab}	1.70^{ab}
8	6.25^{b}	2.29^{ab}	117.00^{ab}	319.75^{b}	0.26^{ab}	9.84^{a}	1.70^{ab}
P Value	< 0.0001	0.0007	0.0001	0.0033	0.0432	< 0.0001	< 0.0001
LSD	0.3657	0.545	52.821	98.197	0.1293	21.4581	0.2954

Means with "ns" did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 5: Leaf mineral analysis at the Elgin clay-loam loam site in February 2009.

Treatment	N	P	K	Ca	Mg	Na	Mn	Fe	Cu	Zn	B
	(%)	(%)	(%)	(%)	(%)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
1	2.18^{a}	0.11^{c}	2.11^{a}	0.95^{ns}	0.19^{b}	226.75^{a}	43.00^{a}	132.75^{ns}	6.00^{b}	14.25^{ab}	41.50^{ns}
2	2.18^{a}	0.12^{c}	1.97^{ab}	0.94	0.19^{b}	209.75^{ab}	38.50^{ab}	97.25	8.00^{b}	12.00^{ab}	37.75
3	2.24^{a}	0.18^{b}	1.97^{ab}	1.05	0.23^{a}	202.75^{ab}	29.75^{bc}	109.25	6.75^{b}	16.75^{a}	42.75
4	2.09^{ab}	0.17^{b}	2.05^{a}	0.97	0.21^{ab}	203.25^{ab}	28.50^{c}	117.50	6.50^{b}	13.00^{b}	38.00
5	1.93^{bc}	0.18^{ab}	1.86^{b}	1.01	0.23^{a}	190.25^{bc}	31.50^{bc}	121.50	6.25^{b}	15.25^{ab}	37.50
6	2.23^{a}	0.20^{ab}	1.96^{ab}	1.02	0.23^{a}	184.00^{bc}	25.75^{c}	123.25	16.25^{a}	12.50^{b}	42.50
7	1.84^{c}	0.20^{ab}	1.87^{b}	0.98	0.20^{b}	161.25^{c}	25.50^{c}	116.25	7.25^{b}	13.00^{b}	41.75
8	1.79^{c}	0.21^{a}	1.85^{b}	1.01	0.20^{b}	201.75^{ab}	28.00^{c}	137.25	7.50^{b}	14.25^{ab}	40.25
P Value	0.0019	<0.0001	0.0413	0.3586	0.0019	0.0223	0.0076	0.1987	0.0466	0.1127	0.3419
LSD	0.2378	0.0343	00.17	0.0974	0.0222	32.663	9.4058	29.725	6.2337	3.3232	5.8995

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 6: Leaf mineral analysis at the Elgin clay-loam loam site in February 2010.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
1	1.94^{abc}	0.15^{d}	1.99^{bc}	1.21^{ns}	0.24^{ns}	311.75^{ns}	229.00^{ns}	192.50^{ns}	7.65^{a}	41.00^{ns}	32.00^{cd}
2	2.04^{a}	0.17^{d}	1.97^{bc}	1.19	0.24	283.50	204.75	175.50	7.90^{a}	36.00	31.00^{d}
3	1.94^{abc}	0.20^{c}	1.91^{c}	1.23	0.25	283.75	209.75	196.25	6.40^{b}	37.75	33.50^{bc}
4	1.97^{ab}	0.20^{c}	2.06^{b}	1.20	0.23	265.50	206.25	206.25	6.53^{b}	38.50	34.25^{bc}
5	1.89^{bc}	0.21^{bc}	1.92^{c}	1.72	0.26	314.00	206.00	201.50	6.85^{b}	37.25	34.25^{bc}
6	1.85^{c}	0.22^{abc}	2.03^{bc}	1.16	0.26	316.58	210.02	211.64	6.65^{b}	38.80	35.02^{ab}
7	1.71^{d}	0.23^{ab}	2.22^{a}	1.10	0.24	281.00	227.00	200.25	6.48^{b}	38.00	37.50^{a}
8	1.62^{d}	0.25^{a}	2.20^{a}	1.16	0.23	292.25	231.75	208.25	6.58^{b}	41.75	35.00^{b}
P Value	< 0.0001	< 0.0001	0.0001	0.8642	0.1518	0.4618	0.0864	0.6726	< 0.0001	0.2505	0.0004
LSD	0.1083	0.0263	0.1287	0.1778	0.0207	54.321	23.671	39.967	0.5121	4.0847	2.3045

