THE EVALUATION AND MANAGEMENT OF DIFFERENT GRASSES AND LEGUMES AS POTENTIAL COVER CROPS IN THE VINEYARDS OF SOUTH AFRICA

by

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DECLARATION

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

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ABSTRACT

A selection of species suitable for cover crop management in the different wine grape regions is required to enable more producers to apply this environment friendly practice in a sustainable manner as part of an integrated production strategy. The correct management practice(s) to be applied to these species over both the short and long term in a cooler and warmer wine grape region needed clarification.

The effect of seeding date on the dry matter production (DMP) and weed control efficacy of seven grasses and sixteen legumes, as well as varieties of three of these species, was determined during 1991 and 1992. The decomposition rate of the mulches was determined. In the cooler climate of Stellenbosch (33°55'S, 18°52'E), the *Medicago* species, subterranean clovers, pink Seradella and three *Vicia* species did not compete effectively with the winter weeds if the weekly precipitation from mid-March to mid-May (autumn) exceeded 18 mm. The two oat species, as well as rye and triticale produced more than five t/ha of dry matter if the precipitation exceeded 18 mm per week. The DMP of the above-mentioned species indicated that these species could be considered for cover crop management in Lutzville (31°35'S, 18°52'E), if full surface irrigation of 18 mm per week could be applied for 10 weeks directly after sowing, followed by 18 mm fortnightly. Seeding date had a significant effect on DMP in both regions. A highly significant correlation ($r = 0.85$, $p \leq 0.0001$) existed between the decomposition rate of the mulches and the initial amount of dry matter present on the soil surface.

A second trial was conducted on a sandy soil in a Sauvignon blanc/Ramsey vineyard near Lutzville from 1993/94 to 2002/03. Twenty four treatments, consisting of three management practices and three fertilizer rates applied selectively to four cereals and four legumes, were evaluated. Rye and pink Seradella produced, on average, the highest amount of dry matter at the end of August receiving on average 278 mm of full surface irrigation and rain. A P and K concentration of 10 mg/kg and 78 mg/kg, respectively, in the top 300 mm soil layer, seemed to supply in the needs of grazing vetch. Saia oats performed poorly unless 30 kg of P, 30 kg of K and 42 kg of N were applied during establishment and early growing phase. All the species, except ‘Parabinga’ medic, produced additional fibre from September to November following a

dry winter (201 mm of both rain and irrigation), while none produced additional fibre if the water supply was luxurious. The cover crops did not produce enough seeds to re-establish successfully. The shoot mass of the young grapevines in the grazing vetch and ‘Paraggio’ medic treatments in which post-emergence chemical control was applied from just before bud break (BB), was significantly higher than that of the treatments in which post-emergence chemical control was applied from berry set (AB). It was also significantly higher than that of the treatments in which mechanical control was applied in the working row and chemical control in the vine row from just before bud break (MC), with the exception of rye (AB) and grazing vetch (MC). The first harvest from the young grapevines in the BB treatments was significantly higher than that of the treatment in which no cover crop was sown and BB was applied (weedchem) and the MC treatments. When the grapevines reached full production, the grape yield in the BB treatments, grazing vetch (AB) and pink Seradella (AB) was significantly more than that of weedchem and the control. The NO_3-N concentration in the leaf petioles of all the cover crop treatments was, with the exception of the AB treatments of rye, ‘Parabinga’ medic and grazing vetch, significantly more than that of weedchem and the treatment in which no cover crop was sown and MC was applied (control). The NO_3-N concentration in the leaf petioles of the BB and AB treatment of a species differed significantly. The N concentration in the grape juice of the cover crop treatments was, with the exception of ‘Saia’ oats (MC) and ‘Parabinga’ medic (AB), significantly higher than that of weedchem and the control. The N concentration of the juice in the BB and AB treatments of grazing vetch and pink Seradella was significantly higher than that of the MC treatments, the two rye treatments, weedchem and the AB treatments of the other cover crop species. The concentration of Ca in the juice of the cover crop treatments was, with the exception of the pink Seradella treatments, significantly higher than that of weedchem and the control. Wine quality did not differ between treatments. After 10 years of applying the treatments, the soil organic matter (SOM) content in the 0-600 mm soil layer of grazing vetch (AB), as well as the 0-150 mm soil layer of pink Seradella (AB) and rye (BB), was significantly higher than that of the control and weedchem. The total inorganic N concentration (TIN) of pink Seradella (BB) was the highest in the 0-150 mm soil layer during the full bloom stage of the grapevines and significantly higher than that of the other treatments in the 150-300 mm soil layer. The TIN in the 0-150 mm soil layer of the legumes was, with the exception of pink Seradella (BB), significantly more than that of the control, weedchem and the BB treatments of the grain species as measured after the grapevines were harvested. The TIN in the 150-300 mm soil layers of the AB treatments of pink Seradella, ‘Parabinga’ medic and ‘Paraggio’ medic, was significantly higher than that of the control, weedchem and the grain treatments. Potassium concentrations in the 0-150 mm soil layer of the two pink Seradella treatments, the AB treatment of rye, ‘Paraggio’ medic and grazing vetch, as well as the 150-300 mm soil layer of grazing vetch (BB) and pink Seradella (BB), were significantly higher than that of the control, weedchem and ‘Saia’ oats (MC) after harvest.

A third trial was conducted) on a medium textured soil in a Chardonnay/99 Richter vineyard near Stellenbosch from 1993/94 to 2002/03. Sixteen treatments, consisting of three cereals and five legumes managed according to two cover crop management practices (BB and AB), were included. These treatments were compared to a control (as above) and weedchem treatment managed the same as described for the trial in Lutzville. Rye, ‘Overberg’ oats, ‘Saia’ oats and faba bean (only if BB was applied) showed the ability to produce, on average, significantly more dry matter during winter than the weeds in the region. The DMP of all the cover crops increased from the end of August to the end of November if left to complete their life cycles, with the exception of rye and ‘Overberg’ oats sown in early April. None of the cover crop species were able to re-establish successfully. Total suppression of the winter growing weeds was achieved for six and five of the 10 years with ‘Overberg’ oats (BB) and ‘Saia’ oats (BB), respectively. Effective, long-term control of the summer growing weeds was obtained with rye (BB), ‘Overberg’ oats (BB) and ‘Saia’ oats (BB). The shoot mass of the two year old grapevines in the BB treatments was significantly higher than that of the control and the AB treatments. In the following season, the shoot mass and grape yield of the BB treatments was, with the exception of faba bean and ‘Overberg’ oats, significantly higher than that of the control and weedchem. The grape yield of the control and AB treatments was significantly less than that of weedchem. The petiole NO_3-N and juice N concentrations in ‘Kelson’ medic (BB) were significantly higher than that of the control and weedchem. The juice N concentration of the control and weedchem was significantly less than that of the legume treatments, with the exception of ‘Paraggio’ medic (AB) and ‘Woogenellup’ subterranean clover (AB). Wine quality did not differ between treatments. After five seasons the SOM content in the 0-300 mm soil layer increased in all the cover crop treatments during this period, while that of weedchem and the control remained unchanged and decreased by 16%, respectively. The SOM in the

0-150 mm soil layer of the cover crop treatments was, with the exception of grazing vetch, significantly higher than that of the mechanically cultivated control after a period of 10 years. The SOM in the 0-300 mm soil layer of rye and the treatments in which the legumes were sown (except grazing vetch) was significantly higher than that of weedchem. The TIN of the 0-150 mm soil layer in the BB treatments of the two *Medicago* species and ‘Woogenellup’ subterranean clover, was significantly higher than that of the control, weedchem, and the AB treatments during the full bloom phase of the grapevines. The TIN of the 0-600 mm soil layer in the AB treatment of a species, as measured after the grapes were harvested, tended to be higher than that of the BB treatment of that species.

UITTREKSEL

‘n Verskeidenheid van spesies, geskik vir deklaagbewerking word in die verskillende wyndruifstreke benodig, ten einde meer produsente in staat te stel om dié omgewingsvriendelike praktyk, as deel van geïntegreerde produksie, volhoubaar toe te pas. Die korrekte dekgewasbestuurspraktyk vir beide die kort- en langtermyn vir die koeler en warmer wyndruifstreke moet bepaal word.

Die effek van saaityd op die droëmateriaalproduksie (DMP) en onkruidbeheer vermoë van sewe grasse en sestien peulgewasse, asook vareïteite van drie van hierdie spesies, is in 1991 en 1992 bepaal. Die afbraaktempo van die deklae is bepaal. In die koeler klimaat van Stellenbosch ($33^o55'S$, $18^o52'E$), het die *Medicago* spesies, ondergrondse klawers, pienk Seradella en drie *Vicia* spesies nie effektief met die winteronkruide kompeteer as die weeklikse reënval vanaf middel Maart tot middel Mei (herfs) meer as 18 mm beloop het nie. Die twee hawer spesies, rog en korog het meer as vyf t/ha droë material produseer as die weeklikse reënval 18 mm oorskrei het. Die DMP van bogenoemde spesies dui daarop dat hulle vir deklaagbewerking in Lutzville ($31^o35'S$, $18^o52'E$) oorweeg kan word, mits voloppervlak besproeiing van 18 mm per week vir 10 weke, gevolg deur 18 mm tweeweekliks, toegedien kan word. Saaityd het in beide streke die DMP van die dekgewasse betekenisvol beïnvloed. ‘n Hoogs betekenisvolle korrelasie ($r = 0.85$, $p \leq 0.0001$) is tussen die afbraaktempo van die deklae en die hoeveelheid droë material wat aanvanklik op die grondoppervlak voorgekom het, gevind.

