The effects of organic and inorganic mulches on the yield and fruit quality of 'Cripps' Pink' apple trees

BY

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DECLARATION

I, the undersigned, hereby declare that the entirety of the work contained in this thesis is my own original work and that I have not previously, in its entirety or in part, submitted it at any university for obtaining any qualification.

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SUMMARY

Limited research is available on the effect of mulches on established orchards. Most of the information available stems from research conducted in newly planted orchards or on annual crops such as green peppers and strawberries under greenhouse conditions. To increase the current knowledge on the effect of mulches in established orchards, two field trials were conducted on 14 year old 'Cripps' Pink' orchards. The one trial concentrated on the influence of mulches on the root environment and the other trial on the effect of mulches on growth, yield and fruit quality.

Both trials were conducted at Lourensford Estate near Somerset West, but the sites differed in soil texture between lighter soil (Tukulu) and heavier soil (Clovelly). Four different mulches were used viz. compost, wood chips, vermi-castings (topped with thin layer of woodchips) and a woven geotextile fabric. These four treatments were compared to an un-mulched control, managed according to industry norms.

After reducing irrigation volume in the 2010/2011 season, with a further reduction in the 2011/2012 season, more significant differences were obtained in nutrient levels of fruit and leaves compared to the 2008/2009 and 2009/2010 seasons of the trial. Leaf and fruit nutrients showed significant differences in both sites, but the differences were more pronounced on the lighter soil. At the heavier soil site, the vermi-castings, woodchips and compost treatments increased fruit phosphorus (P) during 2010/2011 and the control treatment increased fruit boron (B) during 2011/2012. Only leaf magnesium (Mg) was increased by woodchips and vermi-castings in 2011/2012 at this site.

In the lighter soil site, the control treatment had the highest fruit B levels in 2010/2011 while the vermi-castings and the woodchips treatments had the highest fruit P levels in 2011/2012. For the same site, vermi-casting and compost treatments improved leaf potassium (K) uptake

in 2010/2011 and 2011/2012, whereas woodchips and geotextile significantly improved leaf copper (Cu) uptake in 2010/2011 compared to the control.

To determine if applied nutrients were trapped in the organic mulches over time, leading to a deficiency in the soil and eventually the tree, a mineral analysis was conducted on the organic mulches at the end of each season. Results of the two seasons indicated that vermi-castings contained higher total nutrient levels than the other two organic mulches, but the difference in nutrient levels were shown not to be directly related to the fertilisers applied during each season. In the case of vermi-castings, nutrient quantities in the original material applied at the beginning of each season were higher than those of the other organic mulches. The higher nutrient levels in organic in comparison to inorganic mulches were however not reflected in the fruit and leaf mineral analysis of these treatments. The overall treatment effect in terms of changes in nutrient levels in the tree became less significant when trees were over irrigated. This became evident as the differences between mulching treatments increased as the irrigation was reduced during the season, indicating the masking effect of irrigation on mulching.

Evaluating the effect of mulches on growth, yield and fruit quality showed significant differences only at the heavier soil site. The vermi-casting treatment had significantly higher yield efficiencies than the control for the 2010/2011 season. Compost had the lowest yield efficiency at both sites, also during the previous two seasons that formed part of an earlier study (Kotze 2012). In 2011/2012, the compost treatment also showed significantly higher shoot growth than the control. Compost therefore could increase vegetative growth in established orchards on a heavier soil after application for four seasons. Taking the cost of mulching into account, wood chips are the only treatment that can be recommended without compromising fruit quality. Wood chips will sustain or even improve yield efficiency in an established orchard on especially heavier soil.

Future research should study the effect of different amounts of irrigation on the various mulches, as the effect of irrigation was not evaluated in this study.

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OPSOMMING

Beperkte navorsing is beskikbaar oor die effek van deklae op bestaande boorde. Die meeste bestaande inligting is gegrond op proewe wat uitgevoer is op nuut aangeplante boorde of op eenjarige gewasse, soos groenrissies en aarbeie, onder kweekhuis toestande. Om bestaande kennis aan te vul rakende die effek van deklae op vrugproduksie en -kwaliteit in bestaande boorde, is twee veldproewe geloots in 14-jaar-oue 'Cripps' Pink' appelboorde. Die een proef het gekonsentreer op die invloed van deklae op die wortel omgewing en die ander proef, op die effek van deklae op groei, opbrengs en vrugkwaliteit.

Beide proewe is uitgevoer op Lourensford Landgoed naby Somerset-Wes en twee verskillende grondtipes is hiervoor gebruik: 'n ligte grond (Tukulu) en swaarder grond (Clovelly). Vier verskillende deklaagtipes is gebruik naamlik: kompos, houtspaanders, 'vermi-castings' (bedek met 'n dun lagie houtspaanders) en geweefde geotekstiel materiaal. Hierdie vier behandelings is vergelyk met 'n onbedekte kontrole wat volgens industrie norm bestuur is.

Nadat die besproeiingsvolume verminder is in 2010/2011 en daarna weer in 2011/2012, het meer betekenisvolle verskille tussen behandelings voorgekom in nutriënt-vlakke van vrugte en blare in vergelyking met die eerste twee jaar van die proef (2008/2009 en 2009/2010). Blaar en vrug nutrient-vlakke het betekenisvolle verskille in beide persele getoon, maar die verskille was meer duidelik in die ligte grondtip. In die swaarder grond perseel het die 'vermi-castings', houtspaanders- en kompos behandelings die vrug fosfaatvlakke (P) betekenisvol verhoog in 2010/2011. In die kontrole behandeling was vrug boorvlakke (B) betekenisvol hoër as die ander behandelings in 2011/2012. In hierdie perseel is net magnesium-vlakke (Mg) in die blare betekenisvol verhoog deur die houtspaanders- en 'vermi-castings' behandelings in 2011/2012.

In die ligte grond perseel het die kontrole behandeling die hoogste vrug B-vlakke in 2010/2011 gehad en die 'vermi-castings' en houtspaander-behandelings gesamentlik, die hoogste vrug P-vlakke in 2011/2012. Die 'vermi-casting' en kompos behandelings het kalium-vlakke (K) opname in die blare in 2010/2011 en 2011/2012 verbeter, terwyl die houtspaanders- en geotekstiel behandelings die koper-vlakke (Cu) in die blare in 2010/2011 verbeter het.

Om te bepaal of die toediening van voedingstowwe oor tyd kan lei tot die 'vashou' daarvan in 'n organiese deklaag en dan tekorte van sekere nutriënte in die grond en uiteindelik die boom kan veroorsaak, is 'n mineral analise van die organiese deklae uitgevoer aan die einde van beide seisoene. Resultate van die twee seisoene het getoon dat 'vermi-castings' hoër totale nutrient-vlakke gehad het as die ander organiese deklae, maar die nutrient-vlakke was nie direk verwant aan die toegediende voedingstowwe nie. In die geval van 'vermi-castings', was nutrient-vlakke van die moedermateriaal, wat toegedien is aan die begin van die seisoen, hoër as die van die ander organiese deklae. Hierdie hoër nutrient-vlakke van die organiese teenoor anorganiese behandelings, is nie gereflekteer in hoër nutrient-vlakke in die vrug- en blaar mineraal analises van die bome nie. Behandelings effekte rakende veranderinge in nutrient-vlakke in die boom, nadat die besproeiing verminder is, het verander in vergelyking met die van die vorige twee seisoene en is 'n aanduiding van die verbloemende invloed van besproeiing op die prestasie van deklae.

Evaluasie van die effek van deklae op groei, opbrengs en vrugkwaliteit het net betekenisvolle verskille in die swaarder grond perseel getoon. Die 'vermi-casting'-behandeling het 'n betekenisvolle hoër opbrengseffektiwiteit as die kontrole getoon in 2010/2011. Kompos het die laagste opbrengseffektiwiteit in beide persele gehad en het resultate van die vorige twee seisoene van Kotze (2012) bevestig. Die betekenisvolle hoër lootgroei van kompos as die ander behandelings het net in 2011/2012 voorgekom. Kompos kan dus groei verhoog in ‘n gevestigde boord, in ‘n swaarder grond, indien besproeiing optimaal is. In terme van kostes, word die gebruik van houtspaanders as deklaag voorgestel vir ‘n gevestigde boord met ‘n swaar slik leem grond, aangesien daar geen nadelige effek op vrugkwaliteit was met die behandeling nie en die opbrengseffektiwiteit van die bome gehandhaaf en selfs verbeter is.

Toekomstige navorsing kan die effek van besproeiing op verskillende deklaag tipes bestudeer, aangesien die bestaande proef dit nie kon aanspreek nie.

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DEDICATION

Dedicated to my family

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TABLE OF CONTENTS

This thesis presents a compilation of manuscripts where each paper is an individual entity and some repetition between chapters, therefore, has been unavoidable.

GENERAL INTRODUCTION

Mulches can be categorised as organic (Forge et al. 2002) or inorganic (Måge 1982) and depending on the composition of the mulch, will affect the growing medium differently. Effects of mulching include an increase of specific mineral elements in the soil as the mulch decomposes, changes in soil pH (Cadavid et al. 1998) and a possible contribution of organic material to the biological component of the soil environment (Forge et al. 2002). In addition, some mulches buffer changes in moisture, which will also have an influence on the soil biology (Autio et al. 1991; Brown and Tworkoski 2003; Arancon et al. 2006). However, whether these changes are sufficient to result in consistent significant changes in the nutrient status of leaves and fruit, which would allow the reduction of fertilizer application of some mineral elements, needs to be considered carefully before recommendations are made to commercial producers.

Other positive effects of mulches like vermi-castings, pine needle, compost, straw and farm yard manure, which can increase the nutrient status of the plant, include the reduction of N fertilization (North et al.2011), suppression of weed growth (Baxter 1970), increased organic matter in the soil (Arancon et al. 2006), increased soil moisture (Barzegar et al. 2002), temperature moderation (Treder et al. 2004) and improved root growth (Acharya and Sharma 1994). Different mulches differ significantly in terms of the above mentioned positive attributes of mulches and generalisations about the effect of a specific mulch should be avoided (Walsh et al. 1996).

Studies on the effects of mulches on yield, growth and nutrition are normally conducted on newly established orchards (Baxter 1970; Autio et al. 1991; Kotzé and Joubert 1992; Smith et al. 2000; Van Schoor 2009) or annual crops (Acharya and Sharma 1994; Atiyeh et al. 2000; Aranconet al. 2004; Ekinci and Dursun 2009). Limited information is available on the effects of organic and inorganic mulches on established orchards (Neilsen et al. 2003), especially under South African conditions. Information on the effect of mulches on two different soil types under the same climate and management is scarce. Therefore, to evaluate the effect of five different mulches (organic and inorganic) on yield, growth, nutrition and fruit quality, in an established orchard, a field trial was conducted on 14-year-old 'Cripps' Pink' apple trees on a lighter soil and heavier soil site.

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LITERATURE REVIEW

1. Introduction

Mulches are organic (Forge et al. 2002) or inorganic (Måge 1982) materials that are applied on top of a soil to both annual and perennial crops. When organic or inorganic material is used in the production of perennial crops it is mainly applied in the tree row to reduce costs, and target the root area of the crops, similar to the irrigated area. Organic mulches include wood chips, pine needles, straw, which have little or no nutritional value, compost and vermicompost, both of which contain nutrients. Inorganic mulches include woven geotextile fabric and plastic and rocks, which contain no nutrients.

Beneficial attributes ascribed to mulches include their use as an alternative to herbicides in weed control (Baxter 1970) and as additional nutrient supplements to organic fertilizers. Mulches also significantly improve water retention of the soil (Barzegar et al. 2002), which is widely reported to increase yield and growth (Autio et al. 1991; Kotzé and Joubert 1992). The frequent use of some herbicides has led to weed resistance in some areas. Mulching as an alternative method for weed control could be very beneficial.

The cost of fertilizer is a very important factor in the viability of fruit production. Any improvements that can be made to either reduce the volume of applied fertilizer or the efficiency of nutrient uptake by the plants will contribute towards making farming more profitable.

Presently, a major concern in the deciduous fruit industry is the expected decline in rainfall predicted for the Western Cape, South Africa, which is already being experienced in some fruit production areas (IPCC – Intergovernmental Panel on Climate Change, 2007). This may lead to a decline in fruit yield, fruit quality and overall fruit production, and in the worst case scenarios may even result in the loss of trees, because of insufficient irrigation.

An in-depth review and critical re-assessment of existing information available in literature on the use of mulches on various food crops, for the cost-effective application on established apple trees under commercial conditions, on a feasible scale, is now presented.

2. Organic mulches

Organic mulches can be categorised as mulches containing nutrients (Eneji et al. 2003, Domínguez 2004) and mulches without significant nutrient content (Smith et al. 2000). Different mulches, with different compositions, will affect a growing medium differently (Walsh et al. 1996). The first of the two organic mulch groups that will be discussed is the organic mulches that do not contain any significant nutrient levels, i.e., the non-nutritional organic mulches.

2.1 Non-nutritional organic mulches

Non-nutritional organic mulches comprise mostly of cellulose and contain no significant amount of nutrients. These mulches include, for example, wood chips, pine needles, paper, straw and pine bark mulches. Literature on non-nutritional organic mulches provides sufficient information to indicate that the use of such mulches can nonetheless be beneficial. Their use not only improves the water status, but reduces fluctuations in soil temperature and reduces weed growth. This can improve root growth and indirectly improve vegetative growth, which contributes to successful (environmental) farming.

2.1.1 Growth

Smith et al. (2000) report that a wood chip mulch applied to one-year-old pecan trees had a positive effect on tree height. The increase in tree height was also related to the width of the mulch used: a 2-m strip of wood chip mulch gave better tree height results than a 1-m strip did. (These strips were weed-free throughout the trial.) After three years, the mulch also had a positive effect on tree trunk diameter. In a study conducted by Baxter (1970) on young ‘Hooker’ peach and ‘Golden Delicious’ apple trees in Australia, positive growth results were recorded when a strip of straw mulch was used in the orchards. Results showed that the stem diameter of peach trees that were treated with the mulch increased by 63%, compared to the control (non-mulched). The vegetative growth of the peach trees was also significantly increased, compared to the control. In the apple orchard, the growth results were not as impressive as with the peach trees. The apple trees’ trunk diameter did not differ significantly when, but the overall shoot lengths were higher, giving the impression that an increase in growth was obtained. One possible reason for the difference in results between the apple and peach trees is that wider mulch strips were used in the vase of the peach trees than in the apple trees (Smith et al. 2000). Neilsen et al. (2003) carried out a trial, over a six-year period, in which shredded paper was used as mulch and found that the stem diameters of treated trees were higher (almost double) compared to the control (herbicide), and when using mulches comprising hay and black woven polypropylene fabric.

2.1.2 Moisture

According to Smith et al. (2000), soil moisture is higher under a mulched (wood chips) area than a non-mulched area. At 30- and 60-cm soil depths, a wider (2 m) mulch strip contained more moisture than a narrower (1 m) strip during periods of moisture stress. The mulch caused less fluctuation in soil moisture compared to in the non-mulched areas.

When a straw mulch (15-cm thick) was applied, more available water was present in the soil compared to a (non-mulched) control (Baxter 1970). Tensiometer readings recorded during a drought period also showed less water stress under mulched treatment compared to a control. This is in agreement with the findings of Smith et al. (2000), who used a wood chip mulch.

Evapotranspiration from mulched soils is usually lower than from non-mulched soils, thus the soil contains moisture for longer periods (Baxter 1970).

2.1.3 Nutrition

Another important factor to bear in mind when examining the influence of a mulch on the soil and plant is nutrition. Without nutrients in the soil, growth of trees is restricted, especially in nutrient depleted soils (Neilsen et al. 2003).

Szewczuk and Gudarowska (2004) carried out a study on apples in which a pine bark mulch was used and found that fruit size and fruit calcium (Ca) concentrations increased. The use of pine bark also led to an increase in the fruit potassium (K) concentration over three years, but a herbicide fallow treatment (control) still resulted in higher K concentration. Use of the pine bark mulch also led to increased magnesium (Mg) and Ca levels in apples, but no significant changes in phosphorus (P) levels were reported. Although Ca is an important element in preventing bitter pit, Szewczuk and Gudarowska (2004) found no correlation between the mulch and the number of apples with bitter pit. However, the K/Ca ratio in the fruit of mulched trees was lower than in fruit of non-mulched trees. Although a high K/Ca ratio is advantageous because it is related to fruit with a good eating quality, it negatively influences the storage quality (Marcelle 1995). South African producers will benefit from lower K/Ca ratios, for improved storage quality of apples, because their fruit requires transported to overseas markets (e.g. Europe). Leaf analyses of peach and apple trees that received a straw mulch showed higher levels of foliar K, but lower levels of Mg and Ca (Baxter 1970). The decrease in Ca may lead to an increase in the incidence of bitter pit in apples if an increase in fruit size results from using the mulch. The concentrations of other major elements were within the foliar norms.

Acharya and Sharma (1994) carried out trials in which a pine needle mulch was applied in wheat and maize fields and found that the uptake of nitrogen (N), P and K increased, compared to the control (no mulch). The increase in uptake of these macronutrients may partly explain the increase in growth of these crops.

Walsh et al. (1996) carried out trials in which a straw mulch was applied in an apple orchard, and found that nitrate (NO_3^-) levels in the top soil were higher in the mulch treatment than in the control (grass cover), and in a composted manure mulch. However, the nitrate level decreased as the straw mulch decomposed over the season, thus reducing the amount of N leaching. This also ensured that the hardening off of the trees was not affected by high N levels. Potassium levels were higher under the straw mulch than under an inorganic geotextile mulch, but the straw mulch had no effect on Ca and Mg levels. The higher nutrient levels in trees to which organic mulches were applied is partially due to the higher soil moisture and increase in root growth (Acharya and Sharma 1994). The spreading of roots through a larger soil volume increases the potential absorption of relatively immobile elements such as P and K, which may lead to an increase in yield (Acharya and Sharma 1994).

2.1.4 Yield

According to Szewczuk and Gudarowska (2004), a pine bark mulch improved the yield of two-year-old 'Jonagored' apple trees. The pine bark mulch also increased fruit size, compared to the fruit of trees that were not mulched. The mulched trees produced the highest percentage of apples with diameters >75 mm and good fruit colour.

Barzegar et al. (2002) found that when a straw mulch was used in a semi-arid region on wheat it increased the yield on a dry weight basis. Although other mulches also increased yield, straw is more abundant in the Western Cape than farmyard manure and composted bagasse, and therefore of greater practical benefit to Western Cape producers.

Baxter (1970) showed that yields of both ‘Hooker’ peaches and ‘Golden Delicious’ apples were higher when a straw mulch was used, compared to a control (no mulch). The yield of the mulched peach trees was almost double that of the control trees. Similar results were found for the mulched apple trees. These yield increases (for five-year-old trees) were as high as 20 $t.ha^{-1}$ and 10 $t.ha^{-1}$ for apples and peaches, respectively, over two years. Baxter (1970) and Szewczuk and Gudarowska (2004) found that mulching improved average fruit size. Return bloom usually decreases after a high yield in the previous season, but Baxter (1970) found that mulched trees still had a high return bloom (blossom density) percentage in the following season.

2.1.5 Soil

Many producers apply organic mulches to the soil to increase the organic matter (Barzegar et al. 2002). Barzegar et al. (2002) applied a wheat straw at a rate of 10 Mg ha^{-1}, thereby increasing the soil organic matter by 19%. Wheat straw mulch also improves the porosity of the soil by reducing the bulk density. The higher soil porosity may be related to the higher water infiltration rate. According to Acharya and Sharma (1994), higher soil porosity is very important for commercial crop production because it results in better root growth and a subsequent higher uptake of nutrients.

Acharya and Sharma (1994) carried out trials using a pine needle mulch. Their results were in agreement with those of Barzegar et al. (2002). Acharya and Sharma (1994) compared conventional tillage, with or without mulch, to no-tillage, with or without mulch. The mulch prevented soil compaction. This was quantified by the lower bulk density and higher water infiltration rate of the mulch-treated soil compared to the soil with no mulch.

Application of a pine needle mulch to wheat resulted in higher minimum soil temperatures. This increase in minimum temperature resulted in an increased root growth and had a positive effect on nutrient uptake. The root length increased significantly under the mulch compared to control treatments with no mulch (Acharya and Sharma 1994). Cadavid et al. 1998 found that a grass mulch reduced the soil temperature during the day, which is beneficial to crops.

When mulches are applied to the soil, soil erosion is reduced due to less run-off and a higher infiltration rate of rain water (Acharya and Sharma 1994). Cadavid et al. (1998) found that the pH of non-mulched soil decreases, especially on sandy soils, compared to a soil treated with a grass mulch, in which the pH does not decrease. A low pH tends to cause fixed elements, such as aluminium (Al), to go into solution, which leads to more acidic soils. Sandy soils, being more acid than heavier soily soils, can thus benefit from the use of a mulch.

2.1.6 Weeds

Herbicides have an effect on growth according to Runham et al. (2000). Europe's vegetable industry exhibited reduced crop vigour in the growing season due to herbicide use. Nowadays, there is increasing pressure on producers to reduce their use of herbicides.

A mulch that covers the soil surface can cause some weed seeds to remain dormant or die after germination, due to insufficient light levels below the mulch (Harrington and Bedford 2004). Harrington and Bedford (2004) found that an EcoCover paper mulch reduced the amount of weeds in vegetable crops provided that the paper was not blown away. The paper mulch performed better than a black polythene mulch. Lettuce and cabbage yields (fresh weight) were higher in the mulch treatments than in the control (no mulch added). The suppression of weed growth in the mulch treatments could have contributed to the higher yields by decreasing root competition for nutrients. Only perennial grasses are able to grow through the mulches. An advantage of this paper mulch is that it is biodegradable.

2.1.7 Disadvantages

Although the use of non-nutritional organic mulches has many advantages, there are also associated disadvantages. A paper mulch does suppress weed growth for up to 25 weeks, but only if it remains intact. When the paper mulch becomes wet it is ripped apart by the wind and exposes the soil, resulting in no mulching effect thereafter (Harrington and Bedford 2004). A paper mulch can also result in soil with too much moisture. Furthermore, straw and paper can pose a fire hazard.

2.2 Nutritional organic mulches

The second group of organic mulches that will be discussed contains nutrients. These mulches are compost and vermicompost.

2.2.1 Compost

Composting is the decomposition of organic waste, by microbes, that creates a stable, soil-enriching humus (Eneji et al. 2003). The use of compost may influence the soil and the plant in various ways. Most compost is a mixture of manure (pig, chicken) and plant litter (straw) that is composted under aerobic conditions at high temperatures.

2.2.1.1 Growth

The first important factor that will be considered is the influence of compost on growth. Pinamonti et al. (1995) used compost derived from municipal solid waste. They applied the mulch 5-cm thick, which resulted in applications of 5 $t.ha^{-1}$ and 35 $t.ha^{-1}$ in a vineyard and apple orchard, respectively. The presence of a mulch significantly increased the initial growth of both vines and apple trees in the first three years. Thereafter, there were no further significant differences between the mulch and control treatments. According to Pinamonti (1998), one year after a compost mulch was applied in a vineyard, the growth (as quantified by pruning weights) was 120–140% higher than in the control.

2.2.1.2 Nutrition

When a municipal solid-waste-derived compost was used in a vineyard and an apple orchard, positive results in terms of nutrition were recorded (Pinamonti et al. 1995). In the vineyard trial, over a four-year period, there were significantly higher K levels in the leaves of the compost treatments compared to the control (no compost). Ca levels only differed significantly between the control and compost mulch in the third and fourth years of the five-year trial. P and boron (B) levels fluctuated over the years. The B levels in the leaves of the fruit that received mulch treatment were significantly higher than those in the control treatment during the last four years of the trial. There were no differences between the treatments in terms of N, iron (Fe) and manganese (Mn) levels.

Nutrition results reported by Pinamonti (1998) confirmed that compost increases the concentration of K in the leaves of vines. Levels of P, Ca and Mg decreased over the duration of the experiment. The leaves of the control had a higher P concentration than the leaves of the compost treatment. There were no differences in the N, Fe and Mn concentrations between the compost mulch and the control. This confirmed earlier results where no significant differences were found for N, Fe and Mn (Pinamonti et al. 1995). The fact that there was no significant difference in N concentration between the compost mulch and the control in these trials implies that the compost contributed the same amount of N as the applied fertilizers to the control treatment or microbial nutrient immobilisation may be another factor responsible for the reduction in the leaching of nutrients, such as N.

In the apple orchard, the K levels in the leaves of the trees treated with the composted mulch were significantly higher than K levels in the control trees in four of the five years. No significant differences were recorded for the other leaf nutrients (Pinamonti et al. 1995).

Walsh et al. (1996) also found that a composted manure mulch improved the nitrate levels in the soil in the first year after application in a newly planted apple orchard. This improvement was, however, not replicated in the following year when the mulch was not re-applied. In the second year of the trial, nitrate levels decreased further as a result of weed growth in the mulch.

2.2.1.3 Fruit and yield

When a municipal solid-waste-derived compost was used in a vineyard, grape yields were significantly increased in the first year after application in a four-year trial (Pinamonti 1998). In contrast, Kotze (2012) found that compost reduced yield efficiency of ‘Cripps’ Pink’ apple trees after two years of compost application.

2.2.1.4 Soil and soil moisture

Compost improved the soil moisture in an apple orchard and a vineyard. The soil moisture level was always higher, above the wilting point, in the compost treatment than in the control (no mulch). Results of studies carried out on mulches in vineyards by Pinamonti (1998) showed that the soil moisture in the composted treatment was higher than in the control (no compost) and the plastic mulched treatments. The non-nutritional compost mulch improved the infiltration rate and percentage of organic material in the soil. Other factors that were positively influenced included an increased water storage capacity and a reduction in evaporation. These improvements can be related to the increased porosity and available water. The compost also reduced temperature fluctuation, which is good for root development (Pinamonti et al. 1995; Pinamonti 1998).