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 7: Fruit mineral analysis, of the main harvest, at the Elgin clay-loam site February 2009.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
1	52.50^{ns}	6.23^{c}	123.25^{ns}	6.50^{ns}	4.95^{ns}
2	54.25	6.59^{c}	199.25	6.13	5.03
3	45.50	7.78^{bc}	111.75	7.15	4.80
4	52.50	10.12^{a}	128.00	5.98	5.03
5	52.50	9.60^{bc}	117.75	6.98	5.10
6	51.25	10.30^{a}	126.75	7.20	5.48
7	48.00	10.54^{a}	122.25	7.63	5.25
8	48.00	11.41^{a}	133.25	6.70	5.08
P Value	0.6336	<0.0001	0.0859	0.3641	0.7608
LSD	10.275	1.8342	13.484	1.5379	0.7778

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 8: Fruit mineral analysis, of the main harvest, at the Elgin clay-loam loam site in February 2010.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
1	81.00^{a}	8.64^{d}	138.25^{ns}	7.10^{ns}	7.22^{a}	29.38^{ns}	0.90^{ab}	2.48^{bc}	0.53^{ns}	0.35^{a}	2.38^{ns}
2	73.50^{a}	9.23^{cd}	144.75	6.63	7.00^{a}	26.68	0.93^{a}	3.03^{ab}	0.48	0.38^{a}	2.38
3	60.00^{bc}	9.42^{bcd}	132.50	6.30	6.60^{a}	30.15	0.75^{bc}	3.45^{a}	0.38	0.23^{b}	2.65
4	61.50^{b}	11.40^{abc}	137.25	5.95	6.95^{a}	31.45	0.78^{abc}	2.43^{bc}	0.40	0.20^{b}	2.58
5	59.00^{bc}	11.77^{ab}	138.25	5.70	6.50^{a}	31.58	0.68^{cd}	2.40^{bc}	0.43	0.20^{b}	2.85
6	50.00^{c}	7.62^{d}	106.50	5.10	4.80^{b}	24.75	0.53^{d}	1.98^{c}	0.35	0.20^{b}	2.28
7	50.50^{bc}	12.44^{a}	142.50	6.75	6.40^{a}	29.15	0.78^{abc}	2.03^{c}	0.43	0.20^{b}	3.00
8	51.50^{bc}	11.84^{ab}	142.25	5.53	6.05^{ab}	34.20	0.65^{cd}	2.03^{c}	0.45	0.20^{b}	2.90
P Value	<0.0001	0.0041	0.1563	0.1408	0.0218	0.4488	0.0012	0.0014	0.2850	0.0001	0.1307
LSD	11.436	2.5114	27.365	1.4931	1.2794	8.6208	0.1657	0.6708	0.1423	0.0778	0.5884

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 9: Fruit maturity evaluation, of the main harvest, at the Elgin clay-loam in 2009.

Treatment	Background (Green)	Red (%)	Red (Intensity)	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TSS (^{o}Brix)	TA
1	3.67^{ns}	38.63^{ns}	4.60^{ns}	43.25^{c}	8.42^{ns}	67.12^{ns}	127.27^{ns}	13.83^{b}	0.68^{ab}
2	3.76	44.69	5.48	62.25^{ab}	8.58	67.07	125.91	14.54^{a}	0.69^{a}
3	3.52	35.44	4.23	66.63^{a}	8.36	68.15	133.07	13.38^{b}	0.62^{b}
4	3.54	43.06	5.08	60.25^{ab}	8.58	65.74	125.82	13.75^{b}	0.67^{ab}
5	3.56	43.00	5.03	61.50^{ab}	8.64	67.12	126.14	13.63^{b}	0.68^{ab}
6	3.57	45.56	5.48	64.63^{ab}	8.43	67.24	126.09	13.55^{b}	0.69^{a}
7	3.58	41.75	4.91	62.06^{ab}	8.41	68.12	131.70	13.40^{b}	0.69^{a}
8	3.52	42.13	4.90	55.13^{b}	8.53	66.95	126.97	13.30^{b}	0.69^{a}
P Value	0.3449	0.5416	0.5082	0.0044	0.8074	0.3546	0.8833	0.0025	0.3443
LSD	0.2284	10.37	1.2791	10.459	0.4155	2.035	13.068	0.5366	0.0676

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 10: Fruit maturity evaluation, of the main harvest, at the Elgin clay-loam site in 2010.