‘n Tweede proef is op ‘n sandgrond in ‘n Sauvignon blanc/Ramsey wingerd naby Lutzville vanaf 1993/94 tot 2002/03 uitgevoer. Vier en twintig behandelings, bestaande uit drie bestuurspraktyke en drie bemestingshoeveelhede wat selektief op vier grane en vier peulgewasse toegepas is, is geëvalueer. Rog en pienk Seradella het gemiddeld die meeste droë material teen einde Augustus geproduseer, indien dit 278 mm water in die vorm van voloppervlak besproeiing of reën ontvang het. Die resultate het daarop gedui dat ‘n P en K konsentrasie van 10 mg/kg en 78 mg/kg, onderskeidelik, in die boonste 300 mm grondlaag in die voedingsbehoefte van weiwieke kon voorsien. ‘Saia’ hawer het swak presteer tensy 30 kg P, 30 kg K en 42 kg N tydens vestiging en vroeë groeifase van die spesie toegedien is. Al die dekgewasse, buiten ‘Parabinga’ medic, het addisionele vesel vanaf September tot November geproduseer na ‘n droë winter (201 mm reën en besproeiingswater), terwyl geen spesie meer vesel produseer het indien die watervoorsiening luuks was nie. Die dekgewasse kon nie genoeg saad produseer om self the hervestig nie. Die lootmassa van die jong wingerd in die weiwieke en 'Paraggio' medic behandelings waarin chemiese na-opkomsbeheer vanaf net voor bot toegepas is (BB), was betekenisvol hoër as dié van die behandelings waarin chemiese na-opkomsbeheer vanaf korrelset toegepas is (AB). Dit was ook betekenisvol hoër as dié van die behandelings waarin meganiese beheer in die werksry en chemiese beheer in die wingerdry vanaf net voor bot (MC) toegepas is, met die uitsondering van rog (AB) en weiwieke (MC). Die eerste oes van die jong wingerd in die BB behandelings was betekenisvol hoër as dié van die behandeling waarin geen dekgewas gesaai en BB toegepas is nie (weedchem), asook dié van die MC behandelings. Die oes in die volwasse wingerd van die BB behandelings, weiwieke (AB) en pienk Seradella (AB) was betekenisvol meer as dié van weedchem en die MC behandeling waarin geen dekgewas gesaai is nie (kontrole). Die NO_3-N konsentrasie in die blaarstele van al die dekgewasbehandelings was, met die uitsondering van die AB behandelings van rog, 'Parabinga' medic en weiwieke, betekenisvol hoër as dié van weedchem en die kontrole. Die NO_3-N konsentrasie in die blaarstele van die BB en AB behandeling van 'n spesie het betekenisvol verskil. Die N konsentrasie in die druiwesap van die dekgewasbehandelings was, met die uitsondering van 'Saia' hawer (MC) en 'Parabinga' medic (AB), betekenisvol meer as dié van weedchem en die kontrole. Die N konsentrasie in die sap van die BB en AB behandelings van weiwieke en pienk Seradella was betekenisvol hoër as dié van die MC behandelings, die twee rog behandelings, weedchem en die AB behandelings van die ander dekgewasse. Die Ca konsentrasie in die sap van die dekgewasbehandelings was, met die uitsondering van die pienk Seradella behandelings, betekenisvol hoër as dié van weedchem en die kontrole. Geen verskil in wynkwaliteit is tussen behandelings waargeneem nie. Nadat die behandelings vir 'n periode van 10 jaar toegepas is, was die organiese materiaalinhoud (SOM) in die 0-600 mm grondlaag van weiwieke, asook in die 0-150 mm grondlaag van pienk Seradella (AB) en rog (BB), betekenisvol hoër as dié van die kontrole en weedchem. Die totale anorganiese N konsentrasie (TIN) van pienk Seradella (BB) was die hoogste in die 0-150 mm grondlaag tydens die volblom stadium van die wingerd en betekenisvol hoër in die 150-300 mm grondlaag as dié van die ander behandelings. Die TIN in die 0-150 mm grondlaag van die peulgewasse was, met die uitsondering van pink Seradella (BB), betekenisvol meer as dié van die kontrole, weedchem en die BB behandelins van die grane, soos bepaal nadat die wingerd geoes is. Die TIN in die 150-300 mm grondlaag van die AB behandelings van pienk Seradella, 'Parabinga' medic en 'Paraggio' medic was betekenisvol hoër as dié van die kontrole, weedchem en die grane. Kalium konsentrasies in die 0-150 mm grondlaag van die twee pienk Seradella behandelings, die AB behandeling van rog, 'Paraggio' medic en weiwieke, asook die 150-300 mm grondlaag van weiwieke (BB) en pienk Seradella (BB), was betekenisvol hoër as dié van die kontrole, weedchem en 'Saia' hawer (MC) na oes.

'n Derde proef is op 'n medium tekstuur grond in 'n Chardonnay/ 99 Richter wingerd naby Stellenbosch vanaf 1993/94 tot 2002/03 deurgevoer. Sestien behandelings, bestaande uit twee bestuurspraktyke toegepas op drie grane en vyf peulgewasse (BB en AB) is ingesluit. Dié behandelings is vergelyk met 'n kontrole (soos bo) en weedchem behandeling wat dieselfde bestuur is as in die geval van die Lutzville proef. Rog, 'Overberg' hawer, 'Saia' hawer en fababoon (slegs indien BB toegepas is) het die vermoë getoon om gemiddeld meer droë materiaal as die wintergroeiende onkruide in die streek te produseer. Die DMP van al die dekgewasse, buiten rog en 'Overberg' hawer wat vroeg April gesaai is, het toegeneem vanaf einde Augustus tot einde November indien toegelaat om hul lewenssiklusse te voltooi. Geeneen van die dekgewasse kon hulself suksesvol hervestig nie. Totale onderdrukking van die wintergroeiende onkruide is vir vyf en ses van die 10 jaar met 'Overberg' hawer en 'Saia' hawer, onderskeidelik, verkry. Die somergroeiende onkruide is effektief oor die langtermyn met rog (BB), 'Overberg' hawer en 'Saia' hawer beheer. Die lootmassa van die twee jaar oue wingerd in die BB behandelings was betekenisvol hoër as dié van die kontrole en die AB behandelings. In die daaropvolgende seisoen was die lootmassa en druifproduksie van die BB behandelings, buiten fababoon en 'Overberg' hawer betekenisvol hoër as dié van die kontrole en weedchem. Die druifproduksie van die kontrole en AB behandelings was betekenisvol laer as dié van weedchem. Die NO_3-N konsentrasie in die blaarstele en N konsentrasie in die druiwesap van 'Kelson' medic (BB) was betekenisvol hoër as dié van die kontrole en weedchem. Die N konsentrasie in die sap van die kontrole en weedchem was betekenisvol laer as dié van die peulgewasse, buiten 'Paraggio' medic (AB) en 'Woogenellup' ondergrondse klawer (AB). Geen verskil in wynkwaliteit is tussen behandelings waargeneem nie. Na afloop van vyf seisoene, het die SOM inhoud in die 0-300 mm grondlaag van al die dekgewasbehandelings toegeneem, terwyl dit in weedchem onveranderd gebly en in die kontrole met 16% afgeneem het. Na ‘n periode van 10 jaar, was die SOM in die 0-150 mm grondlaag van die dekgewasbehandelings, met die uitsondering van weiwieke, betekenisvol hoër as dié van die meganies bewerkte kontrole. Die SOM in die 0-300 mm grondlaag van rog en die behandelings waarin N-bindende dekgewasse gesaai is (weiwieke uitgesonder), was betekenisvol hoër as dié van weedchem. Die TIN van die 0-150 mm grondlaag in die BB behandelings van die twee *Medicago* spesies en ‘Woogenellup’ ondergrondse klawer was tydens die volblom stadium van die wingerd betekenisvol hoër as dié van die kontrole, weedchem en die AB behandelings. Die TIN van die 0-600 mm grondlaag in die AB behandelings van ‘n spesie het geneig om hoër te wees as dié van die BB behandeling van dieselfde spesie.

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CHAPTER 1

Introduction

Maintenance and improvement of soil quality is critical to sustaining agricultural productivity and environmental quality for future generations (Reeves, 1997). Consumers of agricultural products, worldwide, demand that both the use of chemicals and the negative impact of agricultural practices on the environment must be restricted. In addition, an increasing number of weed species are developing resistance towards a variety of herbicides used in agriculture (Anonymous, 1997; Henkes, 1997). Although certain weed species can be controlled with biological agents (Cullen *et al*., 1973; Daniel *et al*., 1973; Woodhead, 1981; Phatak *et al*., 1983), the vacated niche will quickly be filled by other weed species (Putnam, 1990). Cover crop mulches, on the other hand, are a non-specific method of pre-emergence weed control (Van Huyssteen *et al*., 1984).

The first written account of cover crops for soil improvement are from the Chou dynasty in China over 3 000 years ago (Burket *et al*., 1997). According to Pieters (1927), cover crops have been used for thousands of years to preserve and enhance soil fertility. Agricultural doctrine of the nineteenth and early twentieth century equated financially successful farming with the use of green manures, because of their ability to protect fields from erosion and to absorb minerals that would otherwise be leached from the soil (Harlan, 1899; Pieters, 1927).

Fusarium avenaceum (Fr.) Sacc. is an important pathogen of *Medicago* species (Lamprecht *et al*., 1988). To restrict the build-up of soil-borne diseases against cover crops, a crop rotation system is important (Lamprecht *et al*., 1990). A variety of species should, therefore, be available for cover crop management in the vineyards of South Africa.

A selection of species suitable for cover crop management in the different wine grape regions is required to enable more producers to apply this environment friendly practice in a sustainable manner as part of an integrated production strategy. The correct management practice to be applied to these species over both the short and long term also needs clarification.

Water, nutritional and climatic requirements of cover crops

Qualitative observations by Burket *et al*. (1997) showed that a dry autumn and/or excessive rainfall and/or a cold spell in November/December severely reduced cover crop growth. The dry matter production of *Avena sativa* L. v. Overberg ('Overberg' oats), *Avena strigosa* L. v. Saia ('Saia' oats), *Triticale* and *Secale cereale* L. (rye) declined significantly if the irrigation rate was reduced from 18 mm per week to 13 mm per week (Van Bosch & Pieterse, 1995). The production and N yield of a mixture of *Medicago scutellata* L. (snail medic) and *M. truncatula* Gaertn. varieties were closely correlated with the growing season rainfall (March to September). Each 100 mm of growing season rainfall resulted in 1.39 t/ha of dry matter and 40 kg/ha of N yield (Weston *et al*., 2002). Clarkson *et al*. (1987) found that both soil type and the amount of rainfall/irrigation received had a highly significant effect on the dry matter production of *Medicago truncatula* Gaertn. v. Jemalong ('Jemalong' medic).

According to Van Bosch & Pieterse (1995), N fertiliser applied at a rate of 50 kg/ha N four weeks after sowing, ensured a sufficient supply of N during the initial growing stages of 'Overberg' oats, 'Saia' oats, *Triticale* and rye. Van Huyssteen & Van Zyl (1984) indicated that a top dressing of 30 kg/ha N at the two leaf stage of grass cover crops (approximately six weeks after emergence) is essential. Fertilisation of 100 kg/ha N increased the mean annual yield of *Lolium perenne* L. (perennial ryegrass) by between 230% and 255% compared to the treatments in which no fertiliser was applied (Ivory, 1982).

Phosphate deficiency limits nodulation indirectly by reducing legume growth thus impacting on the infection process (Bordeleau & Prévost, 1994). Schulz *et al*. (1999) applied 26.2 kg/ha of P at the time of legume sowing to eliminate P as a limiting factor to legume growth. Soil phosphorous levels lower than 30 mg/kg in the 0-100 mm soil layer needs to be increased to ensure good growth rates with the *Medicago* species (Sanderson, 1998). 'Jemalong' medic produced maximum yields at soil P levels of between 31 and 46.5 mg/kg (De Ruiter, 1981). Dahmane & Graham (1981) found that the yield of 'Jemalong' medic increased with an increasing rate of phosphate to an optimum level of 160 ppm, whereafter it decreased. The dry matter production (DMP) of snail medic and *M. truncatula Gaertn.*, established on a soil with 32% clay, 15% silt and

53% sand, a pH (KCl) of 5-6, organic matter content of 2.33% and available P (Bray 1) of 8.2, resulted in yield increases of 15% and 14%, respectively, with the application of 30 kg/ha P (Nnadi & Haque, 1988). Growth depressions of annual *Medicago* species occurred on moderately acid soils (pH 5.5 to 6.0), which has been attributed to effect on nodulation and N fixation rather than to reduced P availability (Helyar & Anderson, 1971). The DMP of 'Jemalong' medic was reduced by 30%, 33% and 70% compared to that produced at a pH of 6.0 at a pH of 5.1, 4.7 and 4.2, respectively (Evans *et al*., 1990).