Although no fertilizers were applied in the compost treatments, the total N in the soil increased. The available P and exchangeable K also increased (Pinamonti et al. 1995;

Pinamonti 1998). These positive effects can be the reason for the increase in root development near the soil surface.

A study conducted by Autio et al. (1991) failed to find a significant difference in growth of newly planted apple trees in normal rainfall years when compost was applied as a mulch. However, in a below-normal rainfall year, they found that the shoot growth in compost treatments increased significantly compared to in the control trees (no compost). This result demonstrates the positive effect of compost on soil moisture, especially during times of drought.

2.2.1.5 Weeds

Pinamonti (1998) found that weed growth was reduced when using a compost mulch; weed control was similar to the level of control achieved with herbicides. Because no significant difference in the reduction of weeds was found between the use of compost mulch and herbicide, in this study, the compost mulch was considered to be a viable replacement for the herbicide.

In trials carried out to address weed reduction, in mature apple orchards, the control had 23% more ground area covered by weeds than the ground covered by mulch comprising poultry manure. (The thickness of the applied mulch had a significant effect on the amount of weeds the thicker the mulch layer, the less weed growth was observed.) Although a compost mulch successfully reduced weed growth, it was only effective for a season, and then had to be applied annually for a lasting effect (Walsh et al. 1996; Brown and Tworkoski 2003).

2.2.1.6 Insects

In the composted poultry manure mulch trial of Brown and Tworkoski (2003), significantly more spiders, and a significant increase in predatory arthropods, were found in mulched soil compared to the control. A slightly reduced number of woolly apple aphids were also observed in the compost treatments.

2.2.1.7 Disadvantages

In the mulch trials carried out by Pinamonti (1998), two types of compost were used: (i) a sewage sludge and (ii) a municipal solid waste. The municipal solid waste had a greater heavy metal content than the sewage sludge. Use of the sewage sludge only led to a significant increase in the total zinc (Zn), as observed over a six-year period. Use of the municipal solid waste led to increases in Zn, nickel (Ni), lead (Pb), cadmium (Cd) and chromium (Cr) concentrations in the soil. Increases in Ni and Cr concentrations were also recorded in leaf samples. High Cd levels present a problem because plants accumulate Cd easily and it is highly toxic to humans if it accumulates in fruits (Pinamonti 1998). Although there was an increase in these metals, no phytotoxicity was observed in the plants.

According to Pinamonti et al. (1995), better results with organic mulches were attained under conditions of deficit irrigation. This suggests that irrigation reduces the effect of the compost, which implies that irrigation should be amended when a compost mulch is applied.

2.2.2 Vermicompost

The interactions between earthworms and microorganisms give rise to vermicompost. Standard compost is the result of microbial degradation whereas vermicompost is microbial formed through degradation in addition to digestive degradation by *Eisenia fetida* earthworms. The composting process includes the degradation of the organic material, which increases the surface area, and in turn significantly improves microbial activity (Kale et al. 1992; Domínguez 2004). This degradation gives the vermicompost a finer texture (Arancon et al. 2004) than standard compost (Contreras-Ramos et al. 2005).

2.2.2.1 Growth

Atiyeh et al. (2000) found that vermicompost, comprising mainly pig manure (10–50%), increased the germination rate of tomato seeds, in comparison to a control of Mix 360 (a standard greenhouse container medium). The rate of germination achieved when using 20–30% pig manure was significantly higher (1%/day higher) compared to the control. The number of leaves per plant was higher with the vermicompost compared to the control. The dry weight of tomato plants was also higher with the vermicompost treatment.

The use of vermicomposted sheep manure in tomato trials resulted in significant plant size increases at the first harvest. The best results were obtained when a medium with 25% vermicompost was used (Gutiérrez-Miceli et al. 2007). In this trial, the vermicompost treatment increased the stem diameter by 0.40 cm as well as the plant height by 0.11 cm, compared to the control. The number of leaves per plant was not affected by the vermicompost treatment.

In trials conducted in Ohio, vermicompost was applied to strawberries (Arancon et al. 2004). Results of plots receiving vermicompost showed no difference in shoot weight or leaf area compared to plots receiving inorganic fertilizers (control). There was, however, a difference in the number of flowers: plants treated with vermicompost had more flowers.

2.2.2.2 Nutrition

The application of vermicompost in pepper fields resulted in an increase in orthophosphates in the soil (Arancon et al. 2006). It was found that the rate of N leaching in the plots that received vermicompost was slower compared to the plots that received inorganic fertilizer (control) and contained no mulch. The favourable reduction in the rate of N leaching is a result of the higher organic material status in the vermicompost plots. Microbial nutrient immobilisation may be another factor responsible for the reduction in the leaching of nutrients, such as N.

2.2.2.3 Fruit and yield

Atiyeh et al. (2000) found that the use of 20% pig manure vermicompost resulted in tomato yield increases of up to 58%, compared to a control (Metro-Mix 360). There was also a 12.4% increase in average weight and the number of marketable tomato fruit.

Premuzic et al. (1998) found that when vermicompost was used, tomato fruit had higher Ca and vitamin C levels than the fruit grown in hydroponics media. No effects on the P and K concentrations were detected.

Arancon et al. (2004) found that the use of vermicompost increased marketable strawberry yields, compared to yields from inorganic fertilizer plots (control). This could be ascribed to the high nutrient levels of the vermicompost material. Data showed no significant differences in average fruit weight and number of fruits between treatments.

2.2.2.4 Soil microbiology

Szczech (1999) carried out an experiment in which vermicomposted sheep manure was used as a mulch on tomatoes. Higher yields and a decrease in infection by *Fusarium oxysporum* sp were achieved. The latter possibly contributed towards the higher yields that were obtained in this experiment. The level of *Fusarium* infection was reduced even further as the application rate was increased. This protective effect is probably due to the bacteria and fungi in the vermicompost, not the chemical factors, because the bacteria and fungi are antagonistic towards *F. oxysporum* sp.

Strawberry plots that received vermicompost had significantly increased microbial biomass compared to the plots that received inorganic fertilizer. It was postulated that the quantity of humic materials in the vermicompost contributed to the increase in growth and yields obtained (Arancon et al. 2004).

2.2.2.5 Weeds

The finer texture of vermicompost compared to coarse compost reduces its effectiveness as a weed suppresser. Atiyeh et al. (2000) report that the germination of seeds is improved in a finer texture of vermicompost compared to a courser mulch, which could lead to weed problems.

2.2.2.6 Disadvantages

When 100% pig manure vermicompost was used with tomato plants, the growth and total yield were reduced (Atiyeh et al. 2000). Vermicompost is very expensive. The cost could be as high as R150 000/ha if applied 5-cm thick and 1-meter wide in a 4.5 m × 1.5 m orchard (personal communication, F. Ungerer). The number of vermicompost producers is currently limited, which further increases application costs due to the transport costs involved.

3. Inorganic mulches

The natural degradation of organic mulches necessitates the annual reapplication of most of these products. As this has an economic implication for producers, the use of alternative mulches (inorganic) that require less frequent has been investigated.

3.1 Growth

Måge (1982) found that use of a black plastic (polyethylene) mulch in a trial with five-year-old apple trees led to increased shoot length in the first year, compared to the other treatments; however, differences in shoot lengths between treatments decreased over time. New growth of trees in the plastic mulch treatment also had the highest number of shoots, and hence the highest total new growth. Over a five-year period, the trunk diameter of the trees treated with the plastic mulch was greater than that of trees in the control (no mulch).

In a vineyard trial carried out with different mulches, Pinamonti (1998) found that use of a plastic mulch treatment resulted in a significantly higher pruning weight than in the case of compost mulches. This can be partly ascribed to the reduction of weeds and less evaporation under the plastic mulch.

In a study conducted in Turkey, Ekinci and Dursun (2009) applied a clear mulch and a black plastic mulch over melon seeds and found that the mulches increased plant growth and plant length, compared to the control (no mulch). The clear mulch gave better results than the black mulch, possibly due to resulting higher soil temperatures (Ekinci and Dursun 2009).

3.2 Nutrition

Inorganic mulches do not only have positive effects on growth, but can also have effects on nutrition. Use of a plastic mulch led to increases in Ca and Mg and a decrease in K concentrations in the leaves of young apple trees, compared to compost mulch (Pinamonti 1998). This may be due to the increased depth of root development. Pinamonti (1998) found that as soil depth increased the uptake of Ca is favoured above K uptake. Temperatures are also lower deeper in the soil, which may affect this uptake.

In a geotextile fabric mulch trial, Walsh et al. (1996) found that nitrate levels in the topsoil were higher than in the case of a ground cover mulch. This contradicts the data of Yin et al. (2007), who conducted a study on sweet cherries; they reported a reduction of nitrate levels in soil covered with polypropylene. Yin et al. (2007) also found a reduction in K, which is in agreement with the results of Pinamonti (1998).

Increases in K and Mg were observed in apples over a three-year period when use of a non-woven polypropylene mulch was compared with a commercial control (Szewczuk and Gudarowska 2004).

Yin et al. (2007) carried out trials with sweet cherry trees over a five-year period. Leaf N concentrations increased by up to 19.3% in the trees mulched with a polypropylene cover. This increase suggests that the decrease of nitrate in the soil is due to the increased uptake of N. The P, Ca and Mg concentrations decreased. Throughout the trial, the non-mulched trees always had higher leaf P concentrations, whereas there was no difference in K concentrations between treatments. The results for the leaves were reflected in the fruit analyses. Fruit N and Sulphur (S) concentrations, were higher in the mulched than the non-mulched trees. Similar to the leaf results, the P concentration was lower in the mulched trees than in the un-mulched trees.

3.3 Fruit and yield

In trials on young apple trees, Måge (1982) found that the yield from trees mulched with a plastic mulch was double the yield of trees with other treatments, but the average fruit size between treatments did not differ significantly. Szewczuk and Gudarowska (2004) report that the use of a non-woven polypropylene mulch resulted in higher yields of 'Jonagored' apple trees, compared to to the use of normal herbicide practices. The average fruit size also increased. In the first year of the study, fruit exposed to the polypropylene mulch had less weight loss after storage compared to fruit exposed to standard herbicide practices.

The use of a black mulch and a clear plastic mulch on melons by Ekinci and Dursun (2009) resulted in a significantly higher fruit diameter, number of fruit per plant and average fruit weight, compared to the controls. The mulches did, however, not have an effect on the firmness, titratable acidity and total soluble solids.

Use of a polypropylene ground cover increased the growth and yield of sweet cherry trees by more than 30% compared to non-mulched trees (Yin et al. 2007). The increase in yield could probably be ascribed to the increase in growth, resulting in more bearing positions.

3.4 Temperature

The improvement in nutrition and yield reported with inorganic mulch treatments may be indirectly due to changes in soil temperature and soil moisture. In a study conducted in Norway, Måge (1982) found that the soil temperature under a plastic mulch was 3 °C warmer, on average, than under other mulches. There were more earthworms in the soil under the plastic than in the control. Improvement of the soil structure under the plastic mulch may be indirectly due to increased earthworm activity. Furthermore, use of the plastic mulch resulted in the highest soil moisture and the soil had to be irrigated less than with other treatments. In a study conducted in Turkey (Ekinci and Dursun 2009), with clear mulches and black mulches, increases in soil temperature of 8 °C and 4 °C, respectively, were obtained.

3.5 Root development

Pinamonti (1998) reported that root development differed under plastic mulch and compost mulch. With compost mulch, root development was near the surface, whereas under plastic mulch significantly more root development was noticed deeper in the soil. This difference in root development resulted in differences in the uptake of Ca and K (Pinamonti 1998).

3.6 Weeds

Harrington and Bedford (2004) carried out a trial in which a plastic mulch was used in the production of lettuce and cabbage and found that the plastic mulch outperformed the control (bare soil) as a weed suppressor. Use of a woven weed mat withstood wind damage, and reduced the amount of weed growth around trees. Weed growth could be suppressed for 25 weeks, which is similar results achieved with plastic mulch (Harrington and Bedford 2004).

According to Pinamonti (1998), the use of a plastic mulch can reduce the growth of weeds for up to six years.

3.7 Disadvantages

The use of a plastic mulch can cause extreme fluctuations in soil temperature. Reduced vegetative growth and an increased number of dead vines on a rootstock could be obtained when applying a plastic mulch in the first year (Pinamonti 1998).

The labour required during use of a plastic mulch is a concern because it needs to be covered at the sides to prevent it being blown away. Furthermore, the removal and disposal of the plastic after use can be an environmental concern because it cannot be recycled.

According to Harrington and Bedford (2004), a plastic mulch cannot cover the areas around plants like a paper mulch can, leading to more weed growth in the plastic mulch treatment. Treatments with plastic mulches cannot be fertilised with conventionally applied fertilizers, and alternative fertilising practices are required if the treatment requires nutrition (Måge 1982). To date, most of the published results on the use of inorganic mulches have been recorded for the use of impenetrable plastic mulches. With this type of mulch, normal micro-jets cannot be used to irrigate and normal fertilizer application cannot be used.

4. Conclusion

Mulches have positive effects on plant growth, soil moisture, nutrient levels and weed control (except vermicompost) and there is sufficient positive evidence to promote the application of organic and inorganic mulches for food production.

However, several shortcomings have been identified. The first is that most of the research to date has been performed in greenhouses or laboratories. Results can thus not always be extrapolated for perennial crops in the field. The second is that most of the research has been done on newly planted, perennial crops or on annual crops, and insufficient information is available for established orchards or vineyards. Existing research shows that mulches enhance plant growth in the first year/years on newly planted perennial crops, which may result in earlier cropping. The third shortcoming is that most of the trials have been conducted over a period of 3–5 years, which does not address the long-term effect of mulches. Mulches tend to show good results in the first few years, but this does not necessarily continue. Finally, substantial research on the use of vermicompost as a mulch and inorganic mulches for fruit production is lacking. There is a shortage of results in the literature pertaining to fruit quality.

Many questions regarding mulch effects are unanswered. The above provides motivation for a project that addresses the use of vermicompost, wood chips, compost and geotextiles in established apple orchards.

In this study, the effects of the above mulches on apple trees and the soil, under South African conditions, will be determined. Data obtained from the trials will contribute to fruit quality results in the literature. Results emanating from the trials should be of great value to the agricultural community.

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Paper 1

Evaluating the contribution of organic and inorganic mulches to the nutrient status of leaves and fruit of 'Cripps' Pink' apple trees on two different soil types

Introduction

Nutrients such as nitrogen (N), potassium (K), phosphorous (P), calcium (Ca) and boron (B) are important for the successful production of apples, in that they do not only positively associated with fruit quality (Fallahi et al. 2010), but are also an integral part of vegetative processes such as shoot growth and leaf development. Leaf and fruit nutrient levels are accurate indications of the tree's mineral status and fruit quality respectively and can be used to determine the fertilizer requirement of an apple orchard (Fallahi et al. 2010). In order to obtain sufficient nutrient levels in the tree (leaves and fruit) in commercial orchards, fertilizers are applied as a soil application or foliar spray, to replenish and supplement the available nutrients in the soil. Although the use of fertilizers may improve the mineral status of fruit trees, it can have a detrimental effect on the soil ecosystems and contaminate soil water (Edmeades 2003; Yin et al. 2007) as well as reduce microbial activity (Glover et al. 1999). In order to reduce the use of fertilizers and possible adverse effects thereof on the environment, alternative ways to increase mineral levels in fruit trees, e.g. application of mulches, need to be evaluated.

Effects of mulching include an increase of specific mineral elements in the soil as the mulch decomposes, changes in soil pH (Cadavid et al. 1998) and a possible contribution of organic material to the biological component of the soil environment (Forge et al. 2002). In addition, some mulches buffer changes in soil temperature and moisture, which will also have an influence on the soil biology (Autio et al. 1991; Brown and Tworkoski 2003; Arancon et al. 2006). Whether these changes are sufficient to result in consistent significant changes in the nutrient status of leaves and fruit, which would allow the reduction of fertilizer application of some mineral elements, needs to be considered carefully before recommendations are made to commercial producers.

Effects of mulches like vermi-castings, pine needles, straw and farm yard manure, which were shown to be able to increase the nutrient status of a plant (Pinnamonti 1998, Arancon et al. 2002), include the reduction of N fertilization (North et al. 2011), suppression of weed growth (Baxter 1970), increased organic matter in the soil (Arancon et al. 2006), increased soil moisture and retention (Barzegar et al. 2002), temperature moderation (Treder et al. 2004) and improved root growth (Acharya and Sharma 1994). These different mulches vary significantly in terms of its contribution of each mulch towards plant growth and generalisations about the effect of mulches as an entity should be avoided (Walsh et al. 1996). This is evident from research already conducted on a variety of mulches.

Leaf analyses from peach and apple trees that received a straw mulch, showed higher K levels, but Mg and Ca levels decreased over a five year period (Baxter 1970). Under South African conditions, Van Schoor (2009) found little change in leaf nutrient concentrations where the straw mulch application was compared to a control, over a six year period, in a newly established pear orchard. In a vine trial (Pinamonti et al. 1995), a compost treatment resulted in significantly higher foliar K levels compared to a control (no compost) in four years of a five year trial. Ca levels only differed significantly between the control and compost mulch in the third and fourth year of the same trial. P levels fluctuated over the years and no significant results were obtained for N, iron (Fe) and manganese (Mn). Foliar B levels of the control treatment were significantly higher than in the mulched treatment during the last four years of the trial (Pinamonti et al. 1995). K levels in the leaves of apple trees treated with composted mulch were significantly higher than levels in the control trees, in four of the five years that the trial was conducted (Pinamonti et al. 1995). Levels of P, Ca and Mg in the leaves of trees that received a mulch decreased over the experimental period. Compost mulches increased soil N and K (Kotzé and Joubert 1992) as well as extractable P, Ca and Mg levels under South African conditions (Van Schoor 2009). Although the soil nutrient levels were influenced by the compost, it did not have an effect on the fruit and leaf minerals in both studies.

Research on the effect of vermi-castings on plant nutrition in field trials is very limited. Results from trials in greenhouses revealed higher P and N levels in the soils when compared to non-mulched soils (Arancon et al. 2006). Kotze (2012) however found that N and B levels in the leaves of 'Cripps' Pink' apple trees were significantly higher when compared to an un-mulched control treatment. The results were only obtained in the first year of the two year trial.

A plastic mulch increased the Ca and Mg and decreased K concentrations in the leaves of young apple trees compared to a compost mulch (Pinamonti 1998). In a mulch trial by Walsh et al. (1996), nitrate levels in the top soil under a geotextile mulch were higher than the control (no mulch). This is in contrast with findings of Yin et al. (2007) who conducted a study on sweet cherries. Results showed a reduction of nitrate in the soil covered with polypropylene. Yin et al. (2007) also found a reduction in K that corresponds with the results of Pinamonti (1998). An increase in K and Mg was observed in 'Jonagored' apples when a non-woven polypropylene mulch was compared to a commercial control with no mulch added (Szewczuk and Gudarowska 2004). Increased leaf N concentrations, up to 19.3 %, were obtained in sweet cherry trees when trees were mulched with a polypropylene cover (Yin et al. 2007). Leaf P, Ca and Mg concentrations showed a decrease under the polypropylene cover. Similar to the leaf results, the P concentration in the fruit was lower where the polypropylene cover was applied compared to the where the cover was not applied

(Yin et al. 2007). Thus, results regarding the effect of an inorganic mulch on leaf nutrient levels varied considerably in reported papers.

Soil type influences nutrient uptake by trees. In sandy soils, mulches containing high K levels reduced the decline in foliar K concentrations over time and thus K fertilizer requirements of the trees were met (Kotzé and Joubert 1992; Neilsen et al. 2003). An increase in N mineralization, which can have a positive effect on growth, was observed in trials conducted on apricots (Kotzé and Joubert 1992). The increase in the mineral uptake by the trees was explained by the improved cation exchange capacity (CEC) of the soil.

Limited information is available on the effects of organic and inorganic mulches on established orchards (Neilsen et al. 2003), especially under South African conditions. Data on the effect of mulches on different soil types under the same climate and management is also very limited. A field trial was therefore conducted to evaluate the nutritional effect of organic and inorganic mulches on established 'Cripps' Pink' apple trees on a lighter soil and heavier soil site.

Materials and methods

Orchard layout

The trial was carried out on Lourensford Estate in Somerset West, Western Cape, South Africa (34˚ 2' S, 18˚ 55' E). Two adjacent orchards consisting of 'Cripps' Pink' apples on M793 rootstocks, planted in 1998, were selected for experimental sites. The two sites differed in soil type, i.e., lighter soil (Tukulu) and heavier soil (Clovelly) (Soil classification working group 1991). Row orientation was in a North East by South West direction with a tree spacing of 4 m × 1.5 m. Trees were trained to a central leader on a three wire training system.

Orchards were not ridged and had no slope. The trial commenced in October 2008 and initial research results from 2008 to 2010 were reported by Kotze (2012).

Treatments and experimental design

Five treatments were carried out comprising a control (no mulch), three different organic mulches and one inorganic mulch. All treatments received a herbicide application whenever weed growth started to show. The organic mulches were course textured wood chips, medium-fine compost and vermi-castings. The wood chips consisted of chipped apple and ornamental trees supplied by the estate and local tree trimmer, respectively. The compost, which was a combination of 20 % mushroom straw compost and 80 % municipal green waste, was supplied by Biocircle (Pty) Ltd, Klapmuts, RSA. The vermi-castings, derived from a cow manure and a wheat straw mixture, were supplied by Worm Works Purveyors (Pty) Ltd, Simondium, SA. Compost and vermicompost differs in the process of compostation. Normal commercial compost is mostly the result of microbial degradation, whereas vermicompost is the result of microbial degradation in addition to the digestive degradation by *Eisenia fetida* earthworms. In this study, the term vermicompost is referred to as vermi-casting to clearly differentiate it as a distinctive product from vermicompost supplied by Wormwork Purveyors (Pty) Ltd. Commercial vermicompost may consist of a mixture of vermicompost and compost, whereas vermi-castings consists of 100% *Eisenia fetida* excrement. The inorganic mulch consisted of a woven geotextile fabric - polytex PT110 and was obtained from Spilo, Paarl, RSA. The geotextile differs from black plastic, as it is woven material and allows water and minerals to reach the soil.

The trial layout was a randomized complete block design, consisting of six replications of four trees per plot with two buffer trees between each plot. Fertilizer was applied to all treatments according to commercial recommendations of the control. Irrigation in both orchards was applied with microjets, one between two trees, at a rate of 42 L h^{-1} (per micro jet) for three hours, twice a week. Irrigation started in October/November till the first rains. During January 2011, the rate of every second micro-jet was reduced to 32 L h^{-1}. In 2012, the rest of the 42 L h^{-1} microjets in the plots were also replaced with 32 L h^{-1} nozzles.

The wood chips, vermi-casting and compost plots received approximately 90 L of material each spread out evenly over the 6 m^2 plots to a thickness of approximately 5 cm. The vermi-castings were topped with a layer of wood chips to prevent them from blowing away. The vermi-castings plots received 60 L of vermi-castings and 30 L of wood chips. During 2009/2010, only the applications for the wood chips treatment were doubled to attain a 10 cm instead of the 5 cm thick bedding in accordance with industry practises. Mulches were re-applied annually during spring (October).

Fruit and leaf mineral analysis

Leaf samples were taken annually at the end of January for two years (2011 and 2012), according to standard procedure (Kotzé 2001). Samples consisted of 10 leaves (five on the NW and five on the SE side) per treatment plot and were placed in plastic bags. Leaves were kept in a cooler box during sampling and transport.

Fruit samples were taken at the main harvest (27 April 2011 and 17 April 2012). Samples consisted of 20 fruit, of similar size (size according to the average size at each plot), randomly taken from each treatment plot for mineral analysis. Samples of fruit and leaves were taken for the analysis on the same day it was sampled. Analyses were performed by Bemlab (Pty) Ltd, Strand, RSA.

Mulch nutrient concentrations

Individual samples (500 ml per plot) from the existing wood chips, compost and vermi-castings mulches, applied in the previous year, were taken for mineral analysis before the new layers of mulch were applied during October 2011 and 2012. The newly applied compost and vermi-casting mulches were sampled by taking one, composite sample of 500 ml from each batch at application during October 2010 and 2011. Analyses were performed by Bemlab (Pty) Ltd.

Soil nutrients

A complete soil mineral analysis was conducted during 2012 at 10, 30 and 50 cm depths. Analysis was done by Bemlab (Pty) Ltd. and is discussed in greater detail in a concurrent study that was conducted at exactly the same sites (Nicholson 2012). In this study, only the sections of the soil mineral analysis that were significantly different and pertain to fruit quality and leaf and fruit mineral contents are presented.

Statistical analysis

Data were analysed statistically with SAS (SAS Institute Inc, Cary, NC, USA 2006). Differences between treatments were determined by calculating least square means and least significant differences (LSD). Significance was determined at a 5 % level ($P < 0.05$).

Results

2010/2011

Fruit mineral analysis

The only significant difference between the treatments occurred for P in the heavier soil (Table 1a). The vermi-castings treatment had a significantly higher P level compared to geotextile and the control, but did not differ significantly from the wood chips and compost treatments. Both the compost and wood chips treatments showed a significantly higher P level compared to the control. The control and geotextile treatment had similar P levels.

In lighter soil site, the only significant difference between the treatments was found for boron (B) (Table 1b). The control had significantly higher levels of B compared to the vermi-castings and wood chips treatments, but did not differ significantly from the compost and geotextile. The lowest B levels were found in the vermi-casting treatment, which differed significantly from the control and compost.

Leaf mineral analysis

At the heavier soil, there were no significant differences between treatments for any of the minerals analysed (Table 2a). At the lighter soil site, however, K levels for compost and vermi-castings treatments were significantly higher compared to the control, geotextile and wood chips treatments (Table 2b). Geotextile and wood chips treatments had significantly higher levels of copper (Cu) compared to the control and compost treatments, but did not differ significantly from the vermi-castings treatment. The other minerals showed no significant differences.