Treatment	Background (green)	Red (%)	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TSS (^{o}Brix)	TA
1	2.95^{ns}	6.16^{ns}	48.06^{ns}	7.96^{dc}	68.37^{ns}	130.95^{ns}	12.48^{ns}	0.54^{bc}
2	3.02	6.20	70.80	7.78^{dc}	75.95	131.27	12.70	0.52^{c}
3	3.01	6.29	67.49	7.74^{dc}	75.36	129.35	12.28	0.51^{c}
4	3.39	5.69	73.35	7.75^{dc}	68.24	131.38	12.60	0.54^{bc}
5	3.03	6.03	65.73	7.63^{d}	68.48	130.94	12.35	0.54^{bc}
6	2.99	6.53	64.58	8.03^{bc}	68.76	134.57	12.50	0.57^{ab}
7	3.06	6.74	59.32	8.39^{a}	69.06	138.20	12.28	0.59^{ab}
8	3.05	7.16	64.54	8.35^{ab}	69.15	137.80	12.79	0.58^{b}
P Value	0.5194	0.4978	0.1341	0.0005	0.6694	0.3313	0.3661	0.0122
LSD	0.4198	1.3797	16.936	0.3356	11.389	8.9642	0.5791	0.0412

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 11: Fruit quality evaluation, of the main harvest, after 8 weeks in cold storage at Elgin clay-loam site in 2009.

Treatment	Background (green)	Red (%)	Red (intensity)	Greasiness (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TSS (^{o}Brix)	TA
1	3.89^{ns}	45.13^{ns}	5.44^{ns}	0.60^{ns}	8.31^{ns}	69.22^{ns}	114.48^{ns}	14.35^{ab}	0.65^{ns}
2	4.44	44.56	5.26	0.50	8.23	70.41	150.43	14.43^{bc}	0.61
3	3.79	40.69	4.68	0.00	8.07	69.32	143.25	13.68^{c}	0.59
4	3.85	47.56	5.76	0.28	8.19	68.67	141.09	13.95^{bc}	0.61
5	3.83	43.69	5.05	0.25	8.40	68.64	140.94	14.18^{c}	0.59
6	3.76	47.56	5.60	0.58	7.97	69.01	143.64	13.75^{abc}	0.62
7	3.84	51.09	6.26	0.25	8.41	68.32	141.11	13.83^{a}	0.67
8	3.82	49.53	5.95	0.35	8.21	70.37	153.03	13.75^{ab}	0.65
P Value	0.2686	0.5291	0.3474	0.4604	0.3302	0.3183	0.3606	0.0217	0.0597
LSD	0.551	10.464	1.366	0.593	0.4003	2.0442	12.392	0.0473	0.5579

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$.

Table 12: Fruit quality evaluation, of the main harvest, after 8 weeks in cold storage at Elgin clay-loam site 2010

Treatment	Background (green)	Red (%)	Red (intensity)	Greasiness (%)	Firmness (kg)	Diameter (mm)	Mass (g)	TSS (^{o}Brix)	TA
1	3.34^{bc}	52.25^{ns}	6.23^{ns}	0.00^{ns}	7.18^{b}	66.30^{ns}	126.30^{ns}	13.08^{ns}	0.49^{ns}
2	3.20^{d}	46.20	5.54	0.01	7.30^{ab}	66.17	124.14	12.92	0.46
3	3.26^{bcd}	49.88	5.90	0.00	7.24^{b}	66.67	128.08	12.90	0.49
4	3.23^{cd}	47.44	5.76	0.03	7.33^{ab}	66.15	124.04	12.83	0.49
5	3.25^{bcd}	49.13	5.95	0.00	7.27^{b}	67.26	128.29	12.85	0.51
6	3.35^{bcd}	47.25	5.74	0.04	7.36^{ab}	66.97	126.54	12.98	0.50
7	3.37^{ab}	56.14	6.03	0.03	7.52^{a}	66.38	125.24	12.89	0.51
8	3.47^{a}	60.40	7.03	0.00	7.52^{a}	68.19	136.08	13.20	0.53
P Value	0.0048	0.0990	0.1735	0.4152	0.0374	0.3615	0.3611	0.6870	0.0865
LSD	0.1288	10.198	1.039	0.0424	0.2226	1.9003	10.541	0.4531	0.044