Increasing the soil P level from 2 to 6 mg/kg promoted significant yield increases from *Trifolium subterraneum* L. Woogenellup ('Woogenellup' subterranean clover) and *T. subterraneum* L. Trikkala ('Trikkala' subterranean clover) on a silt clay loam with a pH (0.01 CaCl) of 4 in the Elgin area of the Western Cape (Wooldridge & Harris, 1987). *T. subterraneum* L. v. Mount Barker ('Mt. Barker' subterranean clover) yielded significantly better at the 16 mg/kg than at the 6 mg/kg level, but in all cases the yield at the 16 mg/kg P level was significantly better than at the 2 mg/kg field P level. Liming and P fertilisation both served to increase average P uptake by the *T. subterraneum* L. varieties. 'Woogenellup' subterranean clover produced maximum yields at soil P levels of between 31 and 46.5 mg/kg (De Ruiter, 1981). The DMP of *T. subterraneum* L. v. Junee was not significantly affected by pH ranging between 4.2 and 6.0. (Evans *et al*., 1990).

On a sandy loam soil (Hutton) deficient in nitrogen, phosphorous and potassium, 45 kg/ha P and 72 kg/ha K was applied to *Vicia dasycarpa* Ten. (grazing vetch), to ensure a sufficient supply of these nutrients to the species (Wassermann *et al*., 1984). De Ruiter (1981), however, observed that grazing vetch produced maximum yields at soil P levels of between 15.5 and 23.2 mg/kg. The DMP of grazing vetch established on a soil with 32% clay, 15% silt and 53% sand, a pH (KCl) of 5-6, organic matter content of 2.33% and available P (Bray 1) of 8.2, resulted in a yield increase of 28% with the application of 30 kg/ha of P (Nnadi & Haque, 1988).

Omithopus sativus L. (pink Seradella) is capable of performing well on low fertility sands (Williams & De Latour, 1975; Gladstones & McKeown, 1977). Forage production of pink Seradella in small plot trials produced yields of up to 10.7 t/ha of dry matter on suitable sites (Taylor *et al*., 1979). The species is considered to have the ability to exploit a large soil volume because of its fibrous and deep rooting character (Gladstones & McKeown, 1977).

The performance of the above-mentioned potential cover crops were significantly affected by the availability of water (rainfall and irrigation), as well as the nutrient supply and other soil conditions. The water and nutritional needs of the cover crops, as well as optimum soil and climatic conditions should, however, be catered for within the framework of the nutritional needs of the grapevine as described by Conradie (1994). It is important, therefore, to determine the performance of these species under the edaphic conditions that prevail in the grapevine regions of South Africa.

Effect of seeding date on cover crop performance

According to Van Heerden (1984), the effects of seeding dates on the performance of a species differ between species, as well as among varieties of the same species. *Medicago* species should be sown early, as the plants will grow much better while the weather is warm (Moulds, 1986). The best time to sow in the southern hemisphere is late February to mid March, as they grow better in warm weather and have a chance to develop a sound root system before the winter cold sets in. In contrast to the *Medicago* species, *Vicia faba* L*. v. Fiord* (fababean) should be established at the end of April or the beginning of May in the winter rainfall region of the Southern and Western Cape (Lochner, 1989). Schultz *et al*. (1999), however, found that the dry matter production of fababean could be halved and that of *Vicia benghalensis* L. (narrowleaf purple vetch) reduced by 20% if sown two weeks later in autumn (12 November as opposed to 29 October) in the warm-temperate climate of Nepal, because of rapidly decreasing minimum temperatures, as well as lower maximum temperatures during late autumn. If allowed to grow for 190 days, the dry matter production (DMP) of *Vicia villosa Roth.* (hairy vetch) and 'Woogenellup' subterranean clover was the highest if sown during early May in the Western Cape, whereas *T. subterraneum* L. v. Clare ('Clare' subterranean clover), *T repens* L. v. Haifa (white clover), Snail medic, pink Seradella and *Lotus hispidus* L*. v. Campbell* (Boyds clover) produced maximally if sown during mid-April (Harris, 1986).

Cover crops in vineyards should be controlled chemically before bud break (Van Huyssteen & Van Zyl, 1984). The effect of the different growing periods resulting from this, as well as the effect of the different climatic conditions during the early growing phases on the performance of potential cover crops by the end of August (just before bud break) for the relatively colder and warmer grapevine regions are not known.

Cover crop performance if allowed to produce seed and its ability to re-establish itself

Lolium multiflorum Lam*.* (Wimmera ryegrass) sown in March, almost doubled its dry matter production from the end of August to mid November when allowed to ripen, while in the same period *Vicia sativa L.* showed an increase of only 12.5% (Van Huyssteen *et al.*, 1984). *Medicago truncatula* Gaertn. v. Paraggio ('Paraggio' medic) allowed to complete its life cycle produced on average 4.2 tons of dry matter per hectare per year over a period of four years (Sanderson, 1998). 'Paraggio' medic and *M. truncatula* Gaertn. v. Parabinga ('Parabinga' medic) re-established themselves successfully within a year if allowed to produce seed (Sanderson, 1998). Only 'Paraggio' medic, however, could do it on a continuous basis. Crawford & Nankivell (1989) reported seed losses of more than 50% in rotation experiments. According to Carter & Challis (1987) and Brahim & Smith (1993), seed reserves of 200 kg/ha are considered adequate to regenerate a productive medic pasture. Kotze *et al*. (1998) sampled *Medicago* seeds in the 0-150 mm soil layer, because of the large effect of seeding depth on regeneration reported by Carter & Challis (1987).

Despite the present preference of controlling the cover crops in vineyards before bud break, the potential of a species to re-establish itself, as well as the potential to produce more fibre if left to produce seeds under conditions prevalent in the vineyards of South Africa should be explored.

Decomposition rate of the mulch and weed control efficacy

It was found that the oat mulch had a decomposition rate slightly higher than *Triticale* and rye (De Almeida, 1985). Due to the greater quantity of residue produced, however, the quality of the mulch still exceeded that of rye and Triticale after 116 days. Studies by Van Huyssteen *et al*. (1984) and Wagner-Riddle *et al*. (1996) indicated a definite tendency for the thicker mulches to show more rapid decay than the thinner mulches, which was ascribed to the fact that the thicker mulches stayed wet for longer periods, especially the plant material in direct contact with the soil. This study also indicated that the decay of broadleaf purple vetch was more rapid than that of Wimmera ryegrass. This was attributed to the C/N ratio of broadleaf purple vetch being narrower than that of Wimmera ryegrass (Alexander, 1961). Amato *et al*. (1987) found that that legume tops decomposed more extensively than wheat straw. This could be attributed to the C/N ratio of the legumes being 13 as opposed to the 73 of the wheat straw. Higher initial N content in plant residues also enhances turnover rates of plant organic matter in soil (Christensen, 1986).

With conventional tillage crop residues are buried and the toxins (allelopathic substances) liberated, are diluted in the soil (De Almeida, 1985). In the non-tillage system they remain in the top soil layer, which contains the majority of annual weed seeds that have the potential to germinate. Post-emergence control of rye with glyphosate and leaving the residue on the surface resulted in weed densities three to eight times lower in newly planted vines than that of the treatments in which rye was mowed or cultivated, respectively (Bordelon & Weller, 1997). Crutchfield *et al*. (1985) showed that weed control improved with an increase in the quality of organic mulches. The *Avena sativa* L. (oat) mulch produced the lowest weed infestation after a period of 118 days, followed by rye (De Almeida, 1985). Although a critical dry mass could not be established, it seemed as if a mulch of 5 tons/ha for Wimmera ryegrass and eight tons/ha for *Vicia sativa* L. (broadleaf purple vetch) could be sufficient for biological weed control in an intensively irrigated vineyard (Van Huyssteen *et al*., 1984).

The cover crop species that will produce significant amounts of quality fibre for effective weed suppression during both winter and summer needs to be identified.

Effect of cover crops on grapevine performance.

Van Huyssteen & Weber (1980a) found that grape production and pruning mass was affected significantly by the soil cultivation practice applied in a non-irrigated Chenin blanc vineyard established on a medium textured soil. The use of a permanent cover crop or a naturally established permanent cover (sward) in the work row resulted in a reduction in grapevine vigour compared to grapevines grown under mulch (Van Huyssteen & Weber, 1980a; Soyer *et al*., 1984; Lombard *et al*., 1988; Pool *et al*., 1990). A permanent grass cover crop or sward also reduced the pruning weight of grapevines in comparison with grapevines in which a clover mix was used as permanent cover crop

(Ingels *et al*., 2005), in which the weeds were disked in during early spring (Van Huyssteen & Weber, 1980; Pool *et al*., 1990; Ingels *et al*., 2005) and in which full surface chemical control was applied (Van Huyssteen & Weber, 1980a; Sicher *et al*., 1995; Pinamonti *et al*., 1996). The use of a permanent cover crop or sward in the work row resulted in a significant reduction in grape yield compared to grapevines grown under other soil cultivation practices (Van Huyssteen & Weber, 1980a; Soyer *et al*., 1984; Lombard *et al*., 1988; Sicher *et al*., 1995; Pinamonti *et al*., 1996). Pool *et al*. (1990) and Ingels *et al*. (2005), however, reported no difference, whereas Anonymous (1984) reported higher yields for grapevines with a permanent cover crop in comparison with grapevines in which other soil cultivation practices were applied. Buckerfield & Webster (1996) observed that the yields of grapevines under total straw or of grapevines in which the cover crop was slashed and thrown in the vine row and controlled chemically before bud break in the work row, were significantly higher than those of grapevines in which clean cultivation was applied.

A permanent grass cover crop significantly decreased the N concentration in the leaves of young *Vitis vinifera* L. cv. Chardonnay vines compared to that of the vines in which full surface chemical control was applied to a bare soil (Tan & Crabtree, 1990; Pinamonti *et al*., 1996). Similar results were reported by Soyer *et al*. (1984), Lombard *et al*. (1988) and Sicher *et al*. (1995). The P and K concentrations in the leaves of grapevines grown under a permanent grass cover crop were significantly higher than that of grapevines grown under full surface chemical weed control or mechanical soil cultivation (Soyer *et al*., 1984; Sicher *et al*., 1995). Grapevine petiole N was significantly higher where a cover crop mix was disked in during early spring compared to grapevines in which weeds were disked in during early spring or where the cover crops were slashed (Ingels *et al*., 2005).

Soil management did not affect the soluble solids content and acidity of the grape juice at harvest (Lombard *et al*., 1988; Ingels *et al*., 2005). A straw mulch cover and full surface chemical control, however, induced a higher total titratable acid in the juice of non-irrigated Chenin blanc vines compared to vines in which a permanent cover crop was grown (Van Huyssteen, 1990). Stuck fermentation occurred for three consecutive years in the musts of non-irrigated Chenin blanc vines in which a permanent cover crop was grown in the work row. Dupuch (1997) indicated that must from a vineyard with green cover in the inter row took much longer to ferment all the sugar, compared to the must from a vineyard with no green cover. This was attributed to the musts being low in ammonium-N (Dupuch, 1997) and an N deficiency in the musts (Van Huyssteen, 1990), respectively, as a result of competition with the grapevines for nutrients during the growing season. Wine quality was affected by the bouquet being masked or denatured and the occurrence of marked bitterness and astringency to the palate in years when the competition of the grass growing in the inter rows with the grapevines was high (Maigre, 1997).

The reviewed literature indicated that a permanent grass cover crop competes with grapevines for water and nutrients. The effect of annual cover crops controlled chemically during different stages of the grapevine growing season on the performance of both young and fully grown vines, requires clarification. The growth and N contribution of cover crops depend on species, length of the growing season, climate and soil conditions (Shennan, 1992). The effect of different cover crop management practices on the ability of cover crops to contribute towards the N status of the vines must, therefore, also be clarified.