Mulch nutrient concentrations

Analyses of mulches sampled one year after application in 2010, indicated that at the heavier soil site, the vermi-casting treatment had significantly higher N, P and Mg levels compared to the compost and wood chips treatments (Table 3a). There were no significant differences between the treatments for moisture and K. For similar samples taken at the lighter soil site, the vermi-castings and compost treatments showed a significantly higher pH than the wood chips treatment (Table 3b). The vermi-casting treatment had significantly higher levels of N, P, Ca and Mg compared to the wood chips and compost treatments. There were no significant differences between the treatments for percentage moisture, K or Ca. The vermi-casting treatment had significantly higher levels of sodium (Na), Mn, Cu, zinc (Zn) and Fe compared to the compost and wood chips treatments (Table 4a). The compost had significantly higher Fe than the wood chips. There were no significant differences between treatments for B. For the lighter soil site, the vermi-castings treatment had significantly higher levels of Na, Mn, Cu, Zn and B compared to the compost and wood chips treatments (Table 4b). There were no significant differences between treatments for Fe.

Mineral analysis of compost and vermi-castings material at application of the mulch.

Tables 5a and 5b show the mineral analysis of the newly purchased compost applied in the 2010 and 2011 seasons, and vemi-castings only for 2011 due to an error. Statistical analyses were not performed, as only one sample of the material was taken and the same material was applied at both sites to indicate mineral composition of these mulches. The differences in nutrient levels between the mulches are a reflection of the differences in composition of the original material and processes used to make these mulches, and emphasises the biological variation in organic mulches over years. The vermi-castings had higher N, P, Ca, Mg, Mn, Cu, Zn and B levels compared to the compost, which has higher K, Na and Fe levels (2011). The newly applied wood chips were not analysed, for it is not usually perceived as a mulch that can contribute nutrients to the soil and plant at application. The newly applied compost material had a slight increase from 2010 to 2011.

2011/2012

Fruit mineral analysis

No significant differences were obtained between treatments in the heavier soil except for B levels (Table 6a). The compost treatment had a significantly higher B level compared to the wood chips and vermi-casting treatments, but did not differ significantly from the control and geotextile treatments. Vermi-castings also had significantly lower B lowers when compared to the control.

In the lighter soil site, P levels of the vermi-casting and wood chips treatments were significantly higher compared to the control, but did not differ significantly from the compost and geotextile treatments (Table 6b). All other minerals did not differ significantly between treatments.

Leaf mineral analysis

Only Mg levels showed significant differences between treatments at the heavier soil (Table 7a). Wood chips and vermi-castings treatments had significantly higher Mg levels compared to the compost, but did not differ significantly from the control and geotextile treatments.

At the lighter soil site, the vermi-casting treatment had significantly higher levels of K compared to the control, geotextile and wood chips treatments, but did not differ significantly from the compost treatment (Table 7b). Compost also had significantly higher K levels when compared to the control and wood chips. No significant differences were found between the treatments regarding the other minerals.

Mulch nutrient contents

In the heavier soil, the vermi-castings and compost treatments was significantly lower compared to the wood chips treatment (Table 8a). The vermi-castings treatment also had significantly higher salinity (EGC), P and Mg levels compared to the wood chip and compost treatments. The vermi-casting treatment had significantly higher Cu and Zn levels when compared to the wood chips and compost treatments (Table 9a). Compost and vermi-castings treatments had significantly higher levels of Fe and B than the wood chip treatment.

The pH of the wood chips treatment at the lighter soil site had a significantly lower pH than the other two treatments (Table 8b). Compost and vermi-castings treatments had significantly higher N and Ca levels compared to the wood chip treatment. Vermi-castings also had significantly higher P and Mg levels than wood chips, but did not differ significantly from the compost treatment. Vermi-castings had significantly higher levels of Mn, Cu and Zn compared to wood chips, but did not differ significantly from the compost treatment (Table 9b). The compost treatments had higher Fe levels than wood chips, but did not differ significantly from vermi-castings. The treatments show no significant differences for sodium (Na) and B.

Trends in nutrient changes from 2009-2012

Fruit nutrient trends

The fruit N levels for all treatments initially increased over the course of the trial at both sites, but there was a drastic decrease between 2010 and 2012 in the heavier soil site (Fig. 1a and 1b). The data point for 2011 was omitted (Fig. 1a), as the analysis was not trustworthy. The fruit P levels of the mulched treatments also showed a bigger increase than the control over the four years of the trial (Fig. 2a and Fig. 2b). During the first three years, there was a reduction in K fruit levels at both sites, except for compost in the heavier soil site, which increased after the second year (Fig 3a and Fig. 3b).

Mg levels in fruit decreased during the first three seasons, before an increase during 2012, at both sites (Fig. 4a and Fig 4b). There was a decrease in fruit Ca levels for the first three years in the heavier soil (Fig. 5a) and only for the first year in the lighter soil site (Fig. 5b) in all the treatments. Although the B levels fluctuated over the four year period (Fig. 6a and Fig. 6b), at both sites, there was a tendency in the first three years, that the mulched plots had lower B levels when compared to the control (Tables 1b and table 6a; Kotze 2012).

Leaf nutrient trends

Levels of N in the heavier soil (Fig. 7a) decreased over the four year period with wood chips being the lowest. In the lighter soil site (Fig. 7b), levels of nitrogen increased slightly with compost having the highest levels and vermi-castings and wood chips the lowest.

Phosphorous levels in the heavier soil increased across treatments, over the four year period (Fig. 8a). However, the increase differed between treatments in the last two years of the trial. The wood chips, compost and vermi-castings P levels were consistently higher than those of the geotextile treatment and control. In the lighter soil site, P levels also showed an increase over the four year period (Fig. 8b). Vermi-castings and compost had the highest levels with geotextile, control and compost the lowest.

The vermi-casting and compost treatments had the highest foliar K levels on the more sandy soil (lighter soil site) during the last two years of the trial, when compared to the other treatments (Fig. 9b). In the heavier soil however, the three organic treatments had the highest levels of K in the leaves (Fig. 9a). There was an increase in K levels over the four years at both sites.

An increase in Ca levels was observed in all the treatments at both sites after the four years (Fig. 10a and 10b). Ca levels of all the treatments, except vermi-castings, decreased in the last three years at the lighter soil site, but the levels of Ca were still higher than the first year.

A decrease in leaf Mg levels in the last three years was obtained in the trial (Fig. 11a and Fig. 11b). Vermi-castings and wood chips had the highest leaf Mg levels in the heavier soil site compared to the other treatments after four years of application (Fig. 11a). In the lighter soil site the vermi-casting and control treatments had the highest leaf Mg levels (Fig. 11b).

Cu levels in the heavier soil (Fig. 12a) decreased constantly over the four years of the trial in all of the treatments. This was not the case in the lighter soil site, where the Cu levels stayed almost constant with little variance between the treatments (Fig. 12b). Cu levels only differed significantly between treatments in the third year of the four year trial at the lighter soil site.

In all treatments and for both sites, B levels showed an increase from the first to fourth year of the trial (Fig. 13a and 13b). The actual B levels between the sites were similar, but the trends differed. B levels in the compost treatments in the lighter soil site decreased between 2009 and 2010 and then increased till 2012.

Discussion

According to Fallahi et al. (2010), macronutrients such as N, P, K and Ca and the micronutrient B, are positively associated with fruit quality of apples. Therefore, in this study, these elements were the main focus when evaluating the contribution of mulches to changes in fruit mineral composition over the four year trial period. Due to the significant differences of Cu and Mg in the leaves, these minerals will also be discussed.

Fruit mineral analysis

The levels of N in all the treatments were in the optimum range of 40-60 mg/100g (Kotzé 2001). Low levels of N can reduce fruit size and can cause early fruit drop, thus levels must be maintained above the 40 mg/100g level.

The increase in P concentration in the fruit resulted in fruit P levels being within the optimum industry norm of 7 – 12 mg/100g (Kotzé 2001) at both sites. The improved P status of the trees that received compost and vermi-castings can partly be ascribed to the higher initial P concentrations of these mulches in comparison to the non-organic mulches and wood-chips (Table 5). An increase in P levels in the fruit can be due to better root distribution (Nicholson

2012, unpublished data), which increases the potential absorptive area for a relative immobile element such as P (Acharya and Sharma 1994; Fallahi et al. 2010). The increase of P in the geotextile treatment can also partly be ascribed to higher soil temperatures and moisture (Nicholson 2012, unpublished data) compared to the control (Neilsen and Neilsen, 2003). The higher temperature and moisture, observed under the geotextile treatment, can increase diffusion of P to the root area, as well as promote additional root growth. An increase of P when using a pine needle mulch was also reported in a study by Acharya and Sharma (1994). Reports by Kale et al. (1992) and Arancon et al. (2006) suggests that vermi-castings increased P levels in the soils and shoots. The higher P levels can reduce the incidence of internal breakdown in fruit, thus increasing storeability of fruit (Neilsen and Neilsen 2003). This is especially important to South African growers who export their fruit around the world.

The increase in K in fruit can be the reason for the larger average fruit size obtained (Paper 2). K levels are above the optimum concentrations of 95-105 mg/100g fresh weight (Kotzé 2001). Although high K levels were obtained in our trial, it did not yet reduce the uptake of other cations such as N, P and Ca levels as reported by Fallahi et al. (2010).

Higher Mg levels in the compost and vermi-casting treatments could be ascribed to the initial higher levels of Mg in these mulches at application. The levels of fruit Mg were near or above the optimum level of 5 mg/100g (Kotzé 2001) and should be monitored. Too high levels could influence the levels of other cations such as K and Ca (Fallahi et al. 2010).

The reason for decrease in fruit Ca concentration in the first year and subsequent increase till the fourth year is not clear, nevertheless the levels of Ca in the fourth year were still above the optimum range of 4.5-5 mg/100g (Kotzé 2001). This could have been the reason why no physiological disorders like bitter pit or internal breakdown occurred in that season (Neilsen and Neilsen 2003; Fallahi et al. 2010). The reason could also be that Ca levels compared to fruit size were also still in the optimum range (Kotzé 2001).

Higher soil temperatures, which improves B uptake, could have been the reason for the high B levels in the control (heavier soil and the lighter soil site) and geotextile (the lighter soil site) treatments (Swietlik and Faust 1984; Nicholson 2012). Although soil analyses of the trials in May 2012 (Nicholson 2012) showed high B levels in especially the vermi-casting treatment (Table 10), this was not evident in the fruit analysis. The adsorption of B to organic matter and the possible leaching of B could have influenced the uptake of B from the organic mulches (Nagy et al. 2011). In the fourth year, the compost and vermi-casting treatments both had higher levels of B in the soil compared to the control at the heavier soil site. Pinamonti et al. (1995) argued that irrigation can reduce the effects of organic mulches in apple orchards. The lower fruit B concentration in, especially in the lighter soil site, could be ascribed to the irrigation. The lower B concentration in the fruit, could therefore be due, at least in part, to over irrigation, despite the reduction in irrigation since 2011. The B levels for all the treatments, including the control, were however above 0.8 mg/kg and therefore defects associated with B deficiencies are not expected (Neilsen and Neilsen 2003).

Leaf mineral analysis

The decrease in leaf N levels at the heavier soil in the fourth year can be ascribed to several possible reasons. Very strong weed growth occurred in the orchard (own observation), which could have competed successfully for the uptake of N (Walsh et al. 1996). The slight increase of N in the lighter soil site corresponds with work done by Acharya and Sharma (1994) on pine needle, Walsh et al. (1996) on compost and Yin et al. (2007) on geotextile mulches. However, despite the drastic decrease at the heavier soil site, the levels of leaf N at both sites were still between the optimum levels of 2.1 – 2.6% (Kotzé 2001). The decreasing N trend at the heavier soil site should be monitored, because levels below 2.1% will influence tree growth and yield negatively (Neilsen and Neilsen 2003). The drop in N levels could potentially be reduced by keeping the tree row clean of weeds and making sure that N fertilizer application is split in two (Kotzé 2001).

The average leaf P levels of the compost, vermi-castings and wood chips treatments of the heavier soil were higher than the lighter soil site levels, while the other two treatments only differed slightly between the two sites. These results contrasted findings of Pinamonti (1998) and Yin et al. (2007), who found that a compost and polypropylene mulch decreased P levels over time. Possible reasons for the increased P levels were discussed in the fruit mineral section and the same reasons could pertain to the results obtained for the leaves. Although there was a slight decrease in both orchards in the fourth year, the levels of P were still higher than the minimum level of 0.14 – 0.19 % (Kotzé 2001). Therefore adequate cell division can occur in the leaves and reduced flowering can be avoided (Neilsen and Neilsen 2003). Applying these mulches, especially the organic mulches, under the same conditions can improve tree P levels over time and maintain good fruit quality.

The increase in K levels could be due to the reduced irrigation which could have caused less K leaching (Neilsen and Neilsen, 2003) and thus increase availability to the roots. Concurrent with the increase in leaf K levels, there was also the increase of leaf Mg levels in the 2011/2012 season (Fig. 4a and Fig. 4b) which was also observed by Fallahi et al. (2010) on 'Fuji' and 'Gala' apples. Higher K levels in leaves corresponds with the findings of Hogue and Neilsen (1987) that mulches with high K levels (Table 5) improves K levels in the leaves. These findings can also be ascribed to the reduced leaching of the mobile K ion (Alfaro et al. 2004) when using organic mulches (Neilsen et al. 2000). This reduction in leaching is due to the binding of K to the organic matter (Neilsen and Neilsen 2003). No significant differences between treatments were found, for K levels, in the soil analysis in 2012 (Nicholson 2012;

Table 10), thus the uptake must be directly from the mulches where high amounts of fine roots were present (Nicholson 2012). Results for the geotextile and control treatments confirmed those of Yin et al. (2007) who reported minimal differences between these two treatments regarding leaf K levels. Increased K levels were observed at both sites over the four year period. K influences fruit size (Neilsen and Neilsen 2003) and the increased levels are reflected in the increased fruit size at both sites (Paper 2). The K levels of all the treatments at both sites were higher than the optimum range of 1.2-1.4 % (Kotzé 2001). Compost (heavier soil and the lighter soil site) and vermi-casting (lighter soil site) treatments had levels exceeded the excess level of 2 % in the fourth year. These increasing levels should be monitored, because too high K levels could influence the uptake of other cations such as Ca and Mg (Neilsen and Neilsen 2003).

The increase in Ca levels in all treatments over the four year period at both sites, is in contrast to findings by Baxter (1970), Pinnamonti (1998) and Yin et al. (2007) who found that Ca levels decreased over a period of time when using straw, compost and geotextile mulches. In our trial, the reduction in irrigation volume and increase in fine root volumes reported by Nicholson (2012) could have resulted in the increased uptake of Ca. In both sites, Ca levels in the fourth year were lower than the optimum range of 1.45-1.6 % (Kotzé 2001) in all the treatments, except the wood chips in the heavier soil. This should be monitored and application of Ca through liming could be implemented to increase Ca levels in the leaves even more.

The higher Mg levels initially found in the vermi-castings and compost were also reflected in higher levels of Mg in the soil analyses of these treatments (Nicholson 2012) compared to the other treatments for the heavier soil site (Fig. 11a and 11b; Table 10). For the last three years of the trial there was a reduction in leaf Mg levels, in all the treatments, at both sites and this could be ascribed to increased leaf K levels (Neilsen et al. 2003. The leaf Mg levels in the heavier soil were below the optimum levels of 0.3-0.4 % (Kotzé 2001) and were near the 0.20 % level (Neilsen and Neilsen 2003) where deficiency symptoms can start to develop in the leaves. This deficiency can have a negative effect on fruit size (Neilsen and Neilsen 2003) due to effect on photosynthesis. Leaf Mg levels in the lighter soil site were above 0.3 %, but there was also a tendency for levels to drop below the 0.3 % level (Fig. 11b).

Decreasing Cu levels in the heavier soil site supports the finding by Neilsen et al. (2003) and Van Schoor (2009), that mulches can decrease Cu availability in an apple orchard. Higher levels of Cu in the wood chips treatment at the lighter soil site could be ascribed to the significantly lower pH of the mulch itself (Table 3b and 5b). Cu is strongly absorbed by organic matter when pH is near 7 (Neilsen and Neilsen 2003) and could cause reduced availability of Cu to the roots. The high leaf Cu levels in the geotextile treatment can be ascribed to the higher levels of Cu in the soil when compared to the other treatments (Table 10). The levels of Cu in the leaves at both sites were below the optimum level of 5 mg/kg. The low levels of Cu in all of the treatments can cause ‘summer dieback’ if this persists in the orchard (Neilsen and Neilsen 2003). The problem could be corrected by Cu foliar applications.

Similar to P and K, the levels of B in leaves were above the norm, in this case above 30-35 mg/kg, but below 140 mg/kg (Kotzé 2001), which is associated with toxicity under South African conditions. Leaf B levels over 70 mg/kg had been associated with bud death and delayed flowering (Neilsen and Neilsen 2003). The increase in B levels should however be monitored by producers so that foliar B applications in corporations with mulching, do not cause toxicity.

Mulches nutrient analysis

From 2011 to 2012, N levels increased in the wood chips and compost mulches and decreased in the vermi-casting mulch in the heavier soil. It could be due to the significantly higher moisture content of the vermi-castings (data not shown). Although the vermi-castings had the lowest amount of N, the three treatments did not differ significantly. In the lighter soil site the wood chips had the highest moisture content (data not shown) and could also explain the significantly lower level of N when compared to the compost and vermi-casting treatments.

Phosphorous levels in the heavier soil declined slightly for the wood chips and vermi-castings, but the vermi-casting still had the significantly higher P levels (Table 8a). The high P levels in the vermi-casting treatment, could be ascribed to higher uptake of P by the trees (Fig. 8a and 8b) that are reflected in the fruit mineral analysis (Fig. 2a and 2b). The mulches in the lighter soil site showed the same trend as the heavier soil.

Levels of K increased for all three treatments over two years, but did not differ significantly from one another. The K levels in the lighter soil site showed the same trend.

The vermi-castings and compost treatments' Ca levels increased over the two years in the heavier soil. In the lighter soil site there was an increase in all three mulches, but differed from the heavier soil, because the wood chips had significantly lower levels of Ca compared to the other two treatments.

For the B levels, wood chips and vermi-casting treatments showed a decrease over the two years in the heavier soil. Compost B levels increased but did not differ significantly from vermi-castings. This in contrast to the lighter soil site B levels that increased in all three treatments. The treatments however did differ significantly.

The reason for the higher nutrient contents of the vermi-casting and compost treatments could be ascribed to the nutrient levels in the newly applied material each year (Table 5a and b). The wood chips does not have significant amount of nutrients in the newly applied material. The nutrient levels in the wood chips could be from fertilizers applied in the tree row through agricultural practices or microbial degradation of the material and the roots in the mulch itself that extracts nutrients from the soil below. If mulches tend to have affinity for some nutrients, it could not be established in the two years of measurements.

Conclusion

The nutrient level in leaves and fruit of 'Cripps Pink' apples changed over the past two seasons (2010 and 2011) when compared to the trends of the two seasons before that. This was partly due to the reduction of irrigation volumes since 2011. However, none of the mulches had a negative effect on fruit and leaf nutrient levels and outperformed the control treatment in most of the nutrient levels. The only two nutrients that could be reduced in terms of artificial fertilizer applications were K and P, if compost and vermi-casting are applied. Woodchips, in together with a normal fertilizer program, can successfully be used in established orchards under the same conditions as this trial.

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Table 1a: The effect of different mulches on the mineral status of 'Cripps' Pink' fruit harvested in May 2011 at the experimental heavier soil site.

Treatment	N (mg/100g)	P (mg/100g)	K (mg/100g)	Ca (mg/100g)	Mg (mg/100g)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	275.67[ns]	5.60[c]	107.00[ns]	6.12[ns]	4.73[ns]	8.47[ns]	0.75[ns]	2.78[ns]	0.32[ns]	0.43[ns]	5.30[ns]
Compost	278.17	7.73[ab]	117.00	6.12	5.07	9.43	0.83	3.03	0.32	0.47	5.10
Geotextile	270.00	6.53[bc]	104.67	5.72	4.43	7.83	0.75	3.00	0.28	0.42	5.35
Wood chips	279.17	7.69[ab]	107.00	5.95	4.67	9.02	0.80	3.13	0.32	0.50	5.08
Vermi-castings/wood chips	274.33	8.84[a]	123.17	5.70	4.93	8.45	0.78	3.20	0.32	0.43	4.83
P value	0.7842	0.0019	0.0582	0.9180	0.2794	0.1283	0.7994	0.6589	0.6864	0.6339	0.4311
LSD	16.22	1.46	14.12	1.26	0.62	1.26	0.16	0.60	0.06	0.12	0.61

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

Table 1b: The effect of different mulches on the mineral status of 'Cripps' Pink' fruit harvested in May 2011 at the experimental lighter soil site.

Treatment	N (mg/100g)	P (mg/100g)	K (mg/100g)	Ca (mg/100g)	Mg (mg/100g)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	236.83[ns]	6.23[ns]	98.83[ns]	5.78[ns]	4.63[ns]	9.08[ns]	0.57[ns]	2.67[ns]	0.27[ns]	0.42[ns]	5.02[a]
Compost	237.17	7.20	109.83	6.55	5.10	9.37	0.75	2.90	0.42	0.50	4.85[ab]
Geotextile	237.00	5.78	104.00	6.75	4.67	9.05	0.67	2.98	0.27	0.42	4.47[abc]
Wood chips	241.83	6.58	100.83	6.23	5.03	9.25	0.75	2.90	0.27	0.48	4.32[bc]
Vermi-castings/wood chips	245.00	6.36	100.83	5.85	5.00	9.98	0.65	2.65	0.18	0.48	4.13[c]
P value	0.8608	0.7115	0.2941	0.0503	0.6476	0.8527	0.3991	0.8052	0.5201	0.6215	0.0453
LSD	19.23	2.09	11.04	0.74	0.82	1.93	0.22	0.71	0.32	0.15	0.63

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

Table 2a: The effect of different mulches on the mineral status of 'Cripps' Pink' leaves sampled in Jan 2011 at the experimental heavier soil site.

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	2.28^{ns}	0.17^{ns}	1.78^{ns}	1.41^{ns}	0.30^{ns}	167.33^{ns}	181.50^{ns}	114.83^{ns}	5.00^{ns}	110.50^{ns}	42.67^{ns}
Compost	2.30	0.28	1.95	1.42	0.30	172.33	203.50	120.17	5.00	120.17	42.50
Geotextile	2.38	0.16	1.76	1.35	0.30	161.00	169.67	120.50	5.00	99.83	41.50
Wood chips	2.28	0.28	1.91	1.49	0.31	173.33	187.00	114.17	5.00	122.00	42.83
Vermi-castings/wood chips	2.40	0.28	1.95	1.33	0.31	167.50	180.50	122.00	5.67	114.00	40.83
P value	0.1595	0.0819	0.0869	0.2854	0.5614	0.2609	0.3190	0.8505	0.1180	0.4640	0.8296
LSD	0.12	0.12	0.18	0.16	0.02	12.12	32.54	18.20	0.61	26.97	4.20

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 2b: The effect of different mulches on the mineral status of 'Cripps' Pink' leaves sampled in Jan 2011 at the experimental lighter soil site.

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	2.40^{ns}	0.19^{ns}	1.51^{b}	1.34^{ns}	0.34^{ns}	161.17^{ns}	149.83^{ns}	139.17^{ns}	4.17^{b}	87.50^{ns}	38.00^{ns}
Compost	2.35	0.22	1.82^{a}	1.35	0.32	169.50	164.00	154.33	4.33^{b}	91.00	38.00
Geotextile	2.47	0.18	1.63^{b}	1.41	0.33	175.83	158.17	171.83	5.17^{a}	89.83	35.83
Wood chips	2.41	0.23	1.65^{b}	1.34	0.34	168.00	152.67	166.00	5.17^{a}	95.50	37.83
Vermi-castings/wood chips	2.38	0.26	1.84^{a}	1.29	0.35	169.33	148.17	157.83	4.83^{ab}	87.50	36.50
P value	0.5305	0.0927	0.0025	0.6665	0.6347	0.7926	0.7314	0.7969	0.0182	0.9175	0.9041
LSD	0.14	0.06	0.17	0.15	0.04	23.79	26.93	57.27	0.70	20.21	5.88

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 3a: Macronutrient, pH and moisture analyses of the various mulches sampled at the heavier soil site, one year after application in 2010.

Treatment	pH (KCl)	Moisture (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Compost	6.87[a]	7.20[ns]	0.70[b]	0.14[b]	0.03[ns]	1.28[ns]	0.05[b]
Wood chips	6.53[b]	10.37	0.64[b]	0.12[b]	0.04	1.50	0.04[b]
Vermi-castings/ wood chips	6.92[a]	8.20	1.42[a]	0.47[a]	0.04	1.38	0.25[a]
P value	0.0012	0.2251	0.0010	<.0001	0.2161	0.1904	<.0001
LSD	0.18	3.87	0.35	0.12	0.02	0.24	0.06

Data was significant at 5% level (P<0.05). Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 3b: Macronutrient, pH and moisture analyses of the various mulches sampled at the lighter soil site, one year after application in 2010.

Treatment	pH (KCl)	Moisture (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Compost	6.63[a]	4.60[ns]	0.46[b]	0.10[b]	0.02[ns]	0.72[b]	0.04[b]
Wood chips	6.07[b]	6.43	0.55[b]	0.10[b]	0.03	0.61[b]	0.04[b]
Vermi-castings/ wood chips	6.63[a]	6.38	1.18[a]	0.38[a]	0.03	1.24[a]	0.19[a]
P value	0.0332	0.1468	0.0041	0.0011	0.1228	0.0028	0.0005
LSD	0.47	2.15	0.39	0.13	0.01	0.32	0.07

Data was significant at 5% level (P<0.05). Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 4a: Micronutrient, pH and moisture analyses of the various mulches sampled at the heavier soil site, one year after application in 2010.