Means with “ns” did not differ significantly. Means with different letters differ significantly at $P < 0.05$

GENERAL DISCUSSION AND CONCLUSION

In the first two trials different mulches, compost, wood chips, polytex PT110 woven geotextile fabric (geotextile) and vermi-compost with a wood chip layer (vermi-compost) were compared for their ability to influence plant performance in terms of fruit quality together with regular rates of fertilizer applications. Two commercial 'Cripps` Pink' apple orchards, planted in 1998 on M793 rootstock, both orchards under the same management practices were selected. They differed only in soil type, in order to quantify the effect of soil type on treatment effect.

In the first year after the application of mulches, very few significant results were obtained as adaptation to the new soil environment need to occur during the first season to allow trees to benefit from the mulches.

The different mulches were evaluated on their ability to regulate soil temperatures at different soil depths. Soil temperature probes indicated that the wood chips treatment had the best overall ability to regulate soil temperature in both soil types. We speculate that the ability to regulate soil temperature was closely related to the ability of the mulch to decrease evaporation and preserve soil moisture in the upper soil layers (Pinamonti et al. 1995; Trisdal 1989). Soil texture also had a significant effect on the ability of the mulch type to regulate soil temperature. This was observed at the more sandy loam site (Site 2) where the vermi compost and geotextile treatments were more effective. The regulated soil temperature conditions in the upper soil layer made conditions more favourable for root proliferation (Trisdal 1989) in this layer, expanding the volume for potential mineral and water uptake (Pinamonti et al. 1995).

The increase in available soil water due to mulching (Trisdal 1989; Pinamonti et al. 1995; Bronic and Lal 2004), can affect the uptake and redistribution of minerals (Shear 1980), as well as the nutrient cycling in the soil (Glover et al. 2000). This positive effect of mulching applies to the well-drained, upper soil areas where water shortages may occur. The wood chips and geotextile treatments resulted in the largest roots systems with the highest number of fine feeder roots. The earlier reaction of root proliferation at site 2 than site 1 at Lourensford Estate, confirmed existing information in literature reporting a quicker response after mulching a sandy soil compared to a heavier soil type. Feeder roots, less than 2 mm in diameter, showed the greatest reaction in terms of root proliferation in all mulch treatments at both sites.

After two seasons of treatment, in April in site 1, in the top 10 cm soil, the vermi-compost treatment significantly increased soil phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), zink (Zn) and boron (B) compared to the control. Although it is not possible to quantify at present, these increases could have been due to the composition of the mulch. The wood chips treatment and compost only increased soil K significantly compared to the control. In this case, the increase could only be ascribed to a direct influence of the composition of compost mulch, but not from the wood chips. The geotextile did not show significant changes compared to the control, which was expected as the composition of the geotextile is such that no additional nutritional elements can be added to the soil. For site 2, only wood chips and vermi-compost showed significant increases in soil nutrient elements (K, Mg) compared to the control. The other treatments did not show any significant changes in any elements compared to the control.

The typical lower cation exchange capacity (CEC) of sandy soil, such as at site 2, might have increased the chance of mineral leaching towards the end of the season. Nevertheless, only at site 2, the mineral uptake into the leaves was significantly increased. Sandy soils are generally less fertile and would therefore show a much greater reaction compared to more fertile soils as found at site 1. Furthermore, when the temperature and soil water potential changes due to soil management practices, it can result in differences in mineral uptake (Atkinson and White 1980). This is observed when the distribution of the roots is effected by soil management practices aimed at increasing the interactions of roots with soil resources.

Both vermi compost and compost treatments resulted in significantly higher levels of microelements in the leaves at site 2, however, we speculate that these treatments influenced plant nutrition in different ways. The vermi-compost treatment could have supplied the soil with more nutrients than the other mulches due to its composition. In contrast, results from the mycorrhizal analyses suggested that the compost treatment was more dependent on mycorrhiza for plant mineral uptake.