Effect of cover crops on the soil

Long-term intensive clean cultivation reduces the organic matter content of the top soil layer, promoting soil surface crusting during irrigation or rainfall, causing water runoff and erosion (Laker, 1990). A surface crust can be broken by mechanical cultivation, but may re-appear after a single irrigation (Moore *et al*., 1989). A straw mulch of five tons/ha could prevent the formation of an impermeable crust on the soil surface (Radcliffe *et al*., 1988) and significantly reduce water runoff and erosion (Khan *et al*., 1986; Roth *et al*., 1988). Louw & Bennie (1992) indicated that six to eight tons of dry matter per hectare should prevent runoff and erosion from most soils while Loch and Donnollan (1988) found that as little as 0.1 t/ha could significantly reduce erosion. Stewart & McIntyre (1997) found that the density of earthworms increased dramatically under a straw mulch compared with a soil surface kept clean mechanically or chemically. Trials have shown that the cultivation of vineyards with grass cover (temporary or permanent is a very effective method of soil structure maintenance (Van Huyssteen & Weber, 1980b, Saayman & Van Huyssteen, 1983).

A potential method for reducing nitrate leaching from agricultural soils is to replace some of the applied inorganic N with green manure cover crops, because N from the decomposing material becomes available over a longer time span than most inorganic N (Burket *et al*., 1997). Non-legume cover crops are effective in reducing nitrate leaching from the soil during winter months by absorbing large amounts of available N through their extensive root systems (McCracken *et al*., 1994). The extent of the increase of organic C and N following incorporation of cover crop residues is regulated by a combination of factors, including the amount and quality of the residues, rate and manner of application, soil type, frequency of tillage and climatic conditions (Smith *et al*., 1987).

The effect of floor management practices on the organic matter content seemed to be restricted mainly to the 0-200 mm soil layer (Sicher *et al*., 1995). According to Laker (1990) and Merwin & Styles (1994), intensive clean cultivation reduced the organic matter content of the top soil over the long term. The organic matter content of chemically clean cultivated soils showed a decrease of 5.7% over a period of six years (Merwin & Styles, 1994). After six years of applying no tillage treatments and mechanical soil cultivation on a Hernando loamy fine sand, the soil from the no-tillage treatments averaged 27% more organic matter than the mechanically cultivated treatment in the 0-150 mm soil layer (Gallaher & Ferrer, 1987). The organic matter content in grassed soil management treatments was significantly higher than that of the full surface chemical control and mechanically cultivated treatments (Sicher *et al*., 1995). Approximately 5 to 6 t/ha of plant residue is necessary to maintain the organic C level in soil (Larson *et al*., 1972; Rasmussen *et al*., 1980). A 150 mm thick straw mulch resulted in a 17% increase in organic matter in the 0 to 200 mm soil layer of a Hudson silty-clay loam with textural proportions of 7% sand, 71% silt and 22% clay and an initial organic matter content of 0.53%, over a period of six years (Merwin & Styles, 1994). Continuous winter cropping with rye resulted in a small increase of soil organic carbon (5 to 10 mg/kg) compared to the control treatment in which no cover crop was sown (Kuo *et al*., 1996). The organic matter content in the 0-100 mm soil layer of a sandy loam soil was increased from 0.54% to 0.95% over a period of four years with ‘Paraggio’ medic, if allowed to complete its life cycle and producing on average 4.2 tons of dry matter per hectare per year (Sanderson, 1998). Conradie (1994) indicated that it may not be necessary to apply fertilizer N to vineyards established on soils with a clay content of 6% or more, if the organic matter content exceeded the 1.5% level.

Dou *et al*. (1994) indicated that total N availability was strongly influenced by the tillage method applied. Under no-till a gradual increase, which lasted for approximately eight weeks after the legumes were controlled, was followed by a leveling off phase until the end of the season. The growth and N contribution of cover crops depend on the species, length of the growing season, climate and soil conditions (Shennan, 1992). Amato *et al*. (1987) observed that more N was mineralized from legume tops than from wheat straw. Van Huyssteen *et al*. (1984) found that broadleaf purple vetch had 5.86% N available for recycling compared to the 2.05% N of Wimmera ryegrass. The amount of N fixed by annual medics is closely associated with the total amount of dry matter produced (Holford, 1989; Peoples & Baldock, 2001) and, therefore, determines the N benefits to subsequent crops. Between 10% and 29% of the fixed N of temperate legumes are retained by the roots (Oke, 1967; Whiteman, 1971; Musa & Burhan, 1974; Jenkinson, 1981), indicating that the roots could also make a significant contribution towards the supply of N to subsequent crops. The N concentration of a cover crop varies with the stage of growth (Kuo *et al*., 1996), with the highest amount of N fixed by legumes occurring at the flowering stage or during pod fill (Imsande & Edwards, 1988; Imsande, 1989; Imsande & Touraine, 1994). The extent of mineralization would, therefore, also depend on the growth stage at which the cover crop was incorporated into the soil (Kuo *et al*, 1996). Raised soil nitrate levels were detected three weeks after the incorporation of ‘Paraggio’ medic into the soil, at their highest five to 11 weeks and returning to low levels at 14 weeks (Sanderson & Fitzgerald, 1999). Chemical control of the cover crop also caused an increase in soil nitrate. Although the nitrate levels were not as high in the early breakdown and release phase, nitrate was still detectable in mid-December up to a depth of 500 mm, while it was absent in the cultivated plots.

How different winter growing annual species should be managed as cover crops in the relatively cooler and warmer grapevine regions of South Africa in order to maximize soil fertility and quality whist optimizing grapevine performance needs clarification.

Aim and objectives

The aim of this study was to identify cover crop species and cover crop management practices that can be used in both young and fully grown grapevines in the cooler and warmer grapevine regions of South Africa, which may contribute towards the maintenance of soil quality and sustainable production of quality grapes in an environment friendly manner. The study had the following objectives:

- To determine the suitability of a variety of species for cover crop management in both a warmer and cooler wine grape region of South Africa.
- To determine the effect of seeding date on the performance of these species within the framework of minimum tillage practices presently applied in the vineyards of South Africa
- To determine the effect of different cover crop management practices on the performance of selected cover crop species in both a warmer and cooler wine grape region of South Africa over the medium and long term.
- To determine the effect of the selected annuals (cover crops) controlled chemically during different stages of the grapevine growing season on the performance of both young and fully grown grapevines in both a warmer and cooler wine grape region of South Africa.
- To determine the effect of different cover crop management practices on the ability of the selected cover crops to contribute towards the N status of the grapevines in both a warmer and cooler wine grape region of South Africa.
- To determine the effect of different cover crop management practices applied to selected cover crop species on the soil organic matter and macro-nutrient content of medium textured soils and sandy soils of the cooler and warmer wine grape region of South Africa, respectively.

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CHAPTER 2

Effect of seeding date on the performance of grasses and broadleaf species evaluated for cover crop management in two wine grape regions of South Africa.

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ABSTRACT

A selection of species suitable for cover crop management in the different wine grape regions is required to enable more producers to apply this environment friendly practice in a sustainable manner as part of an integrated production strategy. The effect of seeding date on the dry matter production (DMP) and weed control efficacy of seven grasses and sixteen legumes, as well as varieties of three of these species, was determined. The decomposition rate of the mulches was measured to determine the mulch persistence of the different species. In the cooler climate of Stellenbosch (Coastal region) the *Medicago* species, subterranean clovers, *Ornithopus sativa* L. v. Emena (pink Seradella) and three *Vicia* species did not compete effectively with the winter weeds if the weekly precipitation from mid-March to mid-May (autumn) exceeded 18

mm. The two oats varieties, as well as *Secale cereale* L. (rye) and *Triticale* v. Usgen 18 (triticale), however, produced more than the five tons of dry matter deemed necessary for effective cover crop management if the precipitation exceeded 18 mm per week. The DMP of all the above-mentioned species was consistent between years at the warmer and arid Lutzville (Olifants River Valley) and indicated that these species could be considered for cover crop management in this region as well, if full surface irrigation of 18 mm per week could be applied for the first 10 weeks after sowing, followed by a fortnightly irrigation of 18 mm. Seeding date had a significant effect on DMP in the Stellenbosch region and showed similar trends in Lutzville. The study showed a highly significant correlation ($r = 0.85$, $p \leq 0.0001$) between the decomposition rate of the mulches and the initial amount of dry matter present on the soil surface.

INTRODUCTION

Maintenance and improvement of soil quality is critical to sustaining agricultural productivity and environmental quality for future generations (Reeves, 1997). Consumers of agricultural products worldwide demand that both the use of chemicals and the negative impact of agricultural practices on the environment must be restricted. In addition, an increasing number of weed species are developing resistance towards a variety of herbicides used in agriculture (Anonymous, 1997; Henkes, 1997). Although certain weed species can be controlled with biological agents (Cullen *et al.*, 1973; Daniel *et al.*., 1973; Woodhead, 1981; Phatak *et al.*, 1983), the vacated niche will quickly be filled by other weed species (Putnam, 1990). Long-term intensive clean cultivation reduces the organic matter content of the top soil layer, promoting soil surface crusting during irrigation or rainfall, causing water runoff and erosion (Laker, 1990). A surface crust can be broken by mechanical cultivation, but may re-appear after a single irrigation (Moore *et al.*, 1989). In South Africa, where approximately 78 000 ha of the 101 000 ha under grapevines (Anonymous, 1999) are intensively irrigated or receive supplementary irrigation, clean cultivation does, therefore, not seem to be an environment friendly alternative to full surface chemical weed control.

A straw mulch of five t/ha could prevent the formation of an impermeable crust on the soil surface (Radcliffe *et al.*, 1988) and significantly reduce water runoff and erosion

(Khan *et al.*, 1986; Roth *et al.*, 1988). Louw and Bennie (1992) indicated that six to eight tons of dry matter per hectare should prevent runoff and erosion from most soils, while Loch & Donnollan (1988) found that as little as 0.1 t/ha could significantly reduce erosion. Crutchfield *et al*. (1985) showed that weed control improved with an increase in the quality of the organic mulch. Van Huyssteen *et al.* (1984) indicated that *Lolium multiflorum* Lam. v. Wimmera (Wimmera ryegrass) and *Vicia sativa* L. (broadleaf purple vetch) with a dry matter production (DMP) of five and eight t/ha, respectively, should prevent the establishment of summer growing weeds in an intensively irrigated vineyard. In addition to their potential as a non-specific biological method of pre-emergence weed control, cover crop mulches restrict evaporation from the soil surface (Van Huyssteen *et al.*, 1984), conserve soil moisture (Van Huyssteen & Weber, 1980a; Buckerfield & Webster, 1996), reduce temperature fluctuations in the soil (Van Huyssteen *et al.*, 1984), improve vegetative growth of a crop (Shribbs & Skroch, 1986) and increase crop production (Van Huyssteen & Weber, 1980b; Freebairn *et al.*, 1986; Buckerfield & Webster, 1996). Legume cover crops may fix up to 576 kg of N/ha/yr, depending on the species, seeding date and the period of growth allowed (Harris, 1986; Schultz *et al.*, 1999). This may become available to the grapevine during the successive growing seasons and supplement or even replace the application of inorganic N to vineyards. To achieve these advantages, a cover crop should be able to compete effectively with winter growing weeds and prevent the germination of summer growing weeds by producing enough dry matter to create effective mulch.