Treatment	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Compost	141.02[b]	113.87[b]	543.27[b]	14.58[b]	80.17[b]	5.183[ns]
Wood chips	142.46[b]	135.39[b]	343.78[c]	12.49[b]	71.58[b]	7.367
Vermi-castings/wood chips	186.36[a]	344.22[a]	663.88[a]	26.34[a]	283.09[a]	9.232
P value	0.0300	<.0001	<.0001	0.0002	<.0001	0.0805
LSD	36.02	75.59	89.30	5.02	64.86	3.53

Data was significant at 5% level (P<0.05). Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 4b: Micronutrient, pH and moisture analyses of the various mulches sampled at the lighter soil site, one year after application in 2010.

Treatment	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Compost	122.22[b]	96.91[b]	679.64[ns]	12.35[b]	65.61[b]	3.05[b]
Wood chips	138.18[b]	136.30[b]	585.20	14.14[b]	73.76[b]	4.01[b]
Vermi-castings/wood chips	161.61[a]	304.92[a]	791.68	25.22[a]	245.20[a]	7.16[a]
P value	0.0069	0.0003	0.1226	0.0009	0.0004	<.0001
LSD	21.36	78.25	201.68	5.64	72.78	1.23

Data was significant at 5% level (P<0.05). Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 5a: Mineral analyses of the newly purchased compost and vermi-casting mulches before application in October 2010.

Treatment	pH (KCL)	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	0.96	0.15	0.50	1.46	0.13	1312.74	67.42	890.01	8.23	86.33	7.68

Table 5b: Mineral analyses of the newly purchased compost and vermi-casting mulches before application in October 2011.

Treatment	pH (KCL)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Compost	7.0	1.59	0.34	1.03	1.12	0.21	2203.48	172.93	975.07	16.09	142.39	10.54
Vermi-castings	7.6	2.29	0.90	0.74	1.74	0.59	1510.63	405.55	780.28	40.79	391.16	16.28

Table 6a: The effect of different mulches on the mineral status of 'Cripps' Pink' fruit harvested in May 2012 at the experimental heavier soil site.

Treatment	N (mg/100g)	P (mg/100g)	K (mg/100g)	Ca (mg/100g)	Mg (mg/100g)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	39.83^{ns}	7.81^{ns}	114.67^{ns}	6.83^{ns}	5.28^{ns}	16.15^{ns}	1.27^{ns}	3.33^{ns}	0.17^{ns}	0.50^{ns}	4.90^{ab}
Compost	43.00	10.81	140.50	6.12	5.82	15.55	1.12	2.72	0.23	0.50	5.03^{a}
Geotextile	37.50	8.95	113.00	6.53	5.07	14.58	1.13	3.15	0.28	0.40	4.45^{abc}
Wood chips	40.17	8.19	115.33	6.70	5.33	15.82	1.15	3.20	0.18	0.35	4.40^{bc}
Vermi-castings/wood chips	43.50	9.41	128.17	5.68	5.20	14.53	1.03	2.95	0.18	0.48	4.13^{c}
P value	0.3749	0.2791	0.1467	0.4352	0.4284	0.6545	0.6580	0.2874	0.0502	0.3587	0.0385
LSD	6.88	2.95	25.18	1.40	0.84	2.75	0.32	0.61	0.08	0.19	0.62

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 6b: The effect of different mulches on the mineral status of 'Cripps' Pink' fruit harvested in May 2012 at the experimental lighter soil site.

Treatment	N (mg/100g)	P (mg/100g)	K (mg/100g)	Ca (mg/100g)	Mg (mg/100g)	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Control	43.33^{ns}	6.16^{b}	107.00^{ns}	6.30^{ns}	4.95^{ns}	14.95^{ns}	0.95^{ns}	3.38^{ns}	0.10^{ns}	0.33^{ns}	4.15^{ns}
Compost	51.67	9.45^{ab}	123.33	6.48	5.45	16.23	1.12	3.98	0.17	0.36	4.15
Geotextile	51.67	8.80^{ab}	117.67	6.42	5.48	15.05	1.25	5.73	0.22	0.43	4.42
Wood chips	52.17	10.11^{a}	123.33	6.37	5.55	14.05	1.20	4.30	0.22	0.56	4.23
Vermi-castings/wood chips	53.83	12.17^{a}	143.67	6.03	5.90	15.48	1.22	3.71	0.22	0.33	4.08
P value	0.5592	0.0333	0.0904	0.8795	0.1208	0.5292	0.1485	0.1865	0.2431	0.0941	0.9557
LSD	13.89	3.57	28.34	0.95	0.69	2.60	0.26	2.05	0.12	0.19	0.95

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 7a: The effect of different mulches on the mineral status of 'Cripps' Pink' leaves sampled in Jan 2012 at the experimental heavier soil site.

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	2.20[ns]	0.16[ns]	1.74[ns]	1.41[ns]	0.26[ab]	233.00[ns]	263.33[ns]	99.33[ns]	4.67[ns]	42.83[ns]	41.17[ns]
Compost	2.23	0.26	2.02	1.40	0.24[b]	227.67	268.83	92.50	4.17	36.50	42.17
Geotextile	2.21	0.16	1.75	1.41	0.27[ab]	208.00	246.83	93.67	4.00	36.17	43.00
Wood chips	2.12	0.25	1.95	1.55	0.29[a]	204.17	268.83	99.67	4.17	43.33	42.17
Vermi-castings/wood chips	2.24	0.26	1.82	1.40	0.29[a]	200.50	266.17	97.83	4.50	38.83	40.67
P value	0.1092	0.1303	0.4622	0.1661	0.0303	0.4706	0.8857	0.6466	0.1685	0.6051	0.8097
LSD	0.10	0.11	0.38	0.14	0.03	45.06	51.10	12.30	0.60	12.06	4.32

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 7b: The effect of different mulches on the mineral status of 'Cripps' Pink' leaves sampled in Jan 2012 at the experimental lighter soil site.

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	2.45[ns]	0.17[ns]	1.74[c]	1.22[ns]	0.34[ns]	140.17[ns]	235.00[ns]	142.83[ns]	4.00[ns]	32.00[ns]	45.67[ns]
Compost	2.50	0.20	2.01[ab]	1.30	0.31	157.67	267.67	117.00	4.50	33.67	41.00
Geotextile	2.45	0.16	1.77[bc]	1.32	0.31	153.17	251.17	103.00	4.50	33.50	38.50
Wood chips	2.39	0.17	1.67[c]	1.35	0.32	167.50	282.50	115.33	4.17	36.50	38.67
Vermi-castings/wood chips	2.38	0.22	2.09[a]	1.28	0.34	166.17	239.17	104.83	4.00	32.33	40.50
P value	0.2326	0.4168	0.0100	0.2664	0.2718	0.3904	0.3447	0.3885	0.5625	0.6774	0.1927
LSD	0.12	0.07	0.26	0.12	0.04	31.43	53.73	44.98	0.85	6.85	6.59

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 8a: Macronutrient, pH and moisture analyses of the various mulches sampled at the heavier soil site, two years after application in 2010.

Treatment	pH (KCl)	EG (mS/m)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	C (%)
Compost	6.98^{a}	87.17^{b}	0.83^{ns}	0.15^{b}	0.14^{ns}	1.46^{ns}	0.14^{b}	19.41^{ns}
Wood chips	6.48^{b}	84.92^{b}	0.74	0.08^{b}	0.11	1.23	0.09^{b}	23.99
Vermi-castings/wood chips	7.15^{a}	140.38^{a}	0.28	0.35^{a}	0.14	1.51	0.30^{a}	17.03
P value	0.0008	0.0023	0.2163	<.0001	0.4921	0.2905	0.0005	0.1285
LSD	0.28	28.75	0.70	0.08	0.05	0.41	0.08	7.00

Data was significant at 5% level (P<0.05). Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 8b: Macronutrient, pH and moisture analyses of the various mulches sampled at the lighter soil site, two years after application in 2010.

Treatment	pH (KCl)	EG (mS/m)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	C (%)
Compost	6.72^{a}	118.72^{ns}	1.48^{a}	0.23^{ab}	0.13^{ns}	1.26^{a}	0.21^{ab}	25.77^{ns}
Wood chips	5.57^{b}	80.10	0.90^{b}	0.07^{b}	0.13	0.64^{b}	0.10^{b}	29.80
Vermi-castings/wood chips	6.63^{a}	126.90	1.68^{a}	0.39^{a}	0.16	1.34^{a}	0.36^{a}	28.73
P value	0.0186	0.1883	0.0195	0.0314	0.5564	0.0219	0.0246	0.4945
LSD	0.82	55.94	0.52	0.23	0.07	0.51	0.17	7.57

Data was significant at 5% level (P<0.05). Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 9a: Micronutrient, pH and moisture analyses of the various mulches sampled at the heavier soil site, two years after application in 2010.

Treatment	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Compost	243.04[ns]	212.16[ns]	864.40[a]	12.47[b]	119.36[b]	7.23[a]
Wood chips	242.80	212.20	431.60[b]	9.72[b]	67.17[b]	4.32[b]
Vermi-castings/wood chips	262.60	285.33	1050.40[a]	22.588[a]	222.97[a]	8.64[a]
P value	0.6696	0.1058	0.0021	<.0001	0.0005	0.0031
LSD	55.42	79.02	287.53	4.06	59.25	2.10

Data was significant at 5% level (P<0.05). Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 9b: Micronutrient, pH and moisture analyses of the various mulches sampled at the lighter soil site, two years after application in 2010.

Treatment	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
Compost	222.16[ns]	268.29[ab]	839.20[a]	14.29[ab]	164.57[ab]	11.56[ns]
Wood chips	219.72	169.18[b]	413.50[b]	7.57[b]	69.84[b]	8.82
Vermi-castings/wood chips	303.25	331.72[a]	674.70[ab]	22.00[a]	237.23[a]	12.24
P value	0.1059	0.0363	0.0289	0.0251	0.0436	0.1219
LSD	88.98	119.04	297.84	9.75	126.77	3.53

Data was significant at 5% level (P<0.05). Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 10: Mineral analysis of soil samples for the different treatments at a depth of 0-10 cm for selected nutrient elements only. Samples collected in May 2012 at both the heavier soil and lighter soil sites. Adapted from Nicholson (2012).

Treatment	Heavier soil		Lighter soil		
	Mg (%)	B (mg/kg)	K (%)	Cu (mg/kg)	B (mg/kg)
Control	7.73^{c}	0.47^{bc}	3.62^{ns}	5.80^{b}	0.30^{ns}
Compost	9.15^{bc}	0.76^{ab}	3.44	8.22^{a}	0.41
Geotextile	7.64^{c}	0.37^{c}	2.79	9.16^{a}	0.54
Wood chips	10.36^{b}	0.50^{b}	3.66	8.02^{a}	0.34
Vermi-castings/wood chips	17.06^{a}	0.87^{a}	3.75	9.16^{a}	0.52
P value	<0.001	0.0371	0.9073	0.0079	0.4753
LSD	1.6013	0.3471	2.4187	1.7599	0.3343

Data was significant at 5% level (P<0.05). Means with “ns” was not significantly different. Means with different letters differed significantly.

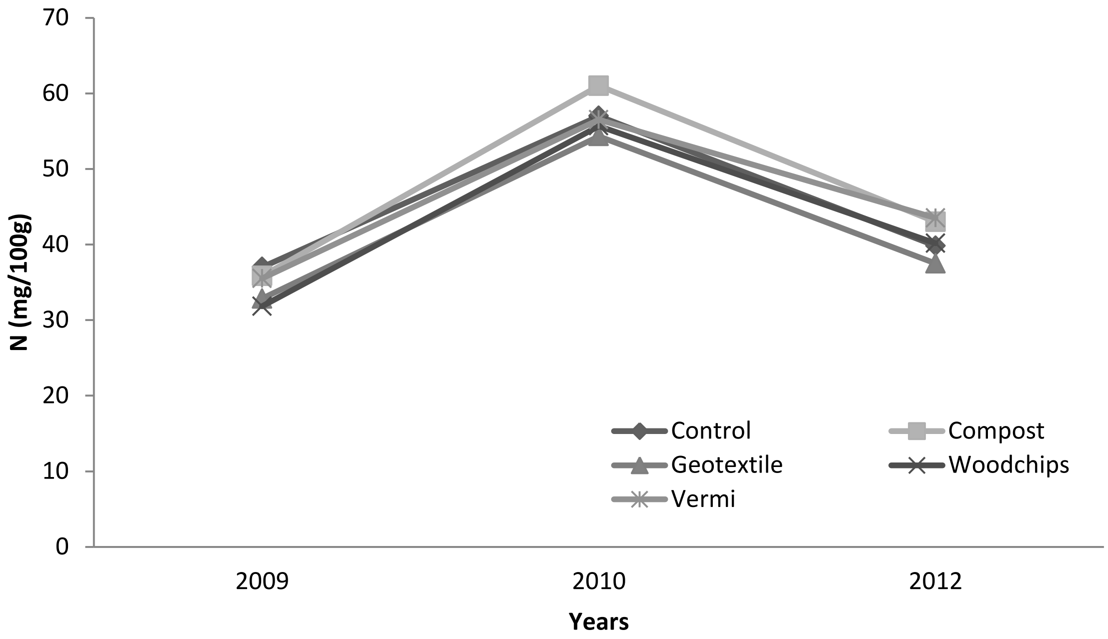

Fig. 1a. The trend in the effect of mulches on nitrogen levels in 'Cripps' Pink' apple fruit in the heavier soil site during four consecutive seasons of application. Unreliable results in 2011.

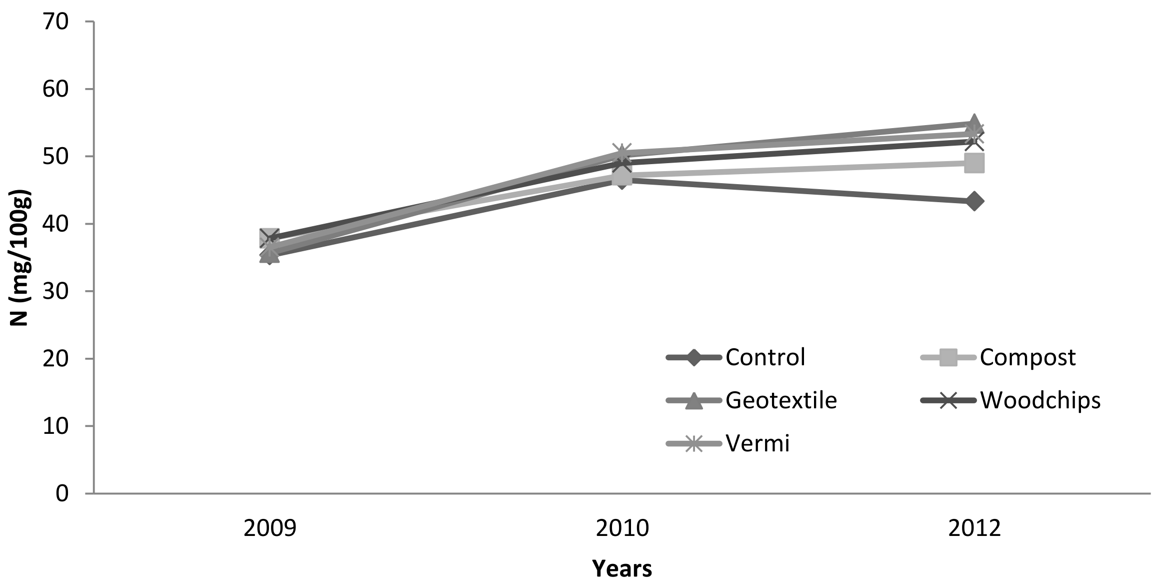

Fig. 1b. The trend in the effect of mulches on nitrogen levels in 'Cripps' Pink' apples in the lighter soil site during four consecutive seasons of application. Unreliable results in 2011.

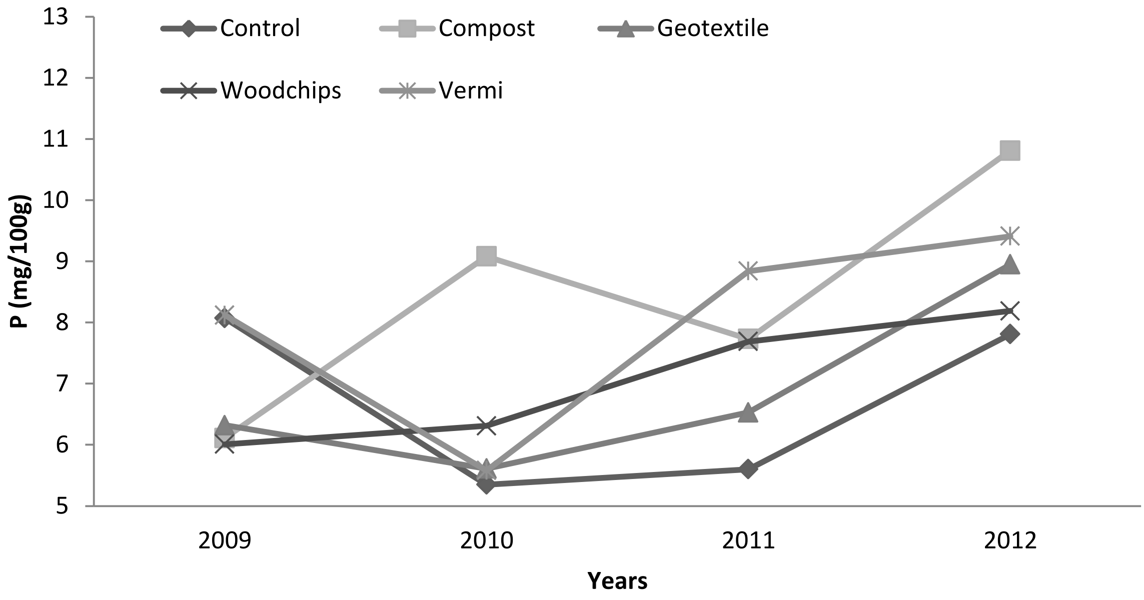

Fig. 2a. The trend in the effect of mulches on phosphorous level in 'Cripps' Pink' apple fruit in the heavier soil site during four consecutive seasons of application.

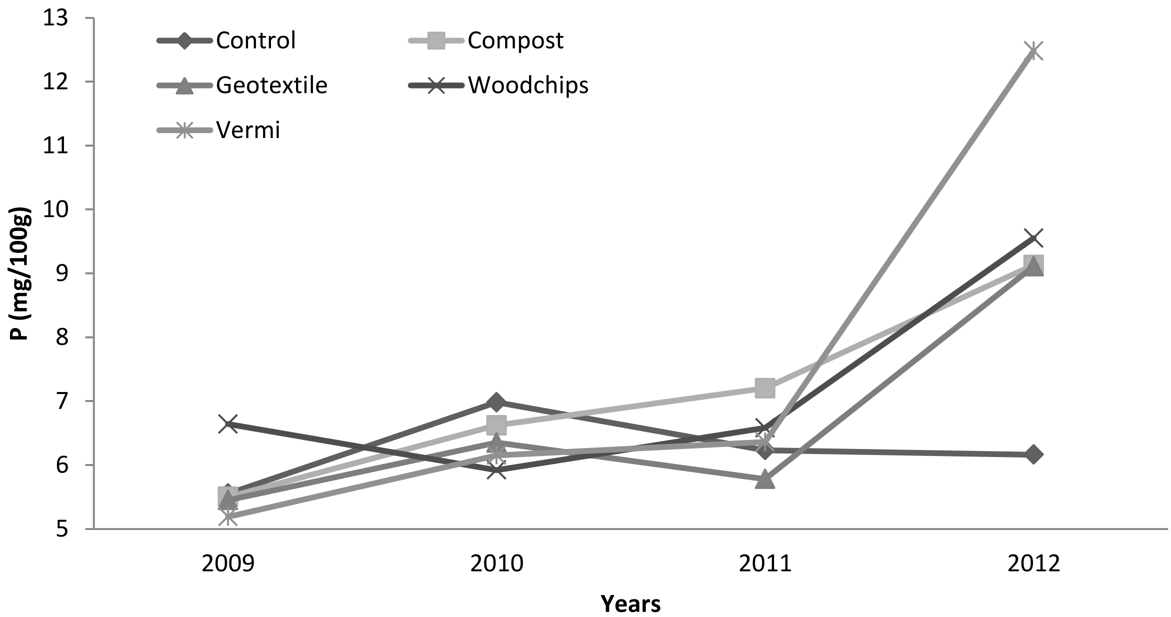

Fig. 2b. The trend in the effect of mulches on phosphorous levels in 'Cripps' Pink' apples in the lighter soil site during four consecutive seasons of application.

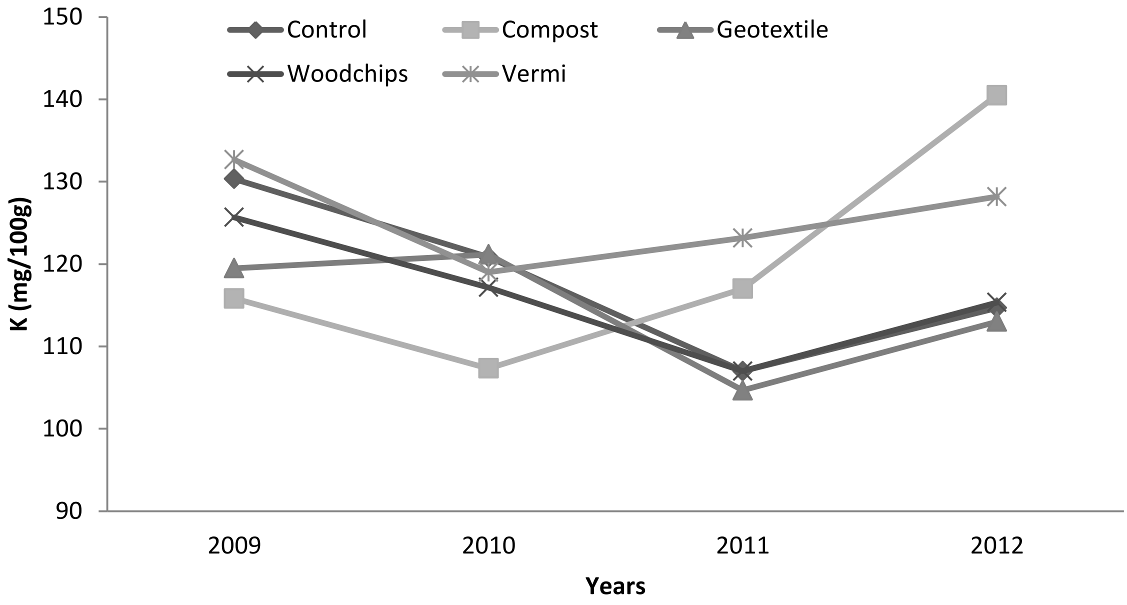

Fig. 3a. The trend in the effect of mulches on potassium level in 'Cripps' Pink' apple fruit in the heavier soil site during four consecutive seasons of application.

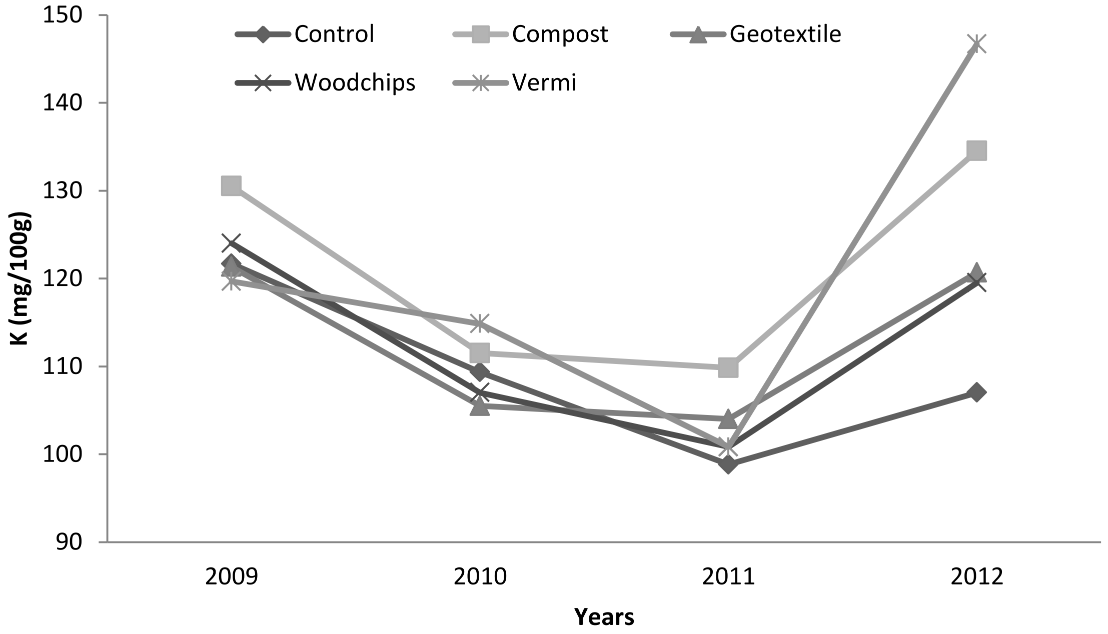

Fig. 3b. The trend in the effect of mulches on potassium levels in 'Cripps' Pink' apples in the lighter soil site during four consecutive seasons of application.