Furthermore, an increase of soil organic matter (functioning plant roots or plant litter (mulch)) has been reported to enhance the efficiency of nutrient uptake and water holding capacity of soil by activation of the soil biological sphere (Ferris and Bongers, 2006; Forge et al., 2008). Thereafter the soil food web becomes more structured as the opportunists are replaced by more specialized feeding groups, which exerts a top-down regulatory effect on the number of opportunists (Ferris and Bongers, 2006; Forge et al., 2008). Based on this, the organic mulches in this trial supplied the existing soil food webs with a durable carbon source and thereby created a well-structured food web, compared to no mulch and inorganic mulch areas. For both the control and geotextile treatments, the tree roots (functioning) were the sole source of carbon input. This resulted in a case where plant parasitic nematodes dominated in numbers. Wood chips, vermi-compost and compost treatments on the other hand supplied an additional source of carbon from which an array of feeding groups could be sustained to create a top-down regulatory system.

The wood chips treatment resulted in the highest yield efficiency, however this was only significant at site 1. Even though the wood chips had little effect on its contributions to the soil minerals, it was able to increase the root volume extensively in the upper soil layers, which enhanced the effective use of the irrigation water and fertilizer, and resulted in the increased yield. Despite the general decrease in yield from 2009 to 2010, as well as the significantly lower yield produced by the compost treatment, fruit size and mineral contribution remained unaffected by treatment applications.

The third trial, was aimed at evaluating a compost mulch topped with straw (compost/ mulch) in the tree row, as an alternative method of fertilization to sustain yield in a ‘Cripps` Pink’ organic orchard over a period of six to seven years. The tree row treatments differed from, un-mulched inorganically fertilized treatments, compared to the compost/ mulch and compost/ mulch together with regular applications of compost tea.

The compost/ mulch and compost/ mulch with compost tea treatments significantly increased the soil cation exchange capacity (CEC) (DFPT Progress report 2007/8 – 282010) and soil carbon percentage. Furthermore, all the mulch treatments contributed significantly to the soil mineral content. This indicated that the mineralization of the mulches was able to supply some minerals to support the crop growth. The rate of mineralization, which is regulated by the C:N ratio of the mulch, was also in balance to allow carbon incorporation into the soil, which was reflected by the improved CEC levels of the mulch treatments. The changes in the soils ability to retain the cations, which are mineralized from the compost/ mulch, would explain the contribution to the increased soil mineral content in comparison to the un-mulched treatments.

Despite the positive effects of the mulching treatments of the third trial at Elgin on the soil chemistry and biology, mulching significantly reduced fruit nitrogen (N) concentration, as well as yield, and resulted in vigorous vegetative growth (DFPT Progress report 2007/8 – 282010). If organic material is to be successfully incorporated into soil organic matter, over time from a mulch, to enhance soil structure, the system should be N limited and the C source should be supplied at a constant, slow rate to support microbial life, as observed in this trial. Ideally, N should be mineralized at a high rate during spring to support fruit set. However, during this time the soil temperature and moisture levels are generally unfavourable for mineralization due to low rates of microbial respiration. This we suspect to be the main reason for the low yields observed in these mulch treatments. However, during the warm summer months, soil temperatures are more favourable for microbial respiration (mineralisation) and large quantities of N are potentially released from the compost, resulting in the unwanted vigorous grow.

During these two seasons, on the three different sites, no definite trends in the influence of mulches on fruit quality or mineral composition of ‘Cripps’ Pink’ could be established from these trials. This may change in future, at the Lourensford Estate trials, once the irrigation practises are adapted and the effect of mulches on soil moisture and thus nutrient availability and uptake become more pronounced.

Still, in spite of the reported decrease in yield efficiency after different mulch treatments, fruit quality was not compromised in either the Lourensford Estate, or Elgin trials. It is of concern though, and needs further investigation.

Thus, based on the inconsistency of the results from the three trials during 2009 and 2010 concerning i) soil environment portrayed by micorrhizae colonization, nematode population dynamics and temperatures, ii) soil-, leaf- and fruit mineral composition, iii) tree performance quantified by root growth, yield, stem water potential and shoot growth and iv) fruit quality – we cannot recommend a specific mulch to satisfy all these requirements at present.

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