To restrict the build-up of soil-borne diseases, a crop rotation system is important (Lamprecht *et al.*, 1990). A variety of species should therefore be available for cover management in the vineyards of South Africa. According to Van Heerden (1984), the effect of seeding date on the performance of a species differs between species as well as among varieties of the same species. Moulds (1986) indicated that *Medicago* species should be sown as early as late February to mid-March in the southern hemisphere, as they grow better in warm weather and have a chance to develop a sound root system before the winter cold sets in. In contrast to the *Medicago* species, *V. faba* L. v. Fiord (fababean) should be established at the end of April or the beginning of May in the winter rainfall region of the Southern and Western Cape (Lochner, 1989). Schultz *et al.* (1999), however, found that the DMP of fababean could be halved and that of *V. benghalensis* L. (narrow-leaf purple vetch) reduced by 20% if sown two weeks later in autumn (12 November as opposed to 29 October) in the warm-temperate climate of Nepal, because of rapidly decreasing minimum temperatures as well as lower maximum temperatures during late autumn. If allowed to grow for 190 days, the DMP of *V. villosa* Roth (hairy vetch) and *Trifolium subterraneum* L. v. Woogenellup ('Woogenellup' subterranean clover) was the highest if sown during early May in the Western Cape, whereas *T. subterraneum* L. v. Clare ('Clare' subterranean clover), *T. repens* L. v. Haifa (white clover), *Medicago scutellata* L. v. Kelson (snail medic), *Ornithopus sativa* L. v. Emena (pink Seradella) and *Lotus hispidus* L. v. Campbell (Boyds clover) produced maximally if sown during mid-April (Harris, 1986). As the cover crops in vineyards should be controlled chemically before bud break (Van Huyssteen & Van Zyl, 1984), the available growth period up to the end of August can be as short as 118 days if sown at the beginning of May. The edaphic conditions of the regions in which deciduous fruit are produced also differ considerably from those prevalent in the grapevine regions. The above-mentioned results could, therefore, not be extrapolated to cover crop management in the different grapevine regions of South Africa.

This study was conducted to determine the suitability of a variety of species for cover crop management in both a warmer and cooler wine grape region of South Africa and to determine the effect of seeding date on the performance of these species within the framework of minimum tillage practices presently applied in the vineyards of South Africa. In doing so, guidelines for the successful application of sustainable cover crop management as part of integrated production of wine grapes, may be developed.

MATERIALS AND METHODS

The trial was conducted on a medium textured soil at the Nietvoorbij experiment farm in Stellenbosch, as well as on a sandy soil at the Nietvoorbij experiment farm in Lutzville (Table 1). The soil was analysed for pH (1.0 M KCl), P and K (Bray no. 2), exchangeable cations, namely K, Ca, Mg and Na (extracted with 0.2 M ammonium acetate) and organic matter (The Non-affiliated Soil Analysis Work Committee, 1990). The percentage total N was determined by means of a Kjeldahl digestion (Bremner, 1965). Stellenbosch (33°55'S, 18°52'E) is situated in the cooler Coastal wine grape region of South Africa, which has a relatively high annual rainfall, occurring mainly in winter, whereas Lutzville (31°35'S, 18°22'E) represents the warmer and arid Olifants

Table 1. Analyses of the medium textured soil in Stellenbosch (sampled 18 March 1991) and the sandy soil in Lutzville (sampled 24 March 1991) determined before the treatments commenced.

Locality	Soil depth (mm)	Clay (%)	Silt (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	pH (KCL)	Electrical conductivity (mS/m)	Organic C (%)	P (mg/kg)	K (mg/kg)	Exchangeable cations (cmol(+)/kg)			
												Ca	K	Mg	Na
Stellenbosch	0-300	18.65	13.31	6.16	15.62	46.26	6.7	15	0.53	11.86	105	4.66	0.68	0.27	0.04
	300-600	19.15	14.39	5.52	14.88	46.06	6.4	19	0.41	6.44	74	3.25	0.73	0.20	0.03
Lutzville	0-300	0.00	1.40	4.07	40.16	54.37	5.9	9	0.13	9.58	202	2.07	0.83	0.41	0.01
	300-600	0.00	1.28	4.82	41.23	52.67	5.8	8	0.10	4.39	240	1.95	1.66	0.57	0.42

River Valley (Table 2). The species were sown at three seeding dates in each of the two regions (Table 3). Twenty-three species, as well as varieties of three of these species, were sown at 2.5 times the seed-rates recommended for grazing crops. Seedbed preparation was done with a disc harrow approximately six weeks before each seeding date. Before sowing, the surface crust of the soil was broken with a cultivator and the seeds covered afterwards using a cultivator. The legume seeds were inoculated with a suitable Rhizobium strain just before it was sown by hand.

All the treatments received 19.5 kg of P/ha during seedbed preparation to supply in the need of especially the broadleaf species (Moulds, 1986; Wooldridge & Harris, 1987) while not exceeding the fertilizer norms for grapevines in South Africa (Conradie, 1994). The grass species received 28 kg of N/ha at the two to four leaf stage as proposed by Van Huyssteen & Van Zyl (1984). An irrigation of 18 mm per week was applied with overhead sprinklers up to 10 weeks after seeding. This was followed by an irrigation of 18 mm every fortnight until chemical control was applied at the end of August. Rainfall that occurred during this period was subtracted from the amount of irrigation that was to be applied. The DMP of both the cover crops and the associated winter growing weeds was determined at the end of August, before post-emergence chemical control was applied. DMP was estimated from a sample by harvesting the above-ground vegetative growth in a 0.5 m^2 sub-plot randomly chosen in the experimental plot. Samples were oven-dried for 48 hours at 105°C. The potential of the cover crop mulches to control summer growing weeds was determined by measuring the weed dry matter at the end of November and end of January. To determine the decomposition rate of the cover crop residue from the end of August to the end of January, five of the fifteen replications (five replications x three seeding dates) in which the percentage contribution of the cover crop to the mulch was the highest, were selected. The rate was calculated for each cover crop and expressed as the slope of the decline in dry matter over time, as determined at the end of August, end of November and end of January.

Statistical procedures

The experimental design was a randomized complete block design. The treatment layout was a split-plot design with seeding date the main factor and species the sub-factor. Each treatment was replicated five times. The experiment was repeated for two

Table 2. The average daily temperature and monthly rainfall for Stellenbosch and Lutzville as measured from March 1991 to February 1993.

	Average daily temperature (°C)						Total monthly rainfall (mm)					
	Stellenbosch			Lutzville			Stellenbosch			Lutzville		
Month	1991	1992	1993	1991	1992	1993	1991	1992	1993	1991	1992	1993
January		21.4	21.9		22.0	22.9		2.3	8.5		0.0	0.0
February		21.8	21.0		22.1	21.7		45.5	42.7		1.5	4.0
March	21.9	21.3		23.2	21.8		15.4	25.1		0.0	0.0	
April	18.8	17.0		20.3	18.8		38.7	87.0		6.2	8.0	
May	16.6	14.3		18.0	16.2		128.0	70.4		4.5	3.7	
June	13.4	12.7		15.1	14.8		212.4	221.1		19.9	11.2	
July	12.7	12.7		14.8	14.5		230.3	114.7		41.4	16.2	
August	11.8	12.9		13.6	14.8		51.2	77.5		4.2	13.5	
September	14.3	13.9		16.2	15.9		117.5	63.1		19.3	5.9	
October	17.2	16.7		17.8	18.4		47.3	94.0		36.4	28.1	
November	18.4	19.2		19.0	20.5		13.6	16.4		0.0	0.7	
December	20.4	19.8		20.6	20.5		14.9	6.2		0.4	0.0	

Table 3. The effect of seeding date on the dry matter production (DMP) of cover crops, determined at the end of August 1991 and 1992 at Stellenbosch.

Species	Sowing density (kg/ha)	DMP (t/ha)					
		Seeding date: 19-22 March		Seeding date: 1-9 April		Seeding date: 2-5 May	
		1991[1]	1992[2]	1991[1]	1992[2]	1991[1]	1992[2]
N-fixing broadleaf species:							
Trifolium subterraneum L. v. Trikkala	35	0.58	1.03	4.15	1.55	2.87	3.08
Trifolium subterraneum L. v. Woogenellup	35	5.21	1.29	3.32	3.03	2.45	1.71
Trifolium subterraneum L. v. Clare	35	2.66	2.25	2.61	1.96	2.88	2.41
Trifolium subterraneum L. v. Mount Baker	35	2.26	0.18	3.08	0.24	4.05	1.15
Trifolium repens L. v. Haifa	12	1.12	0.02	1.22	0.09	0.75	0.61
Trifolium resupinatum L.v. Maral	16	2.14	0.43	2.85	0.67	1.41	0.79
Trifolium hirtum L. v. Kondinin	16	2.81	1.51	2.61	1.49	1.11	1.14
Trifolium balansae L. v. Patrick	4	0.23	0.05	0.00	0.10	0.77	0.14
Trifolium vesiculosum L.v. Zulu	16	3.15	0.54	1.02	0.72	0.68	0.35
Trifolium fragiferum L. v. Palestine	12	0.75	0.00	0.51	0.34	0.24	0.14
Lotus hispidus L. v. Campbell	10	0.46	0.73	0.38	1.68	0.25	1.18
Lotus corniculatus L. v. SOA Gabriel	12	0.02	0.37	0.04	0.25	0.02	0.04
Medicago truncatula Gaertn. v. Paraggio	25	6.62	0.42	4.42	3.27	4.20	1.37
Medicago truncatula Gaertn. v. Parabinga	25	5.19	0.64	5.09	3.66	3.99	2.28
Medicago scutellata L. v. Kelson	25	5.09	0.49	4.70	3.76	4.48	1.30
Medicago littoralis L. v. Harbinger	25	5.13	1.00	3.43	0.72	3.11	0.59
Ornithopus sativa L. v. Emena	25	5.77	1.51	4.57	1.22	2.09	1.56
Vicia faba L. v. Fiord	120	7.24	4.83	7.46	6.10	5.39	2.40
Vicia dasycarpa Ten	50	4.38	3.65	3.55	2.95	3.56	2.11
Vicia sativa L. v. Lima	50	4.94	1.95	4.41	0.78	2.73	1.07
Grasses:							
Lolium multiflorum Lam. v. Energa	40	0.92	3.12	0.81	2.84	0.62	1.38
Lolium multiflorum Lam. v. Midmar	40	0.76	2.84	1.23	1.88	0.74	1.08
Lolium perenne L. v. Nui	40	0.97	2.00	0.79	2.76	0.44	0.44
Phalaris aquatica L. v. Sirosa	25	1.31	2.33	0.42	2.98	0.59	1.15
Avena sativa L. v. Overberg	100	0.78	5.69	1.02	8.88	0.78	1.90
Avena strigosa v. Saia L.	100	2.92	8.90	2.64	8.39	3.09	2.88
Secale cereale L.	100	2.26	4.77	2.88	6.30	2.28	2.95
Triticale v. Usgen 18	100	0.73	4.60	1.18	5.55	1.59	3.79
Hordeum vulgare L.	100	0.75	2.72	1.35	4.70	0.65	1.60
Control (natural weeds)	-	1.85	4.05	1.48	3.68	0.88	2.02
LSD ($p \leq 0.05$)		1.30	1.41	1.30	1.41	1.30	1.41

1. LSD ($p \leq 0.05$) applicable to 1991 data over seeding dates = 1.34
2. LSD ($p \leq 0.05$) applicable to 1992 data over seeding dates = 1.48

successive seasons or (years) and fully randomized between seasons. The size of each experimental unit (plot) was 21 m^2. All variables were measured at random sites within each experimental unit at the end of August, end of November and end of January. Standard split-plot analyses of variance were performed for each season separately, using Genstat 5 release 1.2 and SAS (SAS, 1990). Student's *t*-test was used to test for significant differences between treatment means. The residual variances of each season were tested for comparable precision using Barlett's test (John & Quenouille, 1977). These tests showed that the Lutzville results of the two seasons were of comparable accuracy ($p > 0.05$). Therefore a combined analysis of variance was performed on the Lutzville data. The Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). For each experimental unit a linear regression was fitted for the decomposition rate over the three measuring dates and the coefficients subjected to a completely randomised analysis of variance with twenty-nine treatments and five replications. Correlation analysis was performed between the slopes and the initial DMP.