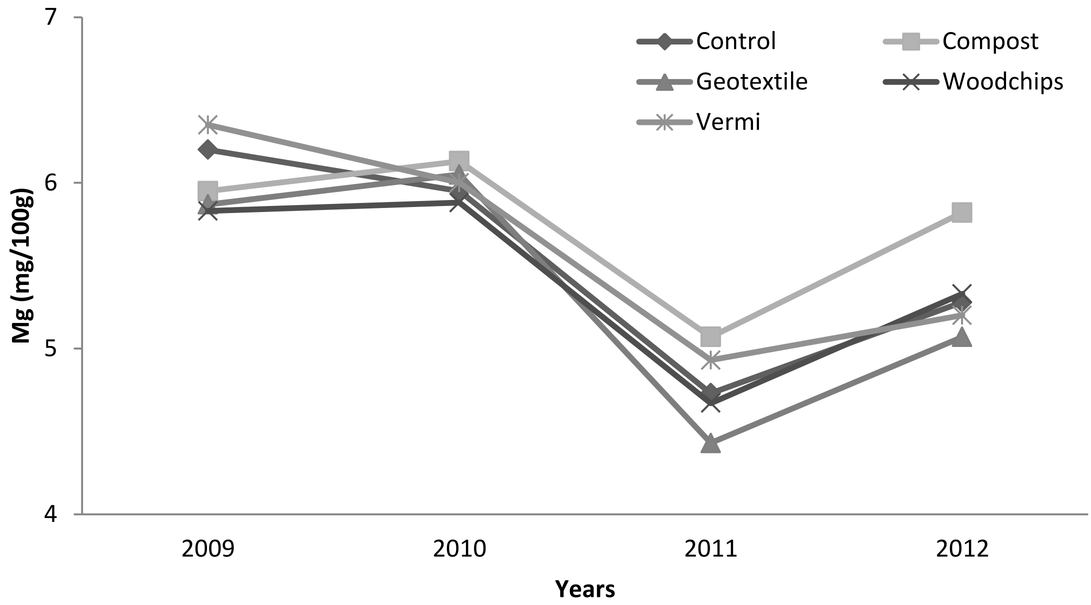

Fig. 4a. The trend in the effect of mulches on magnesium level in 'Cripps' Pink' apple fruit in the heavier soil site during four consecutive seasons of application.

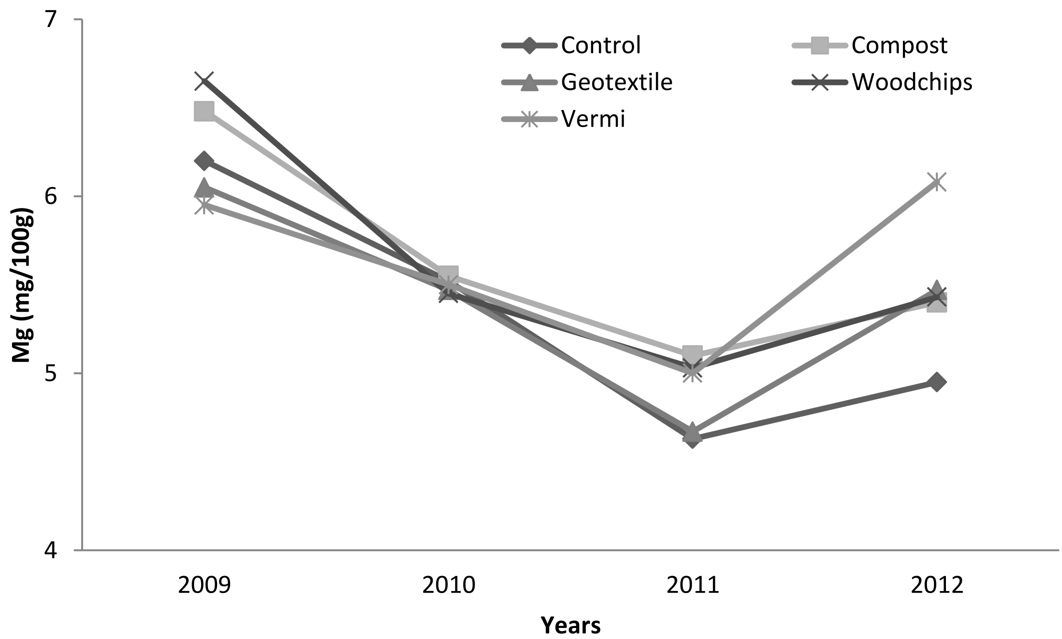

Fig. 4b. The trend in the effect of mulches on magnesium levels in 'Cripps' Pink' apples in the lighter soil site during four consecutive seasons of application.

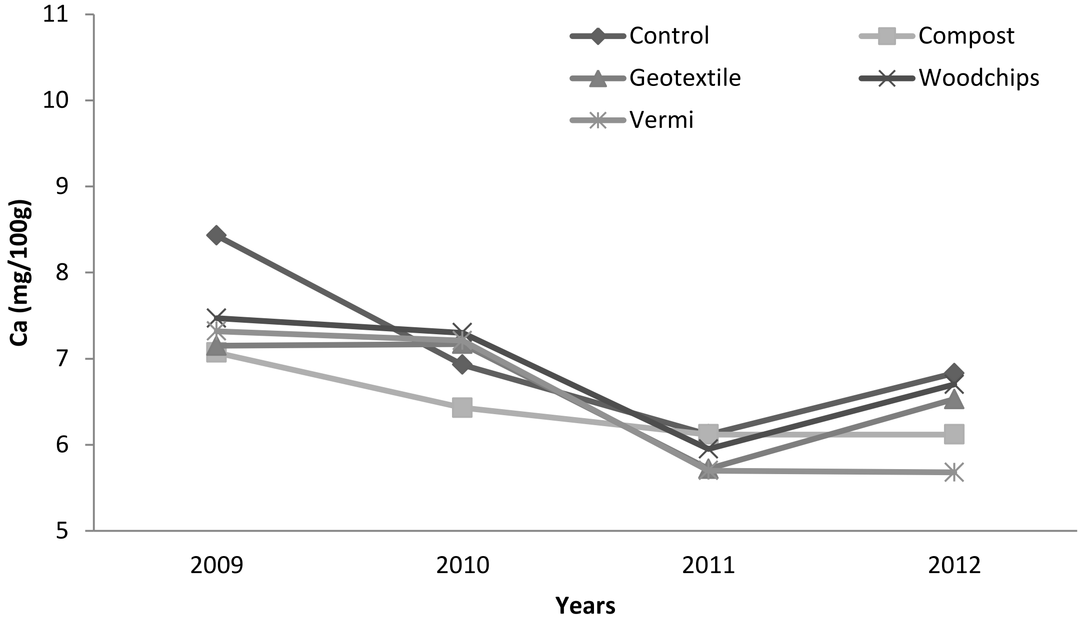

Fig. 5a. The trend in the effect of mulches on calcium level in ‘Cripps’ Pink’ apple fruit in the heavier soil site during four consecutive seasons of application.

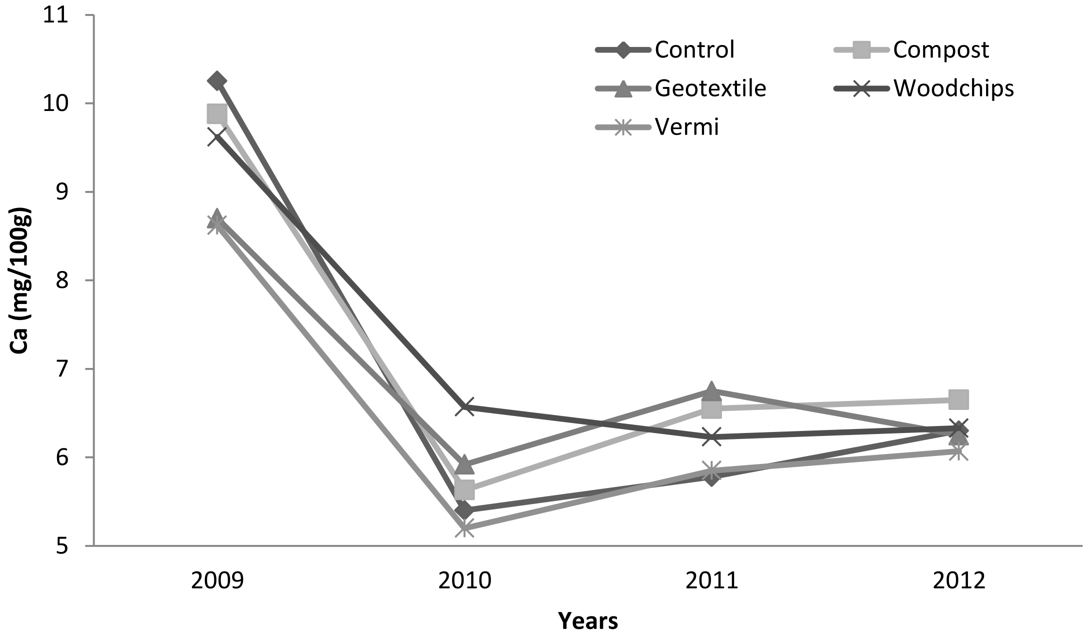

Fig. 5b. The trend in the effect of mulches on calcium levels in ‘Cripps’ Pink’ apples the lighter soil site during four consecutive seasons of application.

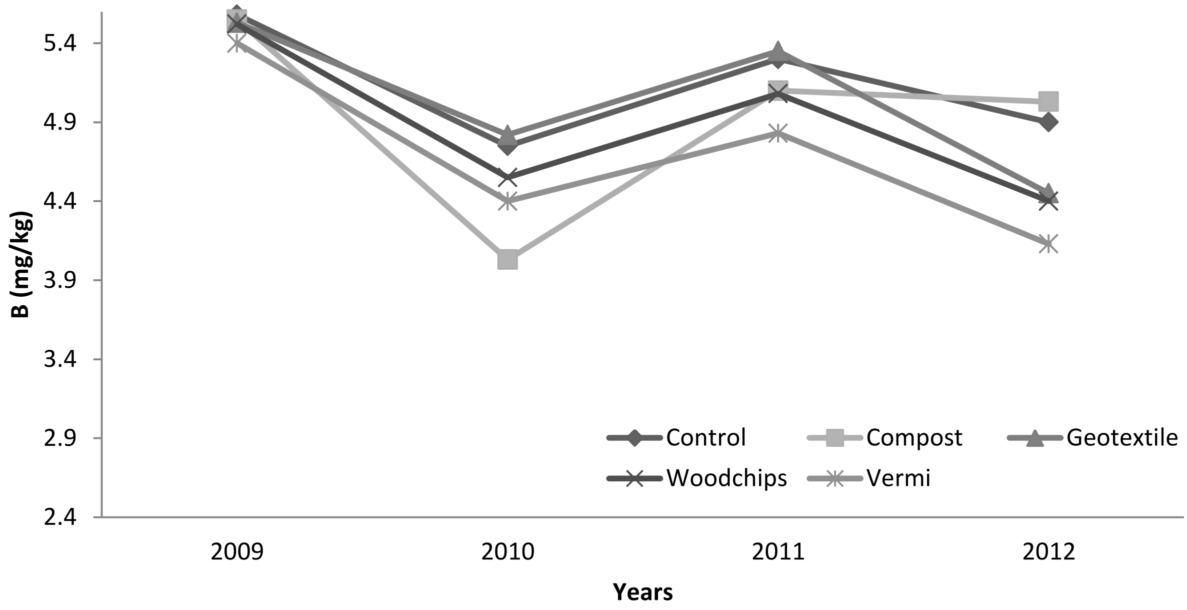

Fig. 6a. The trend in the effect of mulches on boron level in 'Cripps' Pink' apple fruit in the heavier soil site during four consecutive seasons of application.

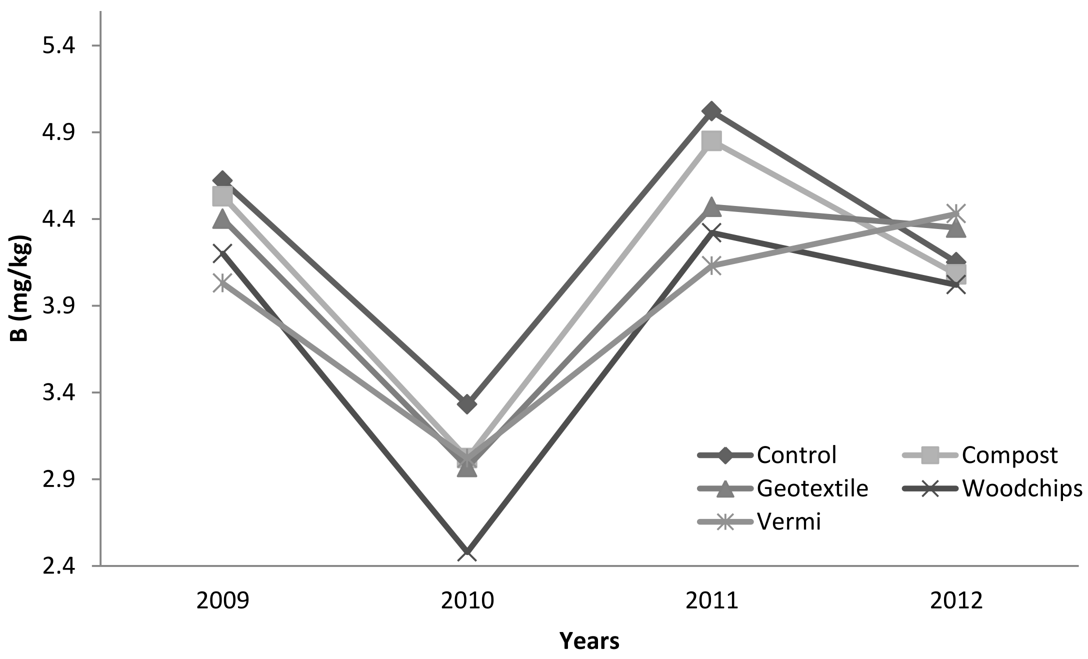

Fig. 6b. The trend in the effect of mulches on boron levels in 'Cripps' Pink' apples in the lighter soil site during four consecutive seasons of application.

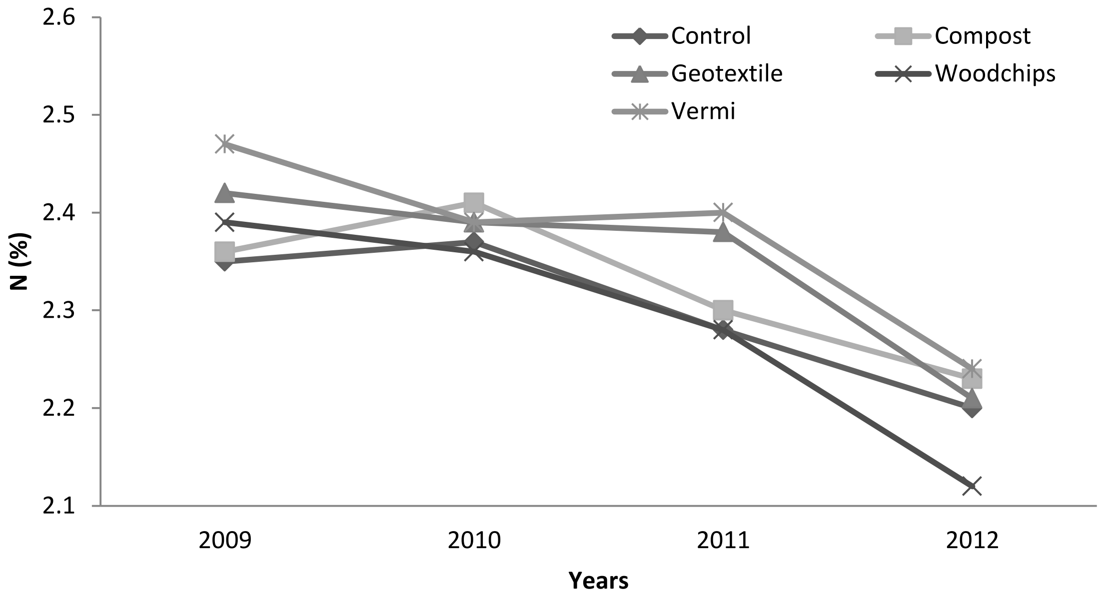

Fig. 7a. The trend in the effect of mulches on nitrogen level in 'Cripps' Pink' leaves in the heavier soil site during four consecutive seasons of application.

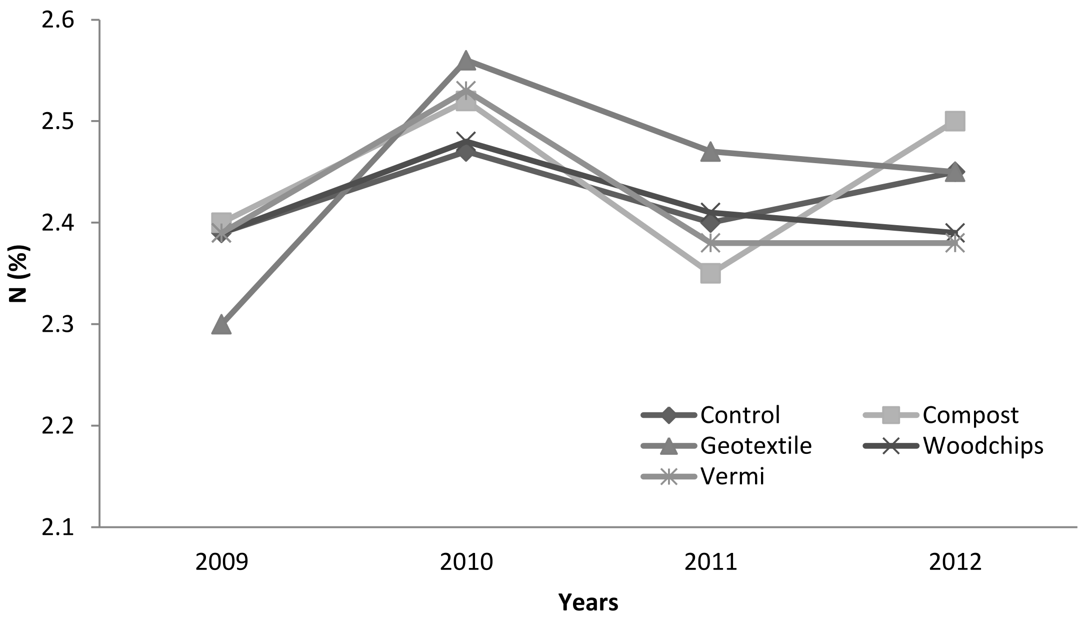

Fig. 7b. The trend in the effect of mulches on nitrogen levels in 'Cripps' Pink' leaves in the lighter soil site during four consecutive seasons of application.

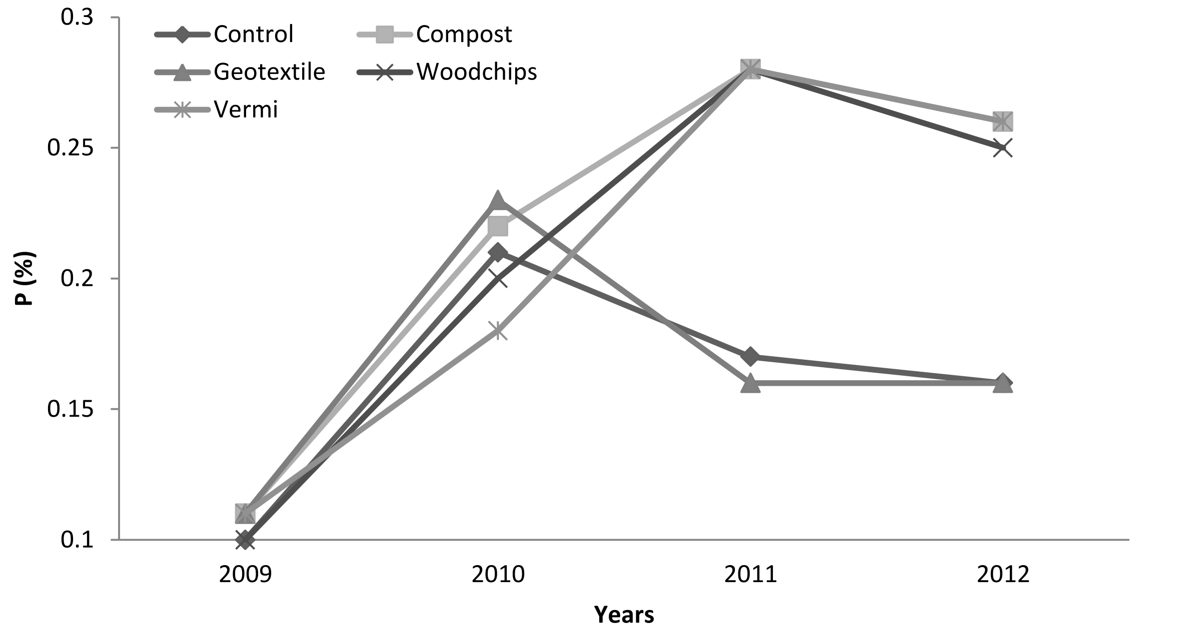

Fig. 8a. The trend in the effect of mulches on phosphorous level in 'Cripps' Pink' leaves in the heavier soil site during four consecutive seasons of application.

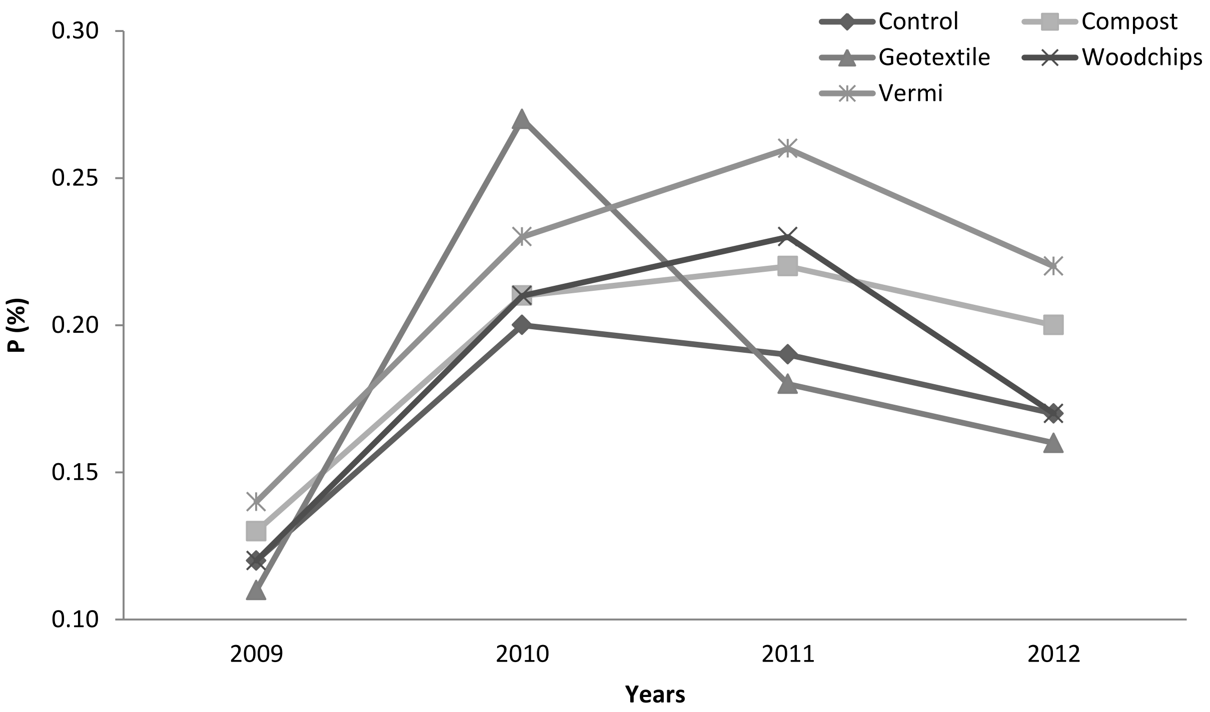

Fig. 8b. The trend in the effect of mulches on phosphorous levels in 'Cripps' Pink' leaves in the lighter soil site during four consecutive seasons of application.

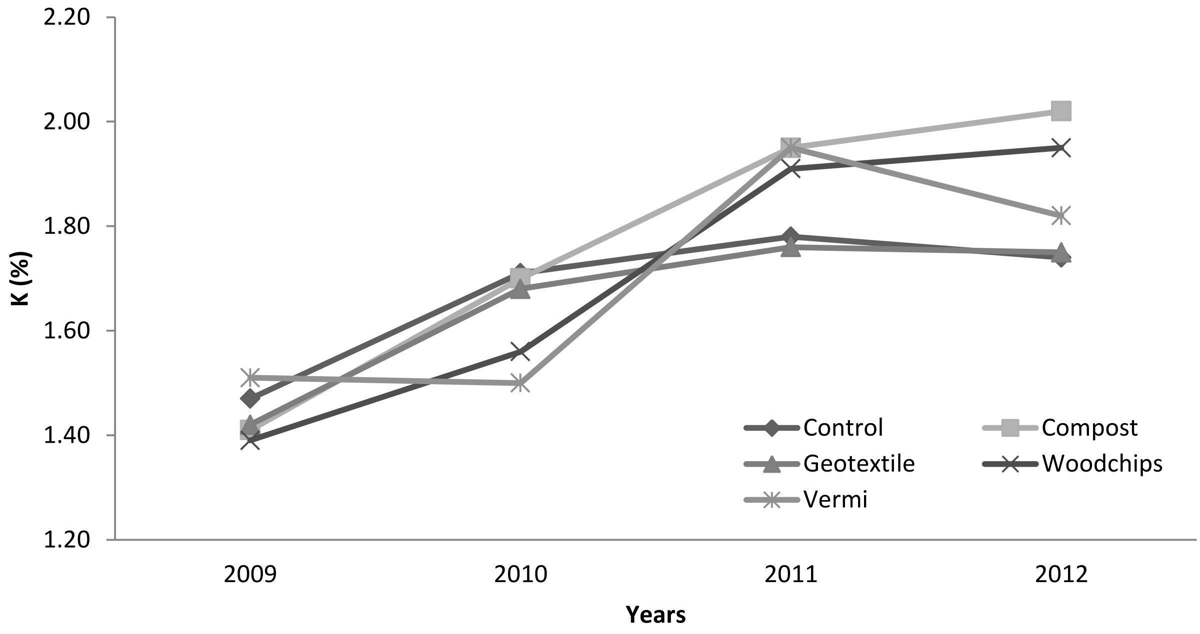

Fig. 9a. The trend in the effect of mulches on potassium level in ‘Cripps’ Pink’ leaves in the heavier soil site during four consecutive seasons of application.

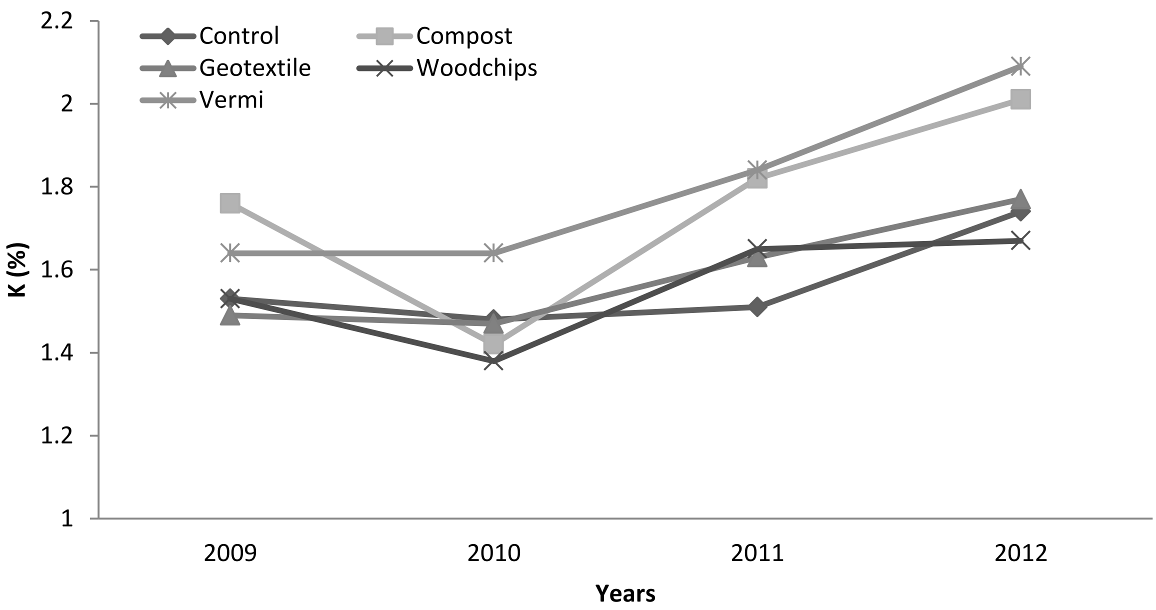

Fig. 9b. The trend in the effect of mulches on potassium levels in ‘Cripps’ Pink’ leaves in the lighter soil site during four consecutive seasons of application.

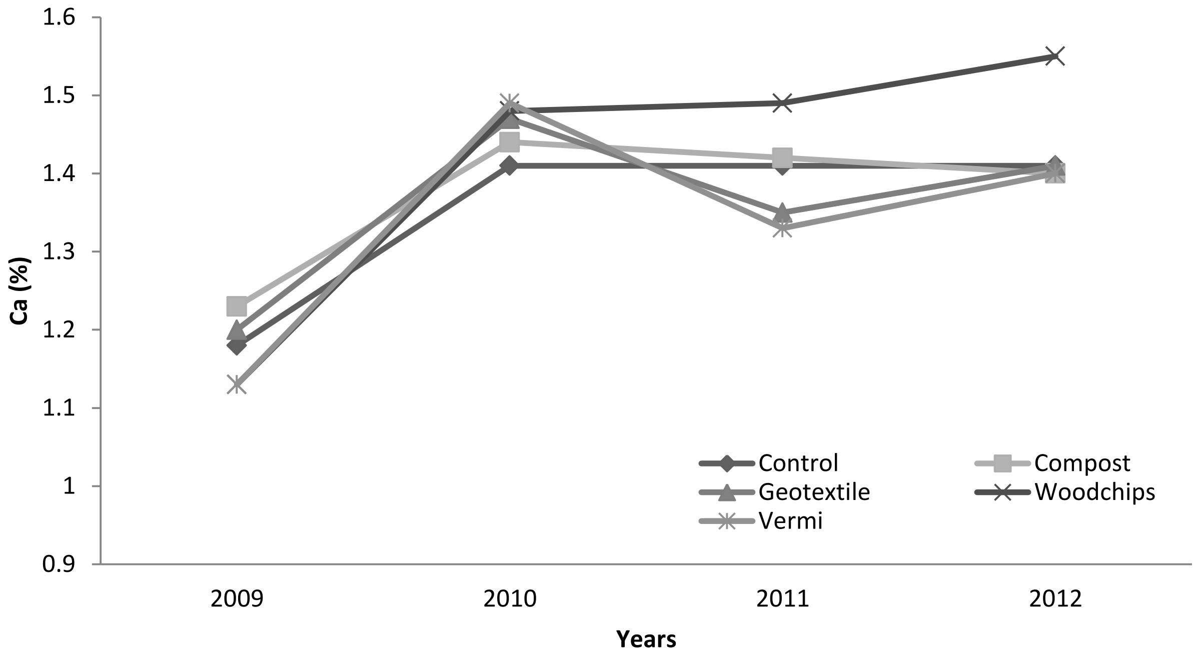

Fig. 10a. The trend in the effect of mulches on calcium level in ‘Cripps’ Pink’ leaves in the heavier soil site during four consecutive seasons of application.

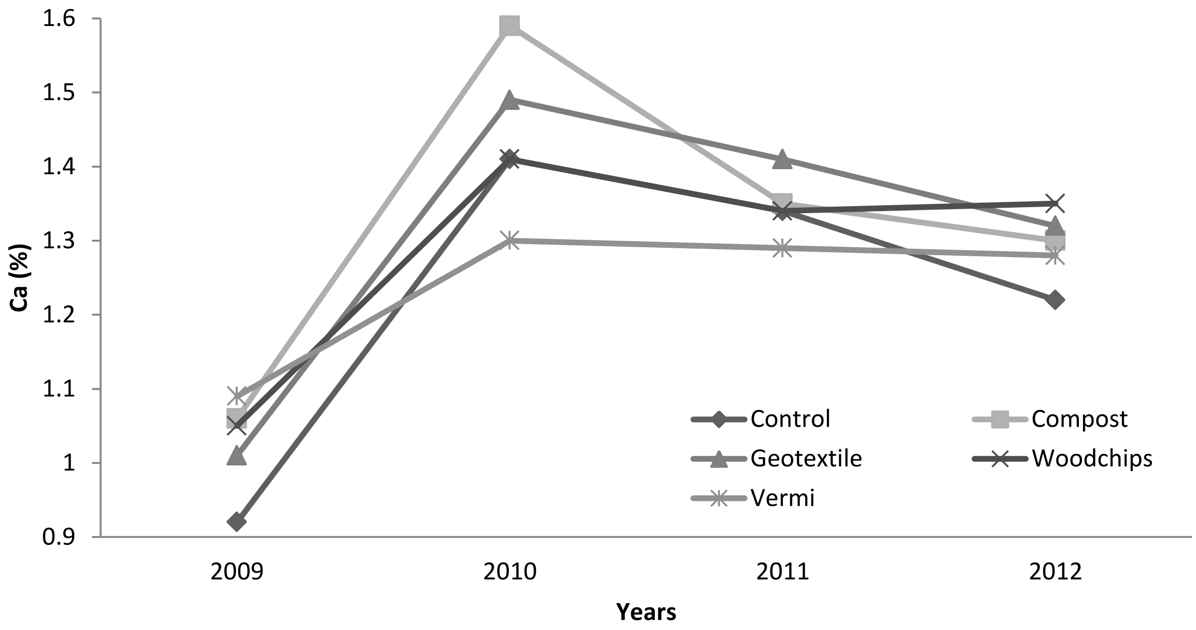

Fig. 10b. The trend in the effect of mulches on calcium levels in ‘Cripps’ Pink’ leaves in the lighter soil site during four consecutive seasons of application.

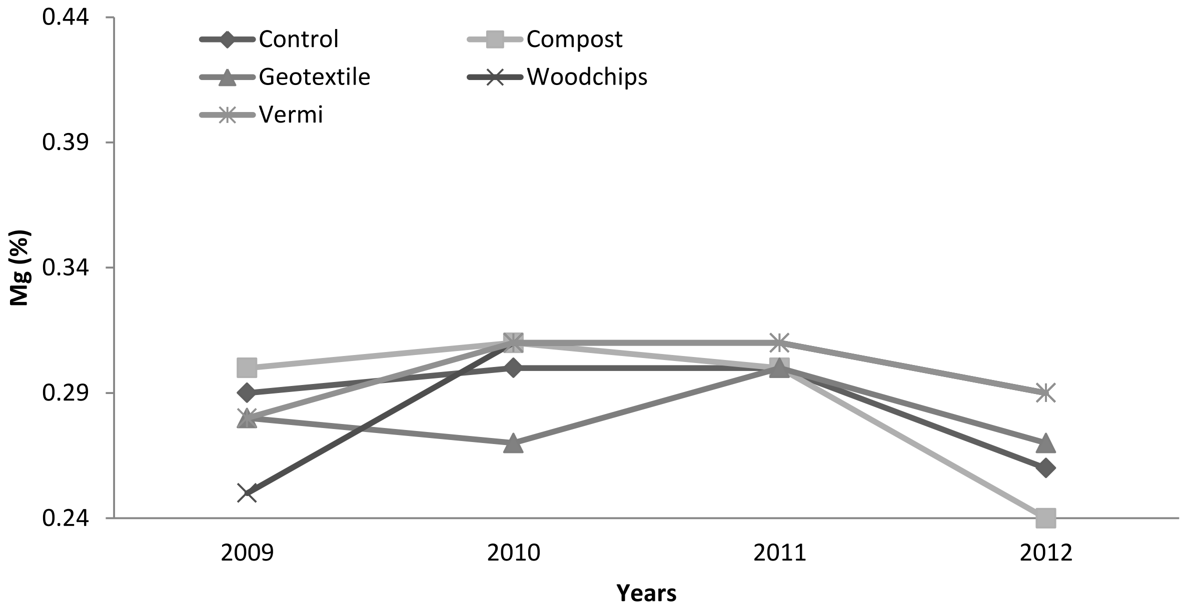

Fig. 11a. The trend in the effect of mulches on magnesium level in 'Cripps' Pink' leaves in the heavier soil site during four consecutive seasons of application.

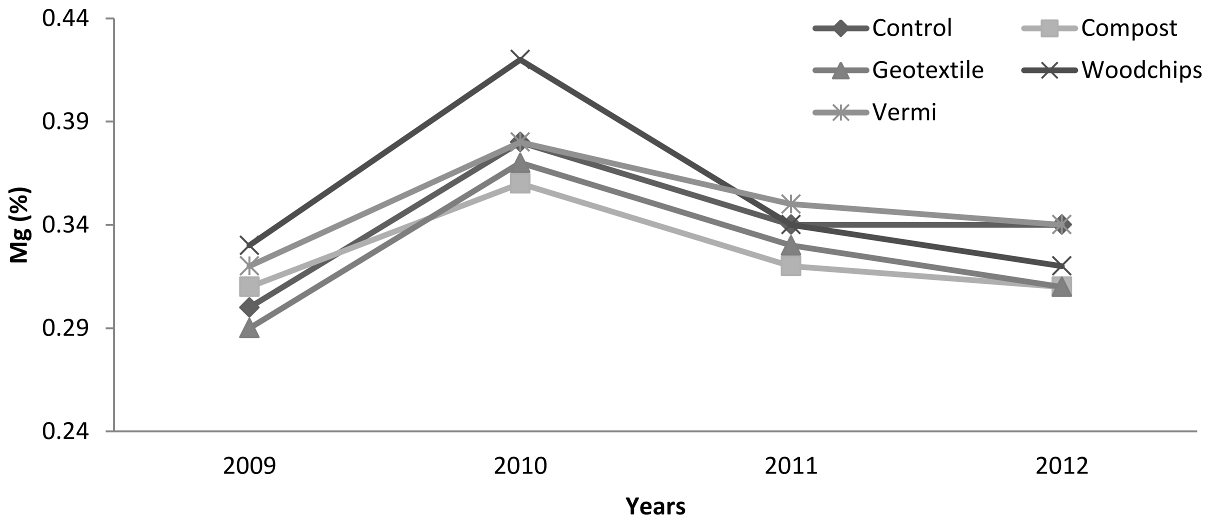

Fig. 11b. The trend in the effect of mulches on magnesium levels in 'Cripps' Pink' leaves in the lighter soil site during four consecutive seasons of application.

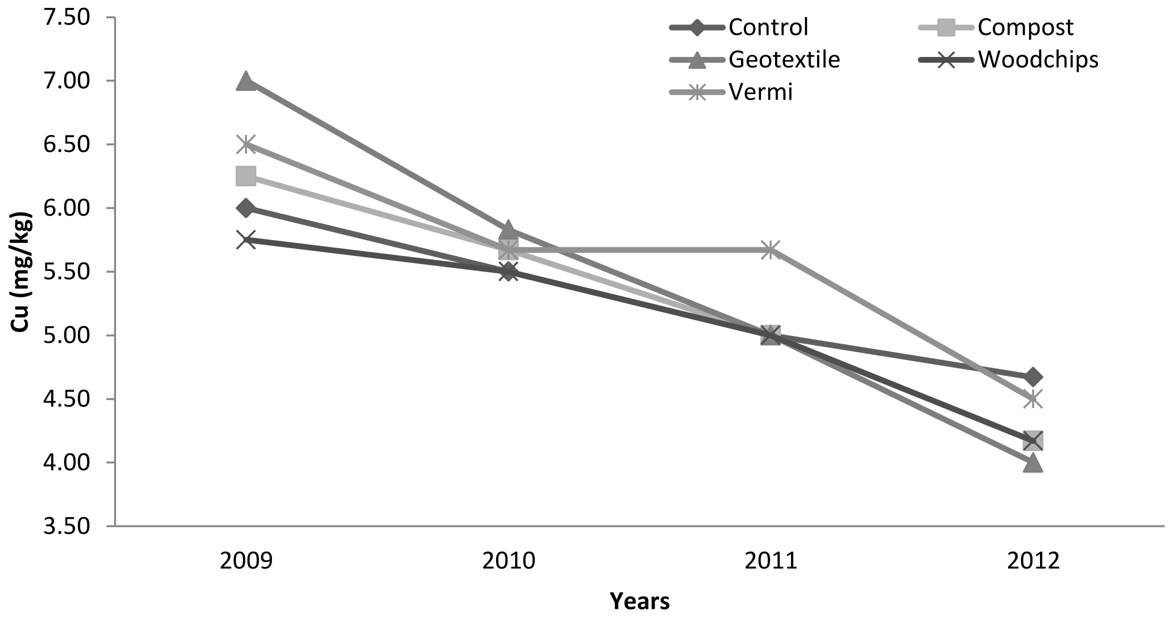

Fig. 12a. The trend in the effect of mulches on copper level in 'Cripps' Pink' leaves in the heavier soil site during four consecutive seasons of application.

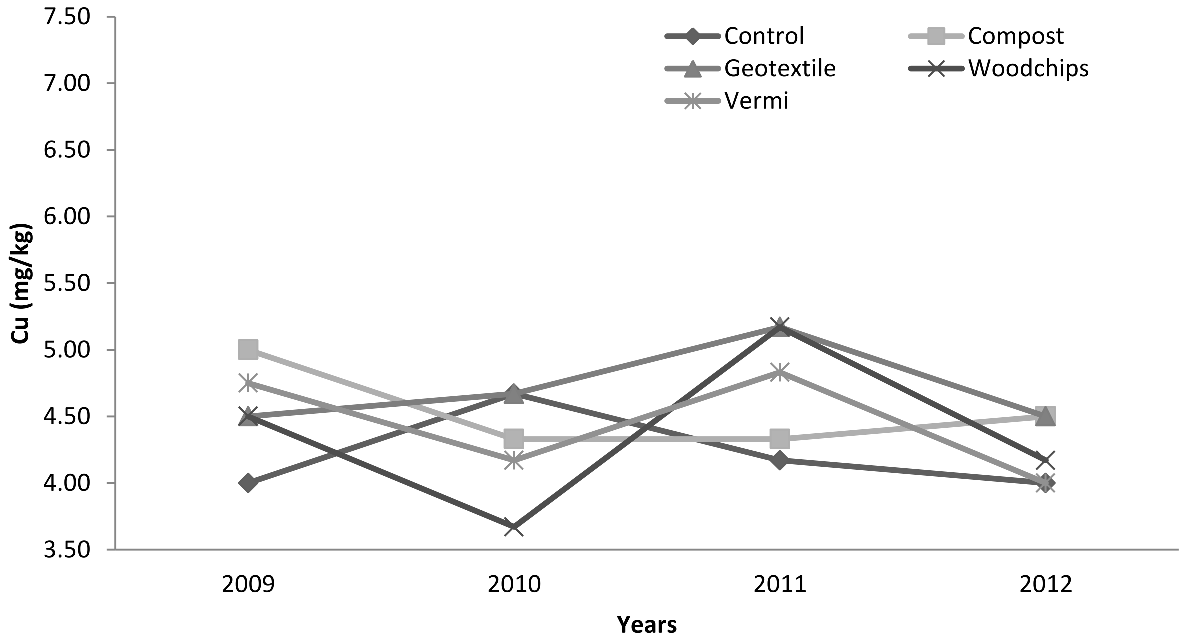

Fig. 12b. The trend in the effect of mulches on copper levels in 'Cripps' Pink' leaves in the lighter soil site during four consecutive seasons of application.

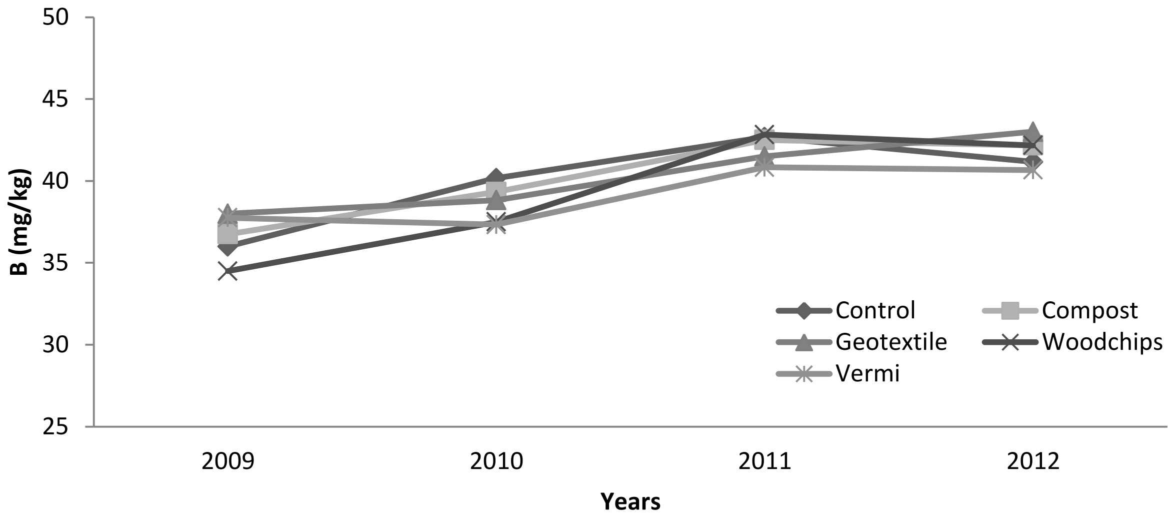

Fig. 13a. The trend in the effect of mulches on boron level in ‘Cripps’ Pink’ leaves the heavier soil site during four consecutive seasons of application.

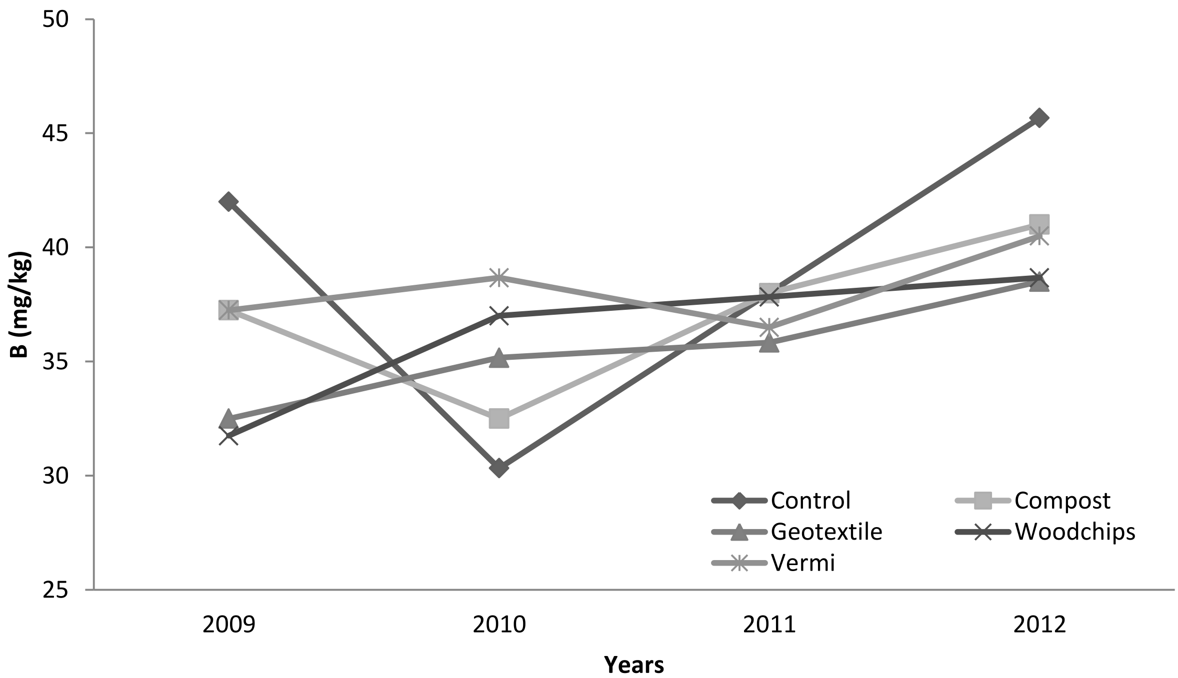

Fig. 13b. The trend in the effect of mulches on boron levels in ‘Cripps’ Pink’ leaves in the lighter soil site during four consecutive seasons of application.

Paper 2

Evaluating the effect of organic and inorganic mulches on fruit quality, yield and growth of 'Cripps' Pink' apple trees on two different soil types

Introduction

Escalating costs on establishing a new orchard means that producers need means at their disposal to improve poor performing orchards, or sustain high yields of established orchards for longer. By sustaining or increasing the yield without compromising fruit quality, producers, especially South African producers, can stay competitive in the overseas markets and attain higher profits. Rising production costs of conventional agricultural practises had renewed the interest in applying organic material in the way of mulches. By applying mulches the soil environment under the mulch could improve and this can be of importance to maintain plant health and yield. Although most studies on the effects of mulches on yield and growth are normally conducted on newly established orchards (Baxter 1970; Autio et al. 1991; Kotzé and Joubert 1992; Smith et al. 2000; Van Schoor 2009) or annual crops (Acharya and Sharma 1994; Atiyeh et al. 2000; Arancon et al. 2004; Ekinci and Dursun 2009), these studies confirm that mulches can make a positive contribution to improving yield, growth and fruit quality. The studies conducted on the effect of mulching on perennial fruit crops are scanty, but those conducted have also indicated positive contributions in terms of tree growth and/or yield, but results vary depending on the type of mulch and fruit type.

Smith et al. (2000) reported that a wood chips mulch had a positive effect on pecan nut tree growth and increased stem diameter as well as shoot lengths. Improved shoot growth was also reported by Baxter (1970) when a straw mulch was used in a young 'Golden Delicious' apple orchard. Using shredded paper as a mulch over a six year period, Neilsen et al. (2003) found an increase apple tree stem diameter (almost double) when compared to a control (herbicide). The increase of tree growth can lead to an increase in storage capacity of non-structural carbohydrates (Smith et al. 2000), which in turn can promote rapid growth in the years to come.

According to Szewczuk and Gudarowska (2004), a pine bark mulch improved the yield and fruit size of two-year-old ‘Jonagored’ apple trees. The same findings were obtained in the study on young fruiting trees by Baxter (1970) who found that yield and fruit size in both Hooker peaches and ‘Golden Delicious’ apples were higher than the control (no mulch) when a straw mulch was used. The mulched peach and apple trees almost produced double the yield of the control trees. Usually, return bloom is lower after a high yield the previous season, but in this case, trees still had a high return bloom (blossom density) percentage the following season (Baxter 1970).

Composted municipal solid waste used by Pinamonti et al. (1995) increased the initial growth of both vineyards and apple trees. This growth was significantly higher for the first three years for both the vineyard and orchard (Pinamonti et al. 1995), but after the three years there were no further significant differences between the mulch and control treatments. Similar short term results were obtained by Pinamonti (1998) where pruning weights in the mulched vine plots were 120 - 140 % higher than the control plots. The yield of the composted plot was also significantly higher when compared to the control and were only observed in the first year of a five year trial.

Vermi-castings research on the growth and yield on apple trees are limited to trials in greenhouses. When vermi-castings were used in tomato and strawberry trials, increases in dry plant weight (Atiyeh et al. 2000), plant size (Gutiérrez-Miceli et al. 2007) and number of flowers (Arancon et al. 2004) were obtained compared to a control.