RESULTS AND DISCUSSION

Dry matter production of cover crops and weed control

Stellenbosch

The difference in the climatic conditions between 1991 and 1992 as measured from March to August in the Stellenbosch region (Table 2) greatly affected both the DMP (Table 3) and weed control efficacy (Table 4) of the species. The effect of seeding date on the DMP (Table 3) and the weed control efficacy (Table 4) of these species varied between species and even between varieties of a species. Seeding date and the difference in climate between the two years (Table 2) had a significant effect on the growth of the weeds in the control as well (Table 4). The soil cultivation during seedbed preparation and during covering of the seeds in May, as well as the shorter growing period from May to August, reduced the weed stand in the control significantly in both years compared to the weed stand in the treatments in which soil cultivation was done during March.

Table 4. The effect of seeding date and cover crops on weed dry matter production (DMP) per hectare, determined at the end of August 1991 and 1992 at Stellenbosch.

Species	DMP (t/ha)					
	Seeding date: 19-22 March		Seeding date: 1-9 April		Seeding date: 2-5 May	
	1991[1]	1992[2]	1991[1]	1992[2]	1991[1]	1992[2]
N-fixing broadleaf species:						
Trifolium subterraneum L. v. Trikkala	2.19	3.71	0.55	2.24	0.41	0.64
Trifolium subterraneum L. v. Woogenellup	0.34	4.09	0.81	0.89	0.63	0.95
Trifolium subterraneum L. v. Clare	1.02	3.05	1.03	2.51	0.21	0.54
Trifolium subterraneum L. v. Mount Baker	1.51	3.73	1.28	2.84	0.27	1.54
Trifolium repens L. v. Haifa	1.30	4.61	1.23	2.63	0.95	1.32
Trifolium resupinatum L.v. Maral	1.16	3.35	0.50	2.37	1.85	1.73
Trifolium hirtum L. v. Kondinin	1.52	3.12	1.30	2.60	1.42	2.13
Trifolium balansae L. v. Patrick	2.43	3.50	1.55	3.04	1.04	1.93
Trifolium vesiculosum L.v. Zulu	1.24	3.64	1.14	2.48	1.31	2.27
Trifolium fragiferum L. v. Palestine	1.50	3.84	1.98	2.94	1.38	2.17
Lotus hispidus L. v. Campbell	2.21	3.29	1.80	2.77	1.44	1.27
Lotus corniculatus L. v. SOA Gabriel	1.59	3.57	1.74	2.77	0.88	1.22
Medicago truncatula Gaertn. v. Paraggio	0.17	5.09	0.24	0.66	0.23	1.18
Medicago truncatula Gaertn. v. Parabinga	0.22	4.10	0.18	0.88	0.47	1.79
Medicago scutellata L. v. Kelson	0.20	3.77	0.99	1.07	0.35	1.29
Medicago littoralis L. v. Harbinger	0.10	4.78	0.86	2.98	0.23	0.92
Ornithopus sativa L. v. Emena	0.48	3.59	0.55	2.87	1.64	1.64
Vicia faba L. v. Fiord	0.77	2.37	0.84	0.84	0.71	0.93
Vicia dasycarpa Ten	0.13	2.56	0.22	1.22	0.10	0.84
Vicia sativa L. v. Lima	0.35	3.52	0.39	2.67	0.24	0.96
Grasses:						
Lolium multiflorum Lam. v. Energa	0.90	0.65	0.67	0.16	0.42	0.14
Lolium multiflorum Lam. v. Midmar	0.84	0.43	0.61	1.57	0.52	0.81
Lolium perenne L. v. Nui	1.10	1.71	0.90	0.17	0.90	1.17
Phalaris aquatica L. v. Sirosa	0.39	1.61	1.14	0.24	0.59	0.80
Avena sativa L. v. Overberg	2.39	0.17	1.38	0.02	0.68	0.47
Avena strigosa v. Saia L.	1.36	0.00	0.74	0.06	0.39	0.07
Secale cereale L.	0.56	0.50	1.06	0.19	0.42	0.08
Triticale v. Usgen 18	1.95	0.87	1.00	0.51	0.74	0.26
Hordeum vulgare L.	1.66	2.23	1.38	0.12	0.87	0.82
Control (natural weeds)	1.85	4.05	1.48	3.48	0.88	2.02
LSD ($p \leq 0.05$)	0.41	1.29	0.41	1.29	0.41	1.29

1. LSD ($p \leq 0.05$) applicable to 1991 data over seeding dates = 0.89
2. LSD ($p \leq 0.05$) applicable to 1992 data over seeding dates = 1.33

Broadleaf species

Comparing the *Trifolium* and *Lotus* species to the control, only the four subterranean clover varieties, *T. resupinatum* L. v. Maral (Persian clover) and *T. vesiculosum* L. v. Zulu (Assegaai clover) produced sufficient amounts of vegetative growth to suppress the winter growing weeds significantly (Table 4). This was only true for the 1991 season and not necessarily for all seeding dates. The higher rainfall during March and April 1992 compared to that of 1991 (Table 2) seemed to benefit the winter growing weeds of this region (Table 5) more than it did the *Trifolium* species, resulting in reduced vegetative growth (Table 3) and poor control of the winter growing weeds by these species (Table 4). 'Woogenellup' subterranean clover, however, suppressed the winter growing weeds significantly in 1992 if sown during the first week of April. A similar result was achieved with 'Clare' subterranean clover and *T. subterraneum* L. v. Trikkala ('Trikkala' subterranean clover) sown during the first week of May. The cooler climate from mid-April to the end of May compared to that from mid-March to mid-April (Table 2) might have retarded the initial growth of the weeds that germinated later than mid-April. This could have enabled 'Woogenellup', 'Clare' and 'Trikkala' subterranean clovers to gain a competitive advantage, resulting in a more consistent DMP between years. It seems that 'Woogenellup' subterranean clover could tolerate the warmer climatic conditions during its initial growing stages and benefit from the longer growing period if sown during early autumn. This is illustrated by a significantly higher DMP of 5.21 t/ha during 1991, if sown during the third week of March compared to the first week of April or May (Table 3). The higher rainfall in March 1992 compared to March 1991 (Table 2), however, caused the weeds to proliferate and outgrow this subterranean clover (Table 3). This variation in climate between years makes it risky to establish 'Woogenellup' subterranean clover during March in the Coastal region. Both seeding date and the variation in climate between years had no significant effect on the DMP of 'Clare' subterranean clover. The level of weed control (Table 4), as well as the amount of dry matter produced despite the shorter growing period (Table 3), indicated that 'Clare' subterranean clover should be established during the first week of May in this region. This corresponds to the results of Harris (1986). Although the DMP (Table 3) and weed control efficacy (Table 4) varied considerably between the two seasons, results indicated that 'Trikkala' subterranean clover should also be established during the first week of May. The DMP and weed control efficacy of the other clover species were erratic.

These species should, therefore, not be considered for cover crop management in this region.

Seeding date had a significant effect on the vegetative growth of the *Medicago* species, depending on the climatic variation and the resulting differences in weed growth between the two seasons (Table 3). Similar to the subterranean clovers, these species did not suppress the winter growing weeds during the cooler and wetter autumn of 1992, if sown during the third week of March (Table 4). *M. littoralis* L. v. Harbinger ('Harbinger' medic) did not suppress the winter growing weeds significantly in 1992, irrespective of seeding date. This resulted in poor DMP by the species (Table 3). Similar to 'Woogenellup' subterranean clover, the DMP of the two *M. truncatula* varieties and snail medic seemed to be more consistent if sown during the first week of April. The *Medicago* species suppressed the winter growing weeds effectively (less than 20% of the weed stand in the control) if DMP exceeded five t/ha.

The effect of seeding date on the vegetative growth of the three *Vicia* species and pink Seradella varied between the two seasons (Table 3). Although *V. dasycarpa* Ten (grazing vetch) gave effective weed control during 1991, if sown during the first week of May, results indicated that these species should not be sown after the first week of April in the Stellenbosch region (Table 4). Fababean and grazing vetch suppressed the winter growing weeds significantly during both seasons if sown during late March or early April. The DMP of pink Seradella and *V. sativa* L. v. Lima (broadleaf purple vetch) measured in 1992, indicated that these species were suppressed by the proliferous winter growing weeds during this season, irrespective of seeding date (Table 3). Despite the fact that the vegetative growth of grazing vetch was less (mostly significantly less) than that of fababean (Table 3), weed control efficacy achieved was similar or even significantly better than that of fababean (Table 4). The superior weed control achieved with grazing vetch is attributed to the dense, creeping and prostrate habitus which created a dense growing mulch. In contrast, fababean has an erect habitus which did not cover the soil surface as effectively, allowing more weeds to germinate.

Grasses

In contrast to the broadleaf species, the DMP of the grass species was, with the exception of *L. multiflorum* Lam. v. Midmar (Midmar ryegrass) sown during the first week of April, much higher in 1992 than in 1991, if sown before the second week of April (Table 3). The poor DMP of the grass species in 1991 indicated that irrigation or rainfall of more than 18 mm per week during March and April is necessary to ensure maximal growth before the onset of the colder winter months. Despite the fact that the winter weeds present in the region (Table 5) proliferated under these conditions, the grasses were able to suppress them effectively (Table 4). The root system of Italian ryegrass can reach a depth of approximately one metre (Steynberg *et al.*, 1994). It seems, therefore, that the root system of the grasses might have developed quicker and more extensively during the initial growing stages than that of the winter growing weeds, enabling them to benefit from water present in the deeper soil layers during 1992. Seeding date also had a significant effect on the DMP of the grass species, as indicated by the 1992 data (Table 3). The absence of similar tendencies in 1991 can be attributed to poor vegetative growth eliminating the effect that seeding date might have had on the performance of these grasses. The DMP in 1992 indicated that the grass species should be sown before the second week of April. *Secale cereale* L. (rye), the perennial *L. perenne* L. v. Nui (perennial ryegrass) and *Hordeum vulgare* L (barley), however, produced significantly more dry matter if established during the first week of April rather than during the third week of March. Although *Avena strigosa* L. v. Saia ('Saia' oats), rye and *Triticale* v. Usgen 18 (triticale) produced significantly less dry matter if sown during the first week of May compared to the DMP if sown during the first week of April (Table 3), the winter weeds were still controlled effectively (Table 4). This illustrated that effective winter weed control realised as a result of both the amount of vegetative growth from the cover crop and seeding date (mechanical weed control during seedbed preparation). At each of the seeding dates significantly less vegetative growth (Table 3) was necessary in the case of the *Lolium* species and *Phalaris aquatica* L. v. Sirosa (Phalaris grass) than in the case of the five grain species to suppress the winter growing weeds effectively (Table 4). This could be attributed to the densely tufted habitus of the first-mentioned species.