A black plastic (polyethylene) mulch used in a four year trial with young apple trees, conducted by Måge (1982), rendered positive results on shoot and trunk diameter growth. However, only during the first year, the plastic mulches produced the longest shoot length of all treatments. In a vineyard trial with different mulches, the plastic mulch treatment had a significantly higher pruning weight than compost mulches (Pinamonti 1998). This result was partly ascribed to the reduction of weeds and less evaporation under the plastic mulch. A polypropylene ground cover increased the growth and yield of sweet cherry trees by more than 30 % compared to non-covered trees (Yin et al. 2007). In trials on young apple trees (Måge 1982), the total yield from trees treated with a plastic mulch was double the yield of the other treatments. The use of a non-woven polypropylene mulch resulted in higher yields of 'Jonagored' apple trees compared to normal herbicide practices (Szewczuk and Gudarowska 2004). Different from Måge's (1982) study, the average fruit size also increased.

Under South African conditions, Kotzé and Joubert (1992) found that the application of rooibos tea waste as a mulch to apricot trees resulted in significantly higher yields and growth when compared to a non-mulched control treatments. Van Schoor (2009) also found a significant improvement of growth by applying compost (plus supplementary compost extract) to pear trees. Although the results were positive, the trials were conducted on newly planted trees. Therefore, to evaluate the effect of five different mulches on yield, growth and fruit quality, in an established orchard, a field trial was conducted on established 'Cripps' Pink' apple trees on two different soil types.

Materials and methods

Orchard layout

The trial was carried out on Lourensford Estate in Somerset West, Western Cape, South Africa (34˚ 2' S, 18˚ 55' E). Two adjacent orchards consisting of 'Cripps' Pink' apples on M793 rootstocks, planted in 1998, were selected for experimental sites. The two sites differed in soil type, i.e., lighter soil (Tukulu) and heavier soil (Clovelly) (Soil classification working group 1991). Row orientation was in a North East by South West direction with a tree spacing of 4 m × 1.5 m. Trees were trained to a central leader on a three wire training system. Orchards were not ridged and had no slope. The trial commenced in October 2008 and initial research results from 2008 to 2010 were reported by Kotze (2012).

Treatments and experimental design

Five treatments were carried out comprising a control (no mulch), three different organic mulches and one inorganic mulch. All treatments received a herbicide application whenever weed growth started to show. The organic mulches were course textured wood chips, medium-fine compost and vermi-castings. The wood chips consisted of chipped apple and ornamental trees supplied by the estate and local tree trimmer, respectively. The compost, which was a combination of 20 % mushroom straw compost and 80 % municipal green waste, was supplied by Biocircle (Pty) Ltd, Klapmuts, RSA. The vermi-castings, derived from a cow manure and a wheat straw mixture, were supplied by Worm Works Purveyors (Pty) Ltd, Simondium, SA. Compost and vermicompost differs in the process of compostation. Normal commercial compost is mostly the result of microbial degradation, whereas vermicompost is the result of microbial degradation in addition to the digestive degradation by *Eisenia fetida* earthworms. In this study, the term vermicompost is referred to as vermi-casting to clearly differentiate it as a distinctive product from vermicompost supplied by Wormwork Purveyors (Pty) Ltd. Commercial vermicompost may consist of a mixture of vermicompost and compost, whereas vermi-castings consists of 100% *Eisenia fetida* excrement. The inorganic mulch consisted of a woven geotextile fabric - polytex

PT110 and was obtained from Spilo, Paarl, RSA. The geotextile differs from black plastic, as it is woven material and allows water and minerals to reach the soil.

The trial layout was a randomized complete block design, consisting of six replications of four trees per plot with two buffer trees between each plot. Fertilizer was applied to all treatments according to commercial recommendations of the control. Irrigation in both orchards was applied with microjets, one between two trees, at a rate of 42 L h^{-1} (per micro jet) for three hours, twice a week. Irrigation started in October/November till the first rains. During January 2011, the rate of every second micro-jet was reduced to 32 L h^{-1}. In 2012, the rest of the 42 L h^{-1} microjets in the plots were also replaced with 32 L h^{-1} nozzles.

The wood chips, vermi-casting and compost plots received approximately 90 L of material each spread out evenly over the 6 m^2 plots to a thickness of approximately 5 cm. The vermi-castings were topped with a layer of wood chips to prevent them from blowing away. The vermi-castings plots received 60 L of vermi-castings and 30 L of wood chips. During 2009/2010, only the applications for the wood chips treatment were doubled to attain a 10 cm instead of the 5 cm thick bedding in accordance with industry practises. Mulches were re-applied annually during spring (October).

Fruit yield, maturity and quality

Multiple harvests during April/May (2011) took place due to the nature of 'Cripps' Pink' apples, while in 2012 all the fruit were harvested in two days in 17/18 of April. At each harvest, fruit from all four trees per plot were used to determine the yield per block.

During the main harvest, when most of the fruit were harvested, two samples of 20 fruit each were taken per treatment plot for fruit quality assessment: one sample for evaluation at harvest and the other for evaluation after two months of cold storage at -0.5 ˚C in regular atmosphere. Fruit of similar size were randomly selected at the main harvest. Evaluation was done by the Department of Horticultural Science, Stellenbosch University. Measuring of fruit size and fruit firmness was performed by an EFM (Electronic Fruit Size Measurement) and a FTA (Fruit Texture Analyser) respectively (GÜSS Manufacturing (Pty) Ltd, Strand, SA). The FTA used a 11 mm tip and measurements were taken on both sides of the fruit, after the peel was removed. Fruit weight was determined with an electronic scale.

For determination of fruit colour, visual inspection of the background colour (green) and pink over colour (the intensity of the pink) was conducted using industry 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 breakdown was visually determined by using a colour chart (Unifruco Research Service (Pty) Ltd, Starch conversion chart (Pome fruit) circular types), after the fruit was cut diagonally painted with a 1% iodine solution and left to dry for thirty minutes.

The remaining halves of the 20 fruit were cut into wedges and juiced in a composite sample (AEG, Electrolux, Typ: JE-107). The total soluble solids (TSS) and titratable acidity (TA) was measured by using a digital refractometer (ATAGOCo. LTD, ATAGO model: PR-32) and a titration with NaOH (0.1 mol L^{-1}) in a Metrohm 760 sample changer, respectively.

Trunk diameter

Measurements for trunk diameter were taken on the day of the main harvest (27 April 2011 and 17/18 April 2012), half-way between the ground and first lateral shoot using a measuring tape for all four trees per plot and all blocks per treatment.

Shoot growth

The length of four, representative one-year-old lateral shoots per block (two on either side of any of the four trees per plot - NW and SE), were determined on the day of the main harvest (27 April 2011 and 17 April 2012). Measurements were taken by using a measuring tape.

Return bloom

From each block, two representative branch units were selected randomly for any of the four trees to determine return bloom. The total number of buds that developed in vegetative and reproductive structures was counted. The percentage of reproductive buds was then calculated.

Plant water potential

Before noon, two shaded mature leaves at a height of 1.5 m were selected per plot. The leaves were enclosed with bags consisting of a black polythene inner lined with a silver reflective tape. The leaves were enclosed for an hour and allowed to reach equilibrium with the stem water potential. Stem water potential measurements were conducted using a pressure bomb (Model 600, PMS Instrument Co, USA), while the leaves were still enclosed in the bag and only had the petiole protruding to prevent rapid changes in vapour pressure deficit (VPD).

Seedling trial

A seedling trial was conducted using 'Cripps' Pink' apple seeds (2011) and bean seeds (2012) to determine if it was the compost itself that had a negative effect on yield efficiency at the heavier soil site (Fig. 1 and Fig. 2). Bean seeds were used in the second year, because the variance in apple seed germination possibly influenced the results obtained in the first trial.

Treatments and experimental design

The trials were carried out using four seedling trays. In the first year, the apple seeds were planted in three different mediums. It consisted of a control (which was soil from control blocks), compost mulch and soil collected from underneath the compost of the compost mulched blocks, hence forth referred to as composted soil. The bean seeds in the second trial were planted in four different mediums: a control, compost, composted soil and a standard plant medium used for germination of bean seeds by Hygrotech, South Africa. The control, compost and composted soil were collected from the sites at Lourensford as composite samples of the different reps. The trays were then placed into a growth cabinet (Economic deluxe, 432L, Snijders Scientific b.v.) and exposed to 12 hour cycles to simulate night (18 ˚C) and day (25 ˚C) conditions. The irradiance during the day time simulation was 29.4 µmol. No fertilizers were added to the mediums. Plants were grown for two months in the growth cabinet. The trial layout was a complete randomized design, consisting of six, single plant replicates.

Plants were taken out of the trays and the medium was carefully removed from the roots by gentle shaking. In the first year, the growth of the apple seedlings was measured by using a ruler, from the base of the stem (where the root growth started) to the tip of the plant. In the second year (bean plants) however, the whole plant were weighed to determine the growth in each medium.

Soil analysis

A complete soil analysis was conducted during 2012 at 10, 30 and 50 cm depths. The analysis was done by Bemlab (Pty) Ltd. and is discussed in detail by Nicholson (2012).

Statistical analysis

Data were analysed statistically with SAS (SAS Institute Inc, Cary, NC, USA, 2006). Differences between treatments were determined by calculating least square means and least significant differences (LSD). Significant were determined at a 5 % level ($P < 0.05$).

Results

2010/2011

Fruit maturity and quality

At both the heavier soil and the lighter soil site, no significant differences were found between treatments regarding fruit maturity parameters at harvest (Table 1a and 1b). After two months of cold storage, there were no significant differences between the treatments for fruit quality parameters in the heavier soil site (Table 2a). At the lighter soil site, fruit quality evaluation after cold storage showed significant differences for the percentage of sunburned fruit. The control had a significantly higher occurrence of sunburn compared to the compost, geotextile and wood chips treatments, but did not differ significantly from the vermi-casting treatment (Table 2b).

Yield

For the first harvest, in the heavier soil site, no significant differences were found between treatments (Table 3a). At the second harvest (main harvest), the vermi-casting treatment had a significantly higher yield compared to the other treatments. The third harvest also showed no significant differences between treatments. The yield efficiency was significantly higher in the vermi-casting treatment compared to the control, compost and geotextile treatments, but did not differ significantly from the wood chips.

At the lighter soil site, there were no significant differences in the yields between treatments (Table 3b).

Shoot growth

No significant differences between treatments were obtained for average shoot growth, in either the heavier soil or the lighter soil site (Table 4).

Return bloom

No significant differences were found between treatments when return bloom data was considered for the heavier soil and the lighter soil site (Table 5).

Plant water potential

The heavier soil and the lighter soil site had no significant differences in stem water potential between treatments (Table 6).

Trunk diameter

No significant differences between treatments in trunk diameter where obtained in both the heavier soil and lighter soil sites (Table 7).

Seedling trial

Total new growth

Soil and mulch samples from the heavier soil did not differ significantly (Table 8). Growth in the mulch medium was significantly more than the growth in the control and composted soil in the lighter soil site.

2011/2012

Fruit maturity analysis at harvest

Percentage starch breakdown was significantly more in the wood chips treatment compared to the control and geotextile treatments, but did not differ significantly from the compost and vermi-casting treatments in the heavier soil (Table 9a). The compost, vermi-castings, control and geotextile treatments did not differ significantly. There were no significant differences between treatments regarding the fruit maturity and quality parameters in the lighter soil site (Table 9b).

Fruit maturity analysis after two months cold storage

At both the heavier soil and the lighter soil site, no significant differences were found between treatments regarding fruit maturity parameters after cold storage (Tables 10a and 10b).

Yield

In the heavier soil the yield efficiency was significantly higher in the wood chips and vermi-casting treatments compared to the compost and geotextile, but did not differ significantly from the control treatment (Table 11a). The lighter soil site had no significant differences in the yields between treatments (Table 11b).

Shoot growth

Shoot growth on trees with compost treatment was significantly more compared to the control, geotextile and wood chips treatments, but did not differ significantly from the vermi-casting treatment in the heavier soil. No significant differences in shoot growth between treatments were obtained in the lighter soil site (Table 12).

Trunk diameter

In the heavier soil site the control, compost, geotextile and vermi-casting treatments had significantly larger trunk diameters than the wood chips treatment (Table 13). In the lighter soil, no significant differences where obtained.

Seedling trial

Total new growth

In the heavier soil, the control and compost treatments had significantly more growth compared to the alternative plant medium, but did not differ significantly from the treatment which was the composted soil (Table 14). The control had significantly more growth than the soil just below the compost and plant medium treatments, but did not differ significantly from the compost treatment in the lighter soil site. The compost treatment did not differ significantly from the alternative plant medium and the treatment which was the soil below the compost (Table 14).

Yield efficiency decreased at both sites, across treatments over the four years of the trial (Fig 1. and Fig. 2), with a slight increase in yield efficiency in the 2011/2012 season in the heavier soil site. The decrease was also apparent in the other 'Cripps' Pink' apple orchards and not only at the trial sites.

At the heavier soil site, the compost had the highest (significant in 2012) shoot growth, with an increase in average shoot growth in all of the treatments during 2012 (Fig. 3). At the lighter soil site, the shoot growth varied slightly between the seasons, but did not show much change over the three year period (Fig. 4).

Discussion

The control treatment had a higher sunburn incidence compared to the mulched treatments in 2011 (Table 2b). Although the vermi-casting treatment (called vermi-compost in Kotze 2012) did not differ significantly from the control, it had an almost 8% lower sunburn incidence than the control, which can be ascribed to higher soil moisture that pertained in the mulched treatments (Nicholson 2012). Significantly higher soil moisture is reported in studies investigating the use of wood chips (Smith et al. 2000), compost (Pinamonti 1998) and plastic film (Måge 1982), as these mulches were shown to reduce evaporation from the soil. Higher soil moisture was shown to allow for more prolonged and intense transpiration from fruit surfaces, which significantly reduced fruit temperature, and thereby reduced the incidence and severity of sunburn on 'Cripps' Pink' apples (Makeredza 2011). The sunburn results were however only obtained in the third season of a four season trial. Other factors not monitored in the current study, which could also have influenced the sunburn incidence, are air temperature and irradiance (Schrader et al. 2003), but this would have been similar for all treatments and both sites.

If drought stress could have been induced in the control, the most efficient mulch to maintain the plant water status during periods of drought could have been determined. Unfortunately, no significant differences between treatments were obtained in terms of plant water potential (Table 6) and is most likely a result of the over irrigation experienced for the biggest part of the trial period. A similar lack of significant plant water potential differences was also reported by Makeredza (2011) and Kotze (2012) for this particular site. Although the irrigation was reduced in 2010/2011 and again in the 2011/2012 season, no measurable water stress in the trees or between treatments could be induced. Shading by the tree canopy has been said to obscure the effect of the mulches (Todd et al. 1991), by reducing the evaporative moisture loss from the control treatments, but in this case, shading would not have played a major role.

The higher yield efficiency in the vermi-casting treatment in the heavier soil site could be partly ascribed to the higher levels of nutrients (Fallahi et al. 2010) such as Mg and B in the topsoil of this treatment, compared to the other treatments (Nicholson 2012). Reports on the yield increases when using vermi-castings as mulch under field conditions are limited. However, several researchers have shown an increase in yield when a mulch like wood chips, or a mulch similar to wood chips, was used (Baxter 1970; Barzegar et al. 2002; Szewczuk and Gudarowska 2004). Increases in soil nutrient levels with vermi-castings were reported by Arancon et al. (2006). The combination of higher nutrient levels and improved root growth (Nicholson 2012) in the vermi-castings treatment could have contributed towards the increase in yield efficiency (Acharya and Sharma 1994).

The compost treatment and the geotextile treatment in 2012 in the heavier soil site, had the lowest yield efficiency compared to the other treatments, except in the fourth year at the lighter soil site (Fig. 1 and Fig. 2). Lower yields in apples were also noted by Hartley and Ruhman (1998), when a compost mulch was used. To verify that the quality of the compost itself was not the cause for the observed yield decrease, especially in 2012, seedling growth tests were conducted where, using the compost as a growing medium, poor seedling growth would have been a direct indicator of inferior compost quality. The seedling growth experiments were conducted using apple seeds in 2011 (Table 8) and runner beans in 2012 (Table 14). Bean seeds were used in the second year, because of their greater sensitivity to subtle changes in the quality of the growth medium. Furthermore, there was a considerable variation in the germination success of the apple seeds, and there was a concern that this might not necessarily be related to the quality of the compost, but rather to insufficient stratification. Using compost samples from the respective sites as a growing medium showed no negative influence of the compost on the growth of the seedlings per se that could explain the reduction in yield efficiency in the field. Based on the results of the seedling growth experiments, one can state that there were other factors influencing the low yield efficiency achieved with the compost treatments in the field e.g. too high soil moisture (Pinamonti et al. 1995).

Compost treatments had significantly higher average shoot growth in 2012 (Table 12) compared to the control treatment, at the heavier soil site. Average shoot growth in the compost treatment showed a constant increase over the years it was measured (Fig. 3). No trend could be established at the lighter soil site (Fig. 4). Improved growth was also reported in other compost mulching trials: apples (Autio et al. 1991; Pinamonti et al. 1995), vine (Pinamonti 1998), apricot (Kotzé and Joubert 1992) and pear (Van Schoor 2009). The improved shoot growth could have been related to the mineral content of the compost mulch itself (Paper 1) that was higher than optimum levels for most of the nutrients. The optimum levels of nitrogen (N), potassium (K) and phosphorous (P) found in the compost mulch analyses are an integral part of vegetative processes such as shoot development (Fallahi et al. 2010; Paper 1). Increased vegetative growth over the last two years could have influenced the yield efficiency of the compost mulch (Andrews 2001; Kotzé 2001).

The significantly higher starch breakdown in wood chips treatment only for the 2011/2012 could not be explained. In a trial by Kotze (2012), significant differences between a compost treatment and control was obtained, however, no explanation was given. The result was also only observed in one year of the four year trial. Limited information is available on the effect of mulches on fruit maturity such as starch conversion. According to Tahir et al. (2005), the relationship between quality parameters, such as starch conversion, and mulches are often masked by seasonal weather variation.

Conclusion

Significant differences between different treatments were only obtained for a few quality parameters and only at the heavier soil site. The vermi-casting treatment had significantly higher yield efficiencies than the control in the 2011/2012 season. Compost had the lowest yield efficiency trends at both sites during the 2010/11 and 2011/12 seasons, confirming results from previous two seasons (Kotze 2012). In 2011/12 season, the compost mulch showed significantly higher shoot growth than the control, indicating a positive effect of the compost mulch in the heavier soil after irrigation was reduced. Taking the cost of mulching into account, wood chips is the only treatment that can be recommended without compromising fruit quality and will sustain or even improve yield efficiency in an established orchard on especially heavier soil.

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Table 1a: The effect of different mulches on fruit maturity at harvest of 'Cripps' Pink' fruit harvested on 27 Apr 2011 at the heavier soil site.

Treatment	Background (green)	Red (intensity)	Red (%)	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	Sunburn (%)	TSS (˚Brix)	TA
Control	3.67[ns]	7.75[ns]	55.04[ns]	62.22[ns]	8.76[ns]	67.76[ns]	142.53[ns]	14.17[ns]	14.73[ns]	0.57[ns]
Compost	3.75	8.73	59.50	70.17	8.69	67.50	139.03	20.83	14.48	0.58
Geotextile	3.64	7.77	51.04	63.42	8.82	67.90	141.71	15.00	14.45	0.56
Wood chips	3.68	8.47	57.42	71.00	8.75	68.00	141.68	18.33	14.87	0.57
Vermi-casting/wood chips	3.63	7.77	54.33	66.42	8.77	67.73	140.32	18.33	14.70	0.61
P value	0.3997	0.3048	0.2588	0.1390	0.9514	0.9864	0.9711	0.6239	0.7885	0.1510
LSD	0.14	1.22	7.89	8.25	0.34	1.93	11.43	9.86	0.80	0.04

Means with "ns" was not significantly different. Colour: 1 = green and 5 = yellow

Table 1b: The effect of different mulches on fruit maturity at harvest of 'Cripps' Pink' fruit harvested on 27 Apr 2011 at the lighter soil site.

Treatment	Background (green)	Red (intensity)	Red (%)	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	Sunburn (%)	TSS (˚Brix)	TA
Control	3.35[ns]	6.84[ns]	50.08[ns]	58.25[ns]	8.44[ns]	68.35[ns]	146.95[ns]	27.50[ns]	13.07[ns]	0.51[ns]
Compost	3.30	8.11	46.67	58.81	8.29	68.07	144.26	22.50	13.30	0.57
Geotextile	3.40	8.33	50.79	60.92	8.43	66.65	138.77	24.17	13.47	0.50
Wood chips	3.46	8.03	49.04	68.08	8.22	67.04	138.43	21.67	13.73	0.51
Vermi-casting/wood chips	3.29	7.38	48.78	62.57	8.34	68.10	143.87	27.50	13.33	0.53
P value	0.1456	0.2862	0.5801	0.4707	0.2610	0.2216	0.3983	0.7848	0.4485	0.2679
LSD	0.15	1.56	5.41	12.13	0.23	1.76	10.61	12.31	0.73	0.07

Means with "ns" was not significantly different. Colour: 1 = green and 5 = yellow

Table 2a: The effect of different mulches on fruit quality after cold storage for 2 months of ‘Cripps’ Pink’ fruit harvested on 27 Apr 2011 at the heavier soil site.

Treatment	Background (green)	Red (intensity)	Red (%)	Firmness (kg)	Diameter (mm)	Mass (g)	Sunburn (%)	TSS (˚Brix)	TA
Control	3.86[ns]	7.53[ns]	56.18[ns]	8.42[ns]	64.69[ns]	123.00[ns]	20.00[ns]	14.83[ns]	0.48[ns]
Compost	3.86	7.97	58.50	8.27	64.86	123.55	11.67	14.37	0.47
Geotextile	3.81	7.69	56.83	8.57	63.63	117.34	18.33	14.77	0.47
Wood chips	3.89	7.81	57.12	8.41	64.00	118.87	10.00	14.87	0.47
Vermi-casting/wood chips	3.80	7.82	55.62	8.53	63.99	118.33	20.00	14.75	0.50
P value	0.1957	0.9437	0.9707	0.6540	0.5823	0.5504	0.0951	0.7384	0.4809
LSD	0.08	1.13	9.01	0.45	1.80	9.51	9.36	0.84	0.04

Means with “ns” was not significantly different. Colour: 1 = green and 5 = yellow

Table 2b: The effect of different mulches on fruit quality after 2 months cold storage of ‘Cripps’ Pink’ fruit harvested in May 2011 at the lighter soil site.

Treatment	Background (green)	Red (intensity)	Red (%)	Firmness (kg)	Diameter (mm)	Mass (g)	Sunburn (%)	TSS (˚Brix)	TA
Control	3.66[ns]	6.73[ns]	51.83[ns]	7.81[ns]	64.75[ns]	125.47[ns]	30.00[a]	13.17[ns]	0.43[ns]
Compost	3.68	6.90	53.58	7.64	64.73	124.94	20.83[bc]	13.32	0.44
Geotextile	3.68	7.20	56.50	7.67	64.10	122.39	19.17[bc]	13.09	0.43
Wood chips	3.65	7.17	56.17	7.62	64.13	121.84	12.50[c]	13.75	0.44
Vermi-casting/wood chips	3.62	6.68	51.94	7.63	64.29	122.36	21.67[ab]	13.42	0.47
P value	0.6943	0.6351	0.3502	0.4584	0.7262	0.7588	0.0106	0.7721	0.4061
LSD	0.10	0.88	6.08	0.24	1.31	7.21	8.84	1.14	0.05

Data was significant $P<0.05$. Means with “ns” was not significantly different. Means with different letters differed significantly. Colour: 1 = green and 5 = yellow

Table 3a: The effect of different mulches on the yield obtained for three harvesting days (1: 14/04/2011) (2: 27/04/2011) (3: 04/05/2011) at the heavier soil site.

Treatment	Harvest 1 (kg)	Harvest 2 (kg)	Harvest 3 (kg)	Total yield (kg)	Yield efficiency ($kg.cm^{-1}$)
Control	18.69^{ns}	44.43^{b}	0^{ns}	63.12^{ns}	0.45^{b}
Compost	19.81	40.93^{b}	1.216	61.96	0.45^{b}
Geotextile	16.52	40.02^{b}	3.751	60.29	0.44^{b}
Wood chips	25.73	44.39^{b}	1.12	71.24	0.57^{ab}
Vermi-casting/ wood chips	21.73	58.55^{a}	5.11	85.39	0.65^{a}
P value	0.4038	0.0435	0.1618	0.0930	0.0491
LSD	10.00	12.74	4.60	37.45	0.16

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 3b: The effect of different mulches on the yield obtained for three harvesting days (1: 14/04/2011) (2: 27/04/2011) (3: 04/05/2011) at the lighter soil site.

Treatment	Harvest 1 (kg)	Harvest 2 (kg)	Harvest 3 (kg)	Total Yield (kg)	Yield efficiency ($kg.cm^{-1}$)
Control	12.71^{ns}	43.61^{ns}	58.44^{ns}	114.76^{ns}	0.79^{ns}
Compost	13.63	55.05	39.45	108.13	0.79
Geotextile	14.68	62.02	46.27	122.97	0.91
Wood chips	12.95	61.27	42.99	117.21	0.88
Vermi-casting/ wood chips	12.10	51.79	56.02	119.92	0.90
P value	0.9528	0.4244	0.3646	0.8867	0.7404
LSD	7.12	22.15	22.77	22.60	0.25

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 4: The effect of different mulches on average shoot growth of one year lateral shoots at the heavier soil and lighter soil site (Apr 2011).

Treatment	Heavier soil (cm)	Lighter soil (cm)
Control	45.02^{ns}	55.18^{ns}
Compost	46.04	57.35
Geotextile	45.00	60.72
Wood chips	37.93	54.12
Vermi-casting/ wood chips	41.11	57.72
P value	0.1116	0.6686
LSD	6.86	9.75

Means with “ns” was not significantly different.

Table 5: The effect of different mulches on return bloom obtained at the heavier soil and lighter soil site (Oct 2011).

Treatment	Heavier soil (%)	Lighter soil (%)
Control	38.13^{ns}	36.54^{ns}
Compost	41.11	32.19
Geotextile	32.89	33.16
Wood chips	43.36	34.72
Vermi-casting/ wood chips	37.39	35.46
P value	0.3386	0.9402
LSD	10.67	11.80

Means with “ns” was not significantly different.

Table 6: The effect of different mulches on plant water potential data obtained at the heavier soil and lighter soil site (Mar 2011/12).

Treatment	2011	2012	
	Lighter soil	Heavier soil	Lighter soil
	(MPa)	(MPa)	(MPa)
Control	-1.25^{ns}	-1.67^{ns}	-0.83^{ns}
Compost	-1.24	-1.75	-1.16
Geotextile	-1.08	-1.68	-1.32
Wood chips	-1.34	-1.74	-1.37
Vermi-compost/ wood chips	-1.26	-1.85	-1.05
P value	0.3247	0.5863	0.2264
LSD	3.72	0.26	0.52

Means with “ns” was not significantly different.

Table 7: Trunk diameter data obtained from the heavier soil site and lighter soil site (Apr 2011).

Treatment	Heavier soil (cm)	Lighter soil (cm)
Control	35.13[ns]	36.98[ns]
Compost	35.13	34.14
Polytex PT 110 woven geotextile	34.61	33.96
Wood chips	31.45	32.95
Vermi-compost/ wood chips	33.85	33.65
P value	0.4135	0.2313
LSD	6.60	3.67

Means with “ns” was not significantly different.

Table 8: The effect of different mediums on apple seed growth data (Aug - Sept 2011).

Treatment	Heavier soil (mm)	Lighter soil (mm)
Control	18.40[ns]	8.50[b]
Compost	10.50	50.00[a]
Soil below compost	32.89	6.80[b]
P value	0.4457	0.0013
LSD	20.71	30.21

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

Table 9a: The effect of different mulches on fruit maturity at harvest of 'Cripps' Pink' fruit harvested on 18 Apr 2012 at the heavier soil site.

.Treatment	Background (green)	Red (intensity)	Red (%)	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	Sunburn (%)	TSS (˚Brix)	TA
Control	2.58[ns]	6.83[ns]	44.97[ns]	26.67[bc]	10.05[ns]	68.35[ns]	131.39[ns]	8.33[ns]	14.27[ns]	0.72[ns]
Compost	2.72	6.93	47.79	31.38[ab]	9.94	69.30	136.76	12.50	14.80	0.72
Geotextile	2.72	5.92	39.58	21.64[bc]	10.30	69.78	139.65	2.50	14.00	0.71
Wood chips	2.75	6.32	43.25	36.71[a]	9.73	70.58	142.51	10.83	14.62	0.73
Vermi-castings/wood chips	2.67	6.71	45.30	29.71[abc]	10.06	69.58	138.63	4.17	14.48	0.74
P value	0.1238	0.1310	0.0947	0.0139	0.1894	0.2111	0.3066	0.2824	0.2276	0.8972
LSD	0.14	0.88	5.92	8.15	0.47	1.88	10.73	10.78	0.74	0.07

Data was significant $P<0.05$. Means with "ns" was not significantly different. Means with different letters differed significantly. Colour: 1 = green and 5 = yellow

Table 9b: The effect of different mulches on fruit maturity at harvest of 'Cripps' Pink' fruit harvested on 17 Apr 2012 at the lighter soil site.

Treatment	Background (green)	Red (intensity)	Red (%)	Starch (%)	Firmness (kg)	Diameter (mm)	Mass (g)	Sunburn (%)	TSS (˚Brix)	TA
Control	2.69[ns]	3.93[ns]	25.74[ns]	28.18[ns]	9.75[ns]	70.40[ns]	144.04[ns]	7.50[ns]	13.05[ns]	0.66[ns]
Compost	2.66	4.55	27.52	33.37	9.47	69.58	139.16	6.67	13.63	0.69
Geotextile	2.92	7.72	27.46	29.54	9.62	69.64	140.61	5.83	14.02	0.67
Wood chips	2.74	3.00	17.75	28.20	9.53	69.34	137.61	3.33	13.99	0.67
Vermi-castings/wood chips	2.54	2.75	17.04	29.39	9.43	70.51	143.40	4.17	13.47	0.68
P value	0.0585	0.2602	0.0580	0.4225	0.3318	0.4807	0.5783	0.8844	0.5466	0.9797
LSD	0.25	4.92	9.40	6.23	0.35	1.63	9.43	9.55	1.33	0.11

Means with "ns" was not significantly different. Colour: 1 = green and 5 = yellow

Table 10a: The effect of different mulches on fruit quality after cold storage for 2 months of 'Cripps' Pink' fruit harvested in Apr 2012 at the heavier soil site.

Treatment	Background (green)	Red (intensity)	Red (%)	Firmness (kg)	Diameter (mm)	Mass (g)	Sunburn (*)	Sunburn (%)	TSS (˚Brix)	TA
Control	3.12^{ns}	7.30^{ns}	56.46^{ns}	9.80^{ns}	66.95^{ns}	126.68^{ns}	-1.39^{ns}	25.01^{ns}	14.77^{ns}	0.61^{ns}
Compost	3.08	6.93	55.75	9.57	66.93	124.83	-1.67	18.86	15.05	0.65
Geotextile	3.06	7.38	57.75	9.89	66.96	125.58	-1.71	20.82	14.87	0.61
Wood chips	3.14	7.28	56.14	9.86	67.82	129.33	-2.08	13.54	14.95	0.62
Vermi-casting/wood chips	7.86	6.11	49.31	9.58	66.35	120.84	-1.71	18.89	14.62	0.64
P value	0.4509	0.1638	0.2165	0.2117	0.5436	0.4852	0.1128	0.1929	0.6404	0.7858
LSD	6.41	1.15	7.76	0.36	1.73	9.63	0.49	9.55	0.62	0.09

Means with "ns" was not significantly different. Colour: 1 = green and 5 = yellow

Table 10b: The effect of different mulches on fruit quality after 2 months cold storage of 'Cripps' Pink' fruit harvested in Apr 2012 at the lighter soil site.

Treatment	Background (green)	Red (intensity)	Red (%)	Firmness (kg)	Diameter (mm)	Mass (g)	Sunburn (*)	Sunburn (%)	TSS (˚Brix)	TA
Control	3.19^{ns}	4.60^{ns}	35.04^{ns}	9.49^{ns}	67.40^{ns}	127.08^{ns}	-1.46^{ns}	18.67^{ns}	13.37^{ns}	0.66^{ns}
Compost	3.00	5.54	44.03	9.31	66.43	120.67	-0.98	27.33	14.28	0.68
Geotextile	3.22	4.75	36.75	9.24	65.95	118.43	-1.36	21.23	14.65	0.67
Wood chips	3.02	4.83	35.96	9.27	65.78	117.54	-1.64	16.42	14.58	0.59
Vermi-casting/wood chips	3.09	4.47	35.67	9.22	67.05	123.60	-1.38	20.21	14.28	0.67
P value	0.9077	0.5612	0.4259	0.4158	0.3648	0.3637	0.0516	0.0524	0.4177	0.7658
LSD	0.59	1.40	10.88	0.32	1.91	10.80	0.43	7.94	1.49	0.15

Means with "ns" was not significantly different. Colour: 1 = green and 5 = yellow

Table 11a: The effect of different mulches on yield (18 Apr 2012) obtained at the heavier soil site.

Treatment	Total Yield (kg)	Yield efficiency ($kg.cm^{-1}$)
Control	100.46[ns]	0.71[ab]
Compost	73.08	0.50[c]
Geotextile	76.14	0.54[bc]
Wood chips	93.77	0.73[a]
Vermi-castings/ wood chips	101.26	0.72[a]
P value	0.0537	0.0284
LSD	22.69	0.17

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

Table 11b: The effect of different mulches on yield (17 Apr 2012) obtained at the lighter soil site.

Treatment	Total Yield (kg)	Yield efficiency ($kg.cm^{-1}$)
Control	103.82[ns]	0.69[ns]
Compost	93.57	0.66
Geotextile	86.12	0.62
Wood chips	98.15	0.72
Vermi-castings/ wood chips	93.82	0.66
P value	0.8352	0.8142
LSD	25.64	0.18

Means with "ns" was not significantly different.

Table 12: The effect of different mulches on average shoot growth of one year lateral shoots at the heavier soil site and lighter soil site (Mar 2012).

Treatment	Heavier soil (cm)	Lighter soil (cm)
Control	42.67[b]	50.46[ns]
Compost	50.83[a]	49.60
Geotextile	41.13[b]	48.79
Wood chips	43.21[b]	42.10
Vermi-castings/ wood chips	46.48[ab]	46.98
P value	0.0205	0.2486
LSD	5.93	7.10

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 13: Trunk diameter data obtained from the heavier soil site and lighter soil site (Apr 2012).

Treatment	Heavier soil (cm)	Lighter soil (cm)
Control	35.22[a]	37.86[ns]
Compost	36.01[a]	35.50
Polytex PT 110 woven geotextile	35.25[a]	34.97
Wood chips	32.27[b]	34.30
Vermi-compost/ wood chips	35.20[a]	35.32
P value	0.0330	0.4812
LSD	2.37	4.19

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

Table 14: The effect of different mediums on bean seed growth data from the heavier soil site and lighter soil site (Apr 2012).

Treatment	Heavier soil (g)	Lighter soil (g)
Control	1.72[a]	2.39[a]
Compost	2.20[a]	1.07[ab]
Soil below compost	1.19[ab]	0.76[b]
Alternative plant medium	0.00[b]	0.57[b]
P value	0.0086	0.0410
LSD	1.20	1.32

Data was significant P<0.05. Means with "ns" was not significantly different. Means with different letters differed significantly.

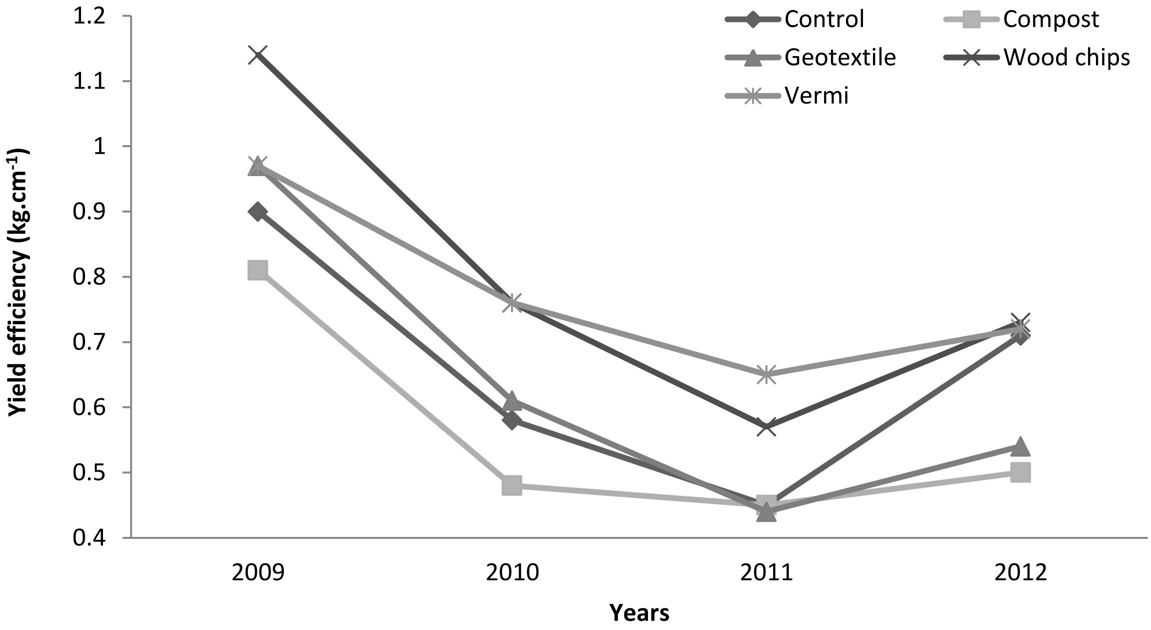

Fig. 1. The trend in the effect of different mulches on yield efficiency in ‘Cripps’ Pink’ apple fruit in the heavier soil site during four consecutive seasons of application.

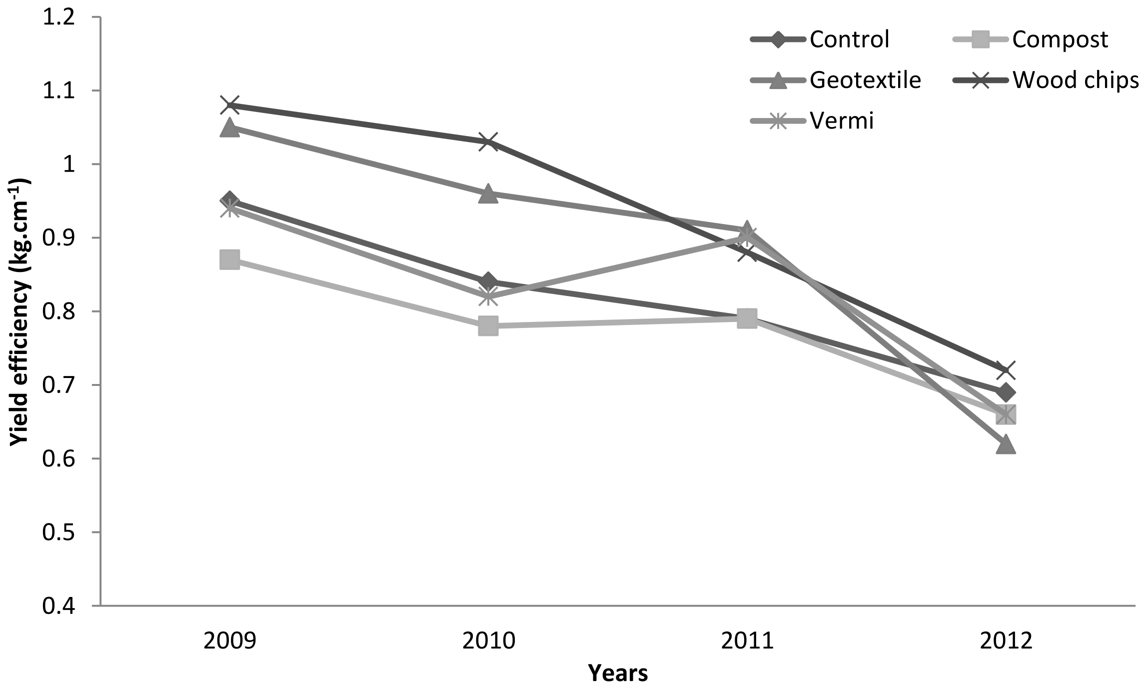

Fig. 2. The trend in the effect of different mulches on yield efficiency in ‘Cripps’ Pink’ apples in the lighter soil site during four consecutive seasons of application.

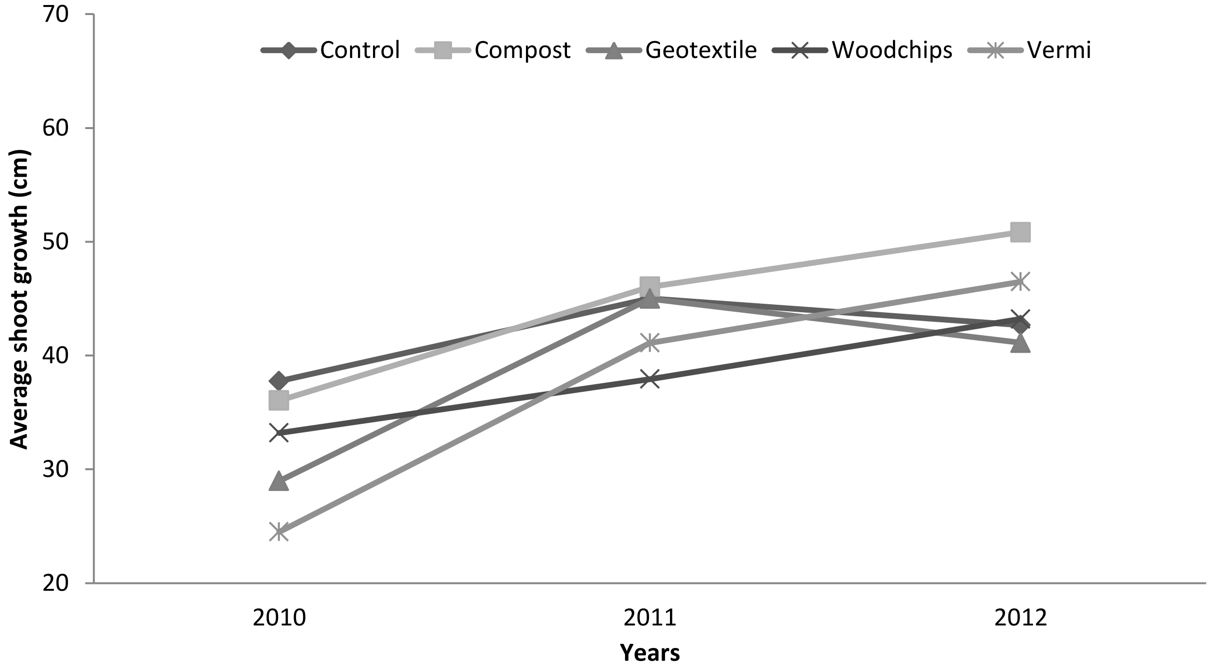

Fig. 3. The trend in the effect of different mulches on average shoot growth in 'Cripps' Pink' apples in the heavier soil site during four consecutive seasons of application.

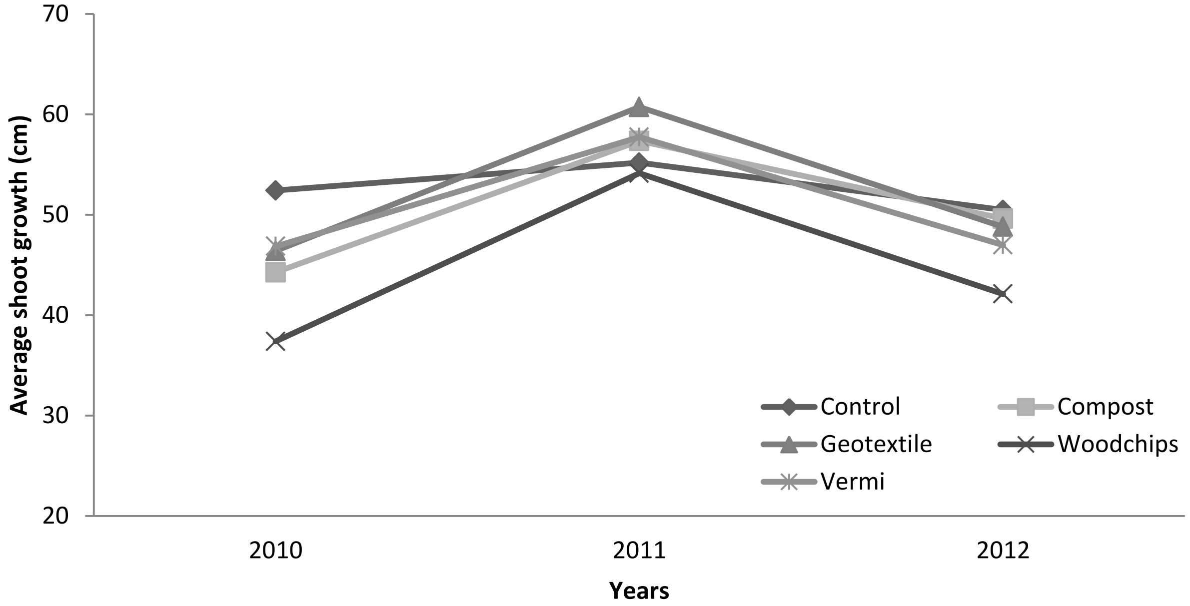

Fig. 4. The trend in the effect of different mulches on average shoot growth in 'Cripps' Pink' apples in the lighter soil site during four consecutive seasons of application.

GENERAL DISCUSSION AND CONCLUSION

This current study presents only a section, the last two years, of a mulching trial that has been on-going for the last four years at the same estate and sites. For the first two years of this four year mulching trial, no significant nutritional trends could be identified (Kotze 2012). We hoped that by evaluating the effects of the compost, vermi-castings, wood chips and polytex PT110 mulch treatments for an additional two years, significant trends, be they positive or negative, would emerge. Although after the additional two years no major trends could be identified, valuable recommendations can be made based on the results. These recommendations can guide commercial producers to decide on an appropriate mulch for their specific commercial orchard.

In the first paper, the effects of the various mulches on tree and fruit nutrition were evaluated against a control (no mulch applied) on two different soil types; heavier soil and lighter soil. Woodchips did not influence fruit and leaf nutrient levels negatively and even improved leaf P, K and Ca levels in the heavier soil. Compost had a more pronounced effect on fruit nutrient levels and improved the levels of P, K and Mg in the heavier soil. Regarding leaf nutrient levels, the compost treatment also increased leaf P and K levels, increasing the K level even more than the woodchips treatments. Similar to the woodchips treatment, the compost treatment showed more increases in the heavier soil. In contrast, the vermi-castings resulted in more changes in nutrient levels at the sandier site. Vermi-castings also had a positive effect on fruit P, K and Mg, especially in the lighter soil site, where it had an even more significant effect compared to the compost. The same trend was observed in the leaf nutrient levels. The geotextile mulch did not improve any nutrient levels, in either the leaves or the fruit, compared to the organic mulches. The geotextile mulch did, however, show higher nutrient levels for most nutrients in the tree compared to the control treatment, for both sites. Results from the treatments differed between the first two and subsequent two seasons of the trial and coincided with the reduction in irrigation volumes. This may partly explain the lack of definite trends in changing nutrient levels after application of the treatments.

Mineral analyses results of vermi-castings indicated the highest nutrient levels of all organic mulches at application, as well as after a growing season. These higher nutrients, however, were not reflected in the leaf and fruit nutrient analyses.

This study supports the argument by Pinamonti et al. (1995) that irrigation can obscure the effect of mulches in an orchard, especially the changes in the nutrient status of the tree as determined by fruit and leaf nutrient analysis. There was a more significant difference in nutrient levels between treatments in the last two years, when irrigation was reduced, compared to the first two years of the trial. Therefore, for future studies, the effect of different amount of irrigation on different mulches should be included.

Higher nutrient levels in the compost and vermi-castings could be ascribed to the combination of fertilizer and the higher initial nutrient levels of these mulches. As definite trends were not identifiable, one cannot quantify the direct contribution of nutrients found in organic mulches towards tree requirements. The only two nutrients that could be reduced in terms of artificial fertilizer applications were K and P, if compost and vermi-casting are applied. Woodchips, together with a normal fertilizer program, can successfully be used in established orchards under the same conditions as this trial. Woodchips are more cost effective than compost and vermi-castings mulches, even though no direct contribution towards nutrition to the soil/tree is possible before decomposition occurs.

In the second paper the effect of the organic and inorganic mulches on tree growth, yield and fruit quality were evaluated against a control (no mulch applied) on two different soil types; heavier soil and lighter soil. By applying compost as a mulch in an established orchard, that has similar conditions to those in this trial, one can expect an increase in vegetative growth when compared to a control. However, using the compost mulch on specifically a heavier soil could result in lower yield efficiency when compared to conventional orchard management (control). This indicates that the use of compost as a mulch not only improves growth in newly established orchards, but also in established orchards if it is required. In contrast, the woodchips mulch tends to have higher yield efficiency and lower shoot growth when compared to the control at both sites. This suggests that using a woodchips mulch could improve an established orchards yield efficiency under the same conditions. The application of vermi-castings did not give the results one would expect from a medium with such high nutrient levels, as it only outperformed the other mulches, in terms of yield efficiency and only in the third year at the heavier soil site. The geotextile mulch did not show promising results regarding yield efficiency or shoot growth.

Although most of the results were inconsistent and varied over the four year period, none of the treatments had a negative effect on fruit quality. Also one can now state that vermi-castings and geotextile mulches did not have more of an effect than the commonly commercially used compost and woodchips. The compost and wood chips can not only improve soil water moisture (Barzegar et al. 2002) and soil structure (Forge et al. 2002) in an established orchard, but also growth and yield respectively.

The decision to use mulches in a commercial situation is based on various suitability and economic factors. To make an informed choice in terms of the suitability of a specific mulch, sufficient information is required regarding the advantages of different mulches under different production conditions, as highlighted in this study. Once the suitability of mulches have been determined for a set of production conditions, the cost of the material, availability thereof and distance that it needs to be transported to the site of application will become determining factors in the final choice of a mulch.

Applying vermi-castings according to the protocol in this paper will amount to a cost of material of approx. R150 000 ha^{-1} p.a. This is drastically more than the calculated cost of medium (not sifted) compost of R20 375 ha^{-1} p.a., wood chips at R18 500 ha^{-1} p.a. and geotextile fabric at R3220 ha^{-1} p.a. (prices established on 2012/09/11). The cost applying of vermi-casting as a mulch was not justified for production conditions on this estate. Although the geotextile treatment would only need to be re-applied every 5 years (according to the manufacturer), it performed similar to the other mulches in the lighter soil site. However, in the heavier soil site, yield efficiency was reduced compared to the control and should not be recommended under similar conditions.

Our results showed that a compost mulch, rather than vermi-castings, can be recommended for newly planted trees or trees with subnormal growth, without significantly influencing fruit quality for a heavier soil. Woodchips can be applied in an established orchard without compromising fruit quality and sustain or even improve the yield efficiency. However, economically, none of the mulches improved fruit quality or yield sufficiently to justify the expense to mulch under these conditions.

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