The DMP of summer weeds measured at the end of November and end of January was very low in all plots, indicating that few weeds germinated in the trial site during this period of the study (data not shown). The ability of the different mulches to control the summer growing weeds of the region could, therefore, not be evaluated.

Table 5. The spectrum of weeds found at the trial sites in Stellenbosch and Lutzville.

Weed species		Trial site				Strong
Specific name	Common name	Stellenbosch[2]	Lutzville[2]	Habitus	Root system	competitor[3]
Arctotheca calendula L.	Cape marigold	*	*	caulescent	tap root	N
Bidens bipinnata L.	Spanish blackjack	-	*	erect	stout tap root	Y
Chenopodium album L.	White goosefoot	*	*	erect	stout tap root	Y
Echium plantagineum L.	Purple Echium	*	-	erect	stout tap root	Y
Ehrharta longiflora J.E. Sm.	Oat-seed grass	*	-	erect	adventitious	N
Emex australis Steinh.	Spiny Emex	*[1]	*	prostrate to semi-erect	stout tap root	N
*Eragrostis cilianensis (*All). Lutati	Stink lovegrass	-	*	erect	adventitious	N
Erodium moschatum (L) L'Herit ex ait	Musk herons bill	*	-	erect to procumbent	stout tap root	Y
Hypochoeris radicata L.	Hairy wild lettuce	*	-	spreading basal rosette	thick fleshy rootstock	Y
Lactuca serriola L.	Wild lettuce	*	-	erect	tap root	N
Oxalis pes-caprae L.	Yellow sorrel	*	-	erect	vertical rhizomes	N
Paspalum dilatatum Pior.	Common paspalum	*	*[1]	tufted	adventitious	Y
Picris echioides L.	Bristly ox-tongue	*	-	erect	stout tap root	Y
Plantago lanceolata L.	Narrow-leaved ribwort	*	-	erect	big rootstocks	Y
Raphanus raphanistrum L.	Wild radish	*	*	erect	stout tap root	Y
Sonchus oleraceus (L.) Hill	Sow thistle	*[1]	*[1]	erect	stout tap root	N
Scenecio arenarius L.	Purple daisy	-	*	erect	tap root	N
Dimorphoteca pluvialis L.	White daisy	-	*	erect	tap root	N

1. Represented less than 5% of the total weeds spectrum.
2. Species present at the trial site are marked with a *.
3. Classified according to Grabandt (1985).

Although Van Huyssteen *et al.* (1984) could not establish the critical dry mass necessary for effective control of summer growing weeds, a DMP of five t/ha was suggested for Wimmera ryegrass and eight t/ha for vetch. Louw & Bennie (1992) indicated that six to eight tons of dry matter per hectare should prevent water runoff. Taking these norms, as well as the ability of the species to suppress the winter growing weeds significantly into account, 'Saia' oats, *A. sativa* L. v. Overberg ('Overberg' oats), rye and triticale should be considered for cover crop management on medium textured soils in the Coastal region. All the broadleaf species, except fababean and *M. truncatula* Gaertn. L. v. Paraggio ('Paraggio' medic), did not produce the amounts of dry matter suggested by Van Huyssteen *et al.* (1984) and Louw & Bennie (1992) to be necessary for effective weed control and reduction of water runoff. Some broadleaf species, however, showed the ability to suppress the winter weeds significantly and produce significantly more dry matter than the winter weeds of this region. Fababean, the four Medicago species, the two vetch species, pink Seradella, as well as three of the subterranean clovers ('Woogenellup', 'Clare' and 'Trikkala'), should, therefore, be included in further studies to determine if the norm of eight t/ha is applicable to these species under different edaphic conditions.

Lutzville

The results of the 1991 and 1992 seasons were statistically of comparable accuracy. The average DMP of the cover crop species and weeds for 1991 and 1992 are therefore presented in Table 6.

Broadleaf species

The DMP of the clover species (Table 6) generally exceeded that produced in the Stellenbosch region (Table 3), indicating that the clover species did benefit from the warmer climatic conditions that prevailed in Lutzville throughout the winter (Table 2). The effect of seeding date on the performance of the subterranean clovers seemed to be similar for both regions (Tables 3 and 6). *T. subterraneum* L. v. Mount Barker ('Mount Barker' subterranean clover) should, however, be sown at the end of March in this region (Table 6) as opposed to the first week of May in Stellenbosch (Table 3). In contrast to the results of Stellenbosch (Table 3), 'Mount Barker' subterranean clover significantly suppressed the winter growing weeds in Lutzville that germinated late March / early April

Table 6. The effect of seeding date on the average dry matter production (DMP) of the cover crops and weeds determined at the end of August 1991 and 1992 at Lutzville.

Species	DMP (t/ha)					
	Seeding date: 25-31 March		Seeding date: 13-18 April		Seeding date: 6-12 May	
	Cover crop[1]	Weeds[2]	Cover crop[1]	Weeds[2]	Cover crop[1]	Weeds[2]
N-fixing broadleaf species:						
Trifolium subterraneum L. v. Trikkala	4.14	1.98	4.67	0.78	2.26	0.73
Trifolium subterranheum L. v. Woogenellup	5.19	0.87	5.39	0.44	2.77	0.87
Trifolium subterraneum L. v. Clare	5.02	1.28	4.26	0.84	3.64	0.46
Trifolium subterraneum L. v. Mount Baker	5.54	1.26	3.99	0.54	3.17	0.36
Trifolium repens L. v. Haifa	1.48	1.88	1.79	1.70	0.68	1.07
Trifolium resupinatum L.v. Maral	3.46	0.97	3.30	0.89	2.55	0.29
Trifolium hirtum L. v. Kondinin	4.43	0.78	4.50	0.72	0.90	0.73
Trifolium balansae L. v. Patrick	3.49	1.56	1.80	2.07	0.98	0.72
Trifolium vesiculosum L.v. Zulu	3.91	1.68	2.90	1.44	2.03	0.48
Trifolium fragiferum L. v. Palestine	1.25	1.75	1.05	1.45	0.59	0.69
Lotus hispidus L. v. Campbell	0.38	2.85	0.76	1.80	0.64	0.89
Lotus corniculatus L. v. SOA Gabriel	0.92	3.30	0.95	2.01	0.14	1.42
Medicago truncatula Gaertn. v. Paraggio	6.58	0.69	5.25	0.82	5.10	0.36
Medicago truncatula Gaertn. v. Parabinga	5.94	0.72	4.74	0.68	4.63	0.46
Medicago scutellata L. v. Kelson	4.47	1.57	3.83	0.94	3.21	0.26
Medicago littoralis L. v. Harbinger	5.54	0.91	4.58	0.44	4.61	0.40
Ornithopus sativa L. v. Emena	6.09	1.29	6.40	0.37	4.63	0.70
Vicia faba L. v. Fiord	4.27	1.87	4.45	1.21	2.89	0.52
Vicia dasycarpa Ten	5.96	0.17	6.73	0.10	4.49	0.16
Vicia sativa L. v. Lima	4.82	0.58	3.53	1.40	2.82	0.42
Grasses:						
Lolium multiflorum Lam. v. Energa	2.83	1.12	2.34	1.34	2.38	0.41
Lolium multiflorum Lam. v. Midmar	2.23	1.05	3.26	0.75	2.48	0.55
Lolium perenne L. v. Nui	2.45	1.55	2.04	1.10	2.20	0.45
Phalaris aquatica L. v. Sirosa	1.78	1.68	1.60	1.45	0.79	0.66
Avenasativa L. v. Overberg	4.78	0.93	5.08	0.34	3.30	0.52
Avena strigosa v. Saia L.	4.97	0.43	5.85	0.24	4.07	0.20
Secale cereale L.	5.08	0.50	5.92	0.33	4.72	0.08
Triticale v. Usgen 18	4.50	0.37	5.00	0.42	5.54	0.35
Hordeum vulgare L.	3.68	1.05	4.22	0.86	3.40	0.39
Control (natural weeds)	3.00	3.00	1.88	1.88	1.12	1.12
LSD ($p \leq 0.05$)	1.13	0.93	1.13	0.93	1.13	0.93

1. LSD ($p \leq 0.05$) applicable to cover crop data over seeding dates = 1.28
2. LSD ($p \leq 0.05$) applicable to weeds data over seeding dates = 0.98

(Table 6). This could be attributed to less competitive weed species growing at this trial site (30% of total spectrum) compared to Stellenbosch (66% of total spectrum), as shown in Table 5. From the results it became clear that the subterranean clovers, *T. hirtum* L. v. Kondinin (Rose clover) and Persian clover should be sown before the fourth week of April, while the other clover species should be sown during the last week of March (Table 6). Although most of the *Trifolium* species showed the ability to suppress the winter growing weeds significantly, preference should be given to the four subterranean clover varieties as cover crops for this region, because the DMP of these species was significantly higher than that of the winter growing weeds in the control, irrespective of seeding date.

The DMP of the *Medicago* species (Table 6) was similar to that produced in 1991 in Stellenbosch (Table 3). Although only the DMP of Paraggio medic differed significantly between seeding dates, all the *Medicago* species produced the highest amount of dry matter if sown during the last week of March. These species also seemed to grow well in the warmer winter climate of this region. Similar to most of the *Trifolium* species, the *Medicago* species suppressed the winter growing weeds significantly if sown before the fourth week of April. The DMP of the *Medicago* species was, irrespective of seeding date, significantly higher than that of the winter growing weeds. All the *Medicago* species should, therefore, be considered for cover crop management in this region, although only 'Paraggio' medic produced the six to eight tons of dry matter deemed necessary by Louw & Bennie (1992) to effectively reduce water runoff in all vineyard soils.

Comparing the DMP (Tables 3 and 6), grazing vetch, broadleaf purple vetch and pink Seradella seemed to be better adapted to both the warmer climate (Table 2) and sandy soil (Table 1) in Lutzville than fababean. Because grazing vetch and pink Seradella suppressed the winter growing weeds effectively and produced more than six tons of dry matter per hectare if sown during mid-April and before the fourth week of April, respectively, these two species should be considered for cover crop management in this region.

Grasses

The grass species, with the exception of the two oats varieties, did not respond significantly to seeding data (Table 6). This absence in response is probably due to the warmer winter climate (Table 2), weed species being less competitive (Table 5), and the poor rainfall (Table 2) at Lutzville, compared to Stellenbosch. Results, however, indicated that the *Avena*, *Secale* and *Hordeum* species should preferably be established in the third week of April to maximize DMP (Table 6). The DMP of triticale was maximized when sown during the first week of May, indicating that it preferred cooler climatic conditions during its initial growing stages. The three *Lolium* species and Phalaris grass suppressed the winter growing weeds significantly if sown during the last week of March. A significant reduction in the stand of winter growing weeds was achieved if the five grain species were sown before the fourth week of April. 'Saia' oats and rye however, suppressed the winter growing weeds effectively irrespective of seeding date. *Triticale* and 'Overberg' oats also controlled the winter growing weeds effectively if sown during the last week of March and the third week of April, respectively. The *Avena*, *Secale* and *Triticale* species produced more than five tons of dry matter per hectare and should therefore be considered for cover crop management on the sandy soils of the warm and arid Olifants River Valley.

The DMP of the summer growing weeds measured in the control plots at the end of November and end of January was insignificant in all the plots, indicating that few weeds germinated in the trial during this period of the study (data not shown). The ability of the different mulches to control the summer growing weeds of this region could, therefore, not be evaluated.

Decomposition rate of the different mulches

The decomposition rate differed significantly between species, years and experimental sites (data not shown). Although the summer rainfall in Lutzville was higher in 1991 than in 1992 (Table 2), the decomposition rate of different groups of species, namely the subterranean clovers, the *Trifolium* species, the *Medicago* species, the *Lolium* and *Phalaris* species, as well as the *Vicia* species and pink Seradella, was higher in 1992 than in 1991 (Table 7). The decomposition rate of the different groups of species also varied quite substantially between years at the Stellenbosch experimental site, despite

Table 7. The decomposition rate and dry matter production (DMP) of the different cover crop groups measured at both Stellenbosch and Lutzville during 1991 and 1992.

Group of species	Stellenbosch				Lutzville			
	Decomposition rate in t/ha/month		DMP in t/ha		Decomposition rate in t/ha/month		DMP in t/ha	
	1991[1]	1992[1]	1991[2]	1992[2]	1991[1]	1992[1]	1991[2]	1992[2]
Trifolium subterraneum varieties	0.99	1.44	5.70	6.06	0.96	2.14	5.58	9.06
Trifolium species	1.02	1.52	4.94	5.56	0.79	1.36	3.48	5.80
Medicago species	1.44	0.80	7.28	4.78	1.25	2.09	6.84	8.64
Vicia species and *Ornithopus sativa* v. Emena	1.32	1.48	7.42	7.04	1.12	1.42	6.18	7.82
Lolium species and *Phalaris aquatica* v. Sirosa	0.41	0.96	2.10	4.86	0.75	1.17	4.14	4.66
Grain species	0.84	0.54	4.08	8.18	1.24	0.76	7.84	5.22
Correlation between decomposition rate and DMP	$r = 0.85, p \leq 0.0001$							

1. Measured over a five-month period from September to January.
2. Measured at the end of August

the edaphic conditions during summer being more or less similar for both years (Table 2). A significant positive correlation was, however, found between decomposition rate and the amount of dry matter present on the soil surface at the beginning of the summer (end of August), as shown in Table 7.

CONCLUSIONS

Taking both the ability of the grass species to suppress the winter growing weeds and produce the five tons of dry matter deemed necessary to control the summer growing weeds into account, ‘Saia’ oats, ‘Overberg’ oats, rye and triticale should be considered for cover crop management in the vineyards of both the Coastal region and the Olifants River Valley. In the cooler climate of Stellenbosch (Coastal region) these crops need more than 18 mm of irrigation or rainfall per week from March to May to match these criteria. In contrast to this, weekly irrigation or rainfall of 18 mm up to 10 weeks after seeding, followed by fortnightly irrigations of 18 mm enabled these species to produce the necessary dry matter in the warmer and arid Lutzville area (Olifants River Valley). None of the broadleaf species could produce more than the minimum norm of eight tons of dry matter suggested to be necessary for effective summer weed control by a broadleaf species. In Stellenbosch, rainfall in excess of 18 mm per week from mid-March to mid-May caused the weeds to outgrow the N-fixing broadleaf species, making it risky in the short-term to use these species as cover crops in this region. Less variation in the climate between years in the warm and arid Olifants River Valley caused the level of DMP of the above-mentioned broadleaf species to be more consistent from year to year. These species, except fababean, seemed to be well adapted to the warmer climate of this region as well as the sandy soil of the trial site. In addition, these broadleaf species have the ability to fix nitrogen and the *Medicago* species, subterranean clovers, pink Seradella, fababean and two vetches should, as a potential supplier of nitrogen to the vine, be considered for cover crop management in vineyards established on sandy, low organic C soils in these regions.

In this study, DMP response of different species and varieties to seeding date differed at both experimental sites, making it very risky to extrapolate these results to new species of the genera or even new varieties of the same species.

Decomposition rate of the different mulches during summer showed a significant correlation with the initial amount of dry matter present on the soil surface.

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CHAPTER 3

Cover crop management in a Sauvignon blanc/Ramsey vineyard in the semi-arid Olifants River Valley, South Africa. 1. Effect of management practices on selected grass and broadleaf species.

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ABSTRACT

The trial was conducted over a period of ten years on a sandy soil in a Sauvignon blanc/Ramsey vineyard in Lutzville (31^{o}35'S, 18^{o}52'E), situated in the semi-arid Olifants River Valley of the Western Cape. Twenty three treatments were applied. Eight cover crop species that received the same amount of fertiliser were controlled chemically at the end of August or at the end of November. Two treatments in which *Avena sativa* L. v. Saia ('Saia' oats) and *Vicia dasycarpa* Ten. (grazing vetch) were controlled mechanically

during bud break were applied as well. In addition to these eighteen treatments, two fertiliser application rates were applied to 'Saia' oats and grazing vetch. A mechanically cultivated control in which no cover crop was sown, was included in the trial. *Secale cereale* L v. Henog and *Ornithopus sativus* L. v. Emena produced, on average, the highest amount of dry matter at the end of August (3.29 t/ha and 3.06 t/ha, respectively), receiving on average 278 mm of water of which 172 mm was supplied by means of a micro-sprinkler irrigation system. The average dry matter produced by *Medicago truncatula* Gaertn. v. Paraggio and 'Saia' oats at the end of August was not significantly lower than that of the first-mentioned two species. Under conditions of this experiment, it seemed that P and K at a concentration of 10 mg/kg and 78 mg/kg, respectively, in the top 300 mm soil layer, supplied the needs of grazing vetch. Saia oats performed poorly unless 30 kg of P, 30 kg of K and 42 kg of N were applied during establishment and early growing phase. All the species, except *M. truncatula* Gaertn v. Parabinga, produced additional fibre from September to the end of November following a dry winter (rain and irrigation applied totaling 201 mm), while none produced additional fibre if the water supply was luxurious up to the end of August (rain and irrigation applied totaling 364 mm).

The cover crops did not produce enough seeds to re-establish successfully over a period of five years. It will, however, be possible to reduce the seeding density of grazing vetch (40% after two seasons) and the two *M. truncatula* varieties (20% after five seasons) if the species were left to ripen their seeds.

INTRODUCTION

The use of cover crops in vineyards has many advantages, *inter alia* reduction of water runoff and erosion (Louw & Bennie, 1992), restriction of evaporation from the soil surface (Van Huyssteen *et al*., 1984), soil water conservation (Buckerfield & Webster, 1996) reduction of temperature fluctuations in the soil (Van Huyssteen *et al*., 1984), as well as being a non-specific method of weed control (Van Huyssteen *et al*., 1984; Fourie *et al*., 2001). A selection of species suitable as cover crops in the different grapevine regions is required to enable producers to apply this environment friendly practice in a sustainable manner, as part of an integrated production strategy (Fourie *et al*., 2001). Fourie *et al*. (2001) indicated that four grain species, four subterranean clover species, four *Medicago* (medic) species, three *Vicia* (vetch) species and *Ornitopus sativus* L. v. Emena (pink Seradella) could be considered as cover crops on the sandy soils of the warm and semi-arid Olifants River Valley in the Winter Rainfall region of South Africa.

This study was conducted to determine the effect of different cover crop management practices on eight selected cover crop species on a sandy soil in the Olifants River Valley. This was done to supply guidelines for sustainable cover crop management in vineyards on the sandy soils of the semi-arid Olifants River Valley.

MATERIALS AND METHODS

Experiment vineyard

The trial was conducted in a Sauvignon blanc/Ramsey vineyard trained on a hedge trellis system (Archer & Booysen, 1987) and established on a sandy soil (Table 1) at the Nietvoorbij experiment farm in Lutzville. The vines were spaced 1.5 m in the row and 3.0 m between rows. The soil was analysed for pH (1.0 M KCl), P and K (Bray no 2), exchangeable cations, namely K, Ca, Mg and Na (extracted with 0.2 M ammonium acetate) and organic matter by means of the Walkley-Black method (The Non-affiliated Soil Analysis Work Committee, 1990). Lutzville (31°35'S, 18°52'E) is situated in the semi-arid Olifants River Valley of the Western Cape and receives an average annual rainfall of 139 mm of which approximately 70% precipitates during the winter months (April to August).

The vineyard was irrigated by means of micro-sprinklers with a 360° wetting pattern, delivering 25.7 L/h and mounted three meters apart on the irrigation line in the upright position. The irrigation of the cover crops was scheduled according to the guideline supplied by Fourie *et al.* (2001), depending on the availability of water during winter (Table 2). In the Olifants River Valley 1210 mm of water per hectare per annum is allocated for irrigation purposes. For the duration of the study this quota was mostly reduced during October, depending on the water level of the Olifants dam that supplies the valley with water for drinking, mining and agricultural purposes. This reduction frequently amounted to as much as 40% of the above-mentioned allocation, restricting the water available for the irrigation of the cover crops during winter. Maintenance work

Table 1. Analyses of the sandy soil in Lutzville determined before the treatments commenced (sampled March 1993).

Soil depth (mm)	Clay (%)	Silt (%)	Course sand (%)	Medium sand (%)	Fine sand (%)	pH (KCl)	Electrical conductivity ($mS.m^{-1}$)	Organic C (%)	P (mg/kg)	K (mg/kg)	Exchangeable cations (cmol(+)/kg)			
											Ca	Mg	K	Na
0-300	0.01	1.43	4.07	40.16	54.37	5.9	9	0.13	15.80	111	0.87	0.46	0.29	0.06
300-600	0.01	1.20	4.82	41.23	52.67	5.8	6	0.10	8.75	96	0.72	0.44	0.26	0.09

Table 2. Total amount of water (rainfall and irrigation) received on a weekly basis from the beginning of April to the end of August, measured over a period of ten years.

Month	Date	Total water (mm)										
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Average
April	1-7	29	12	0	25[1]	2	16[1]	0	0	9	2	9
April	8-14	39	18[1]	19[1]	24	42[1]	32	0	8[1]	24[1]	27[1]	23
April	15-21	4	12	32	22	21	36	52[1]	9	16	21	23
April	22-28	0	18	0	0	2	0	23	18	18	23	10
April/May	29-5	29[1]	18	5	34	21	5	15	8	25	16	18
May	6-12	20	16	9	0	0	16	15	23	16	25	14
May	13-19	16	16	1	24	0	3	25	23	21	37	17
May	20-26	22	7	34	18	67	0	4	0	26	12	19
May/June	27-2	29	0	0	24	4	5	0	1	0	24	9
June	3-9	16	10	4	13	13	8	23	0	12	2	10
June	10-16	15	0	5	7	5	0	2	19	32	33	12
June	17-23	16	6	0	8	5	0	6	6	25	32	10
June	24-30	4	26	0	0	27	23	1	16	23	32	15
July	1-7	2	0	5	24	0	2	24	16	39	0	11
July	8-14	11	0	0	8	0	0	0	10	11	16	5
July	15-21	9	32	9	0	0	3	7	19	36	3	12
July	22-28	13	20	54	13	0	25	4	0	0	6	13
July/August	29-4	10	0	5	0	27	2	56	3	0	5	11
August	5-11	20	4	7	39	0	24	3	39	3	0	14
August	12-18	0	0	0	0	48	2	0	0	7	6	6
August	19-25	20	48	13	0	0	0	11	2	8	3	10
August	26-31	0	0	0	21	9	0	1	2	13	17	6
Total		322	263	199	301	293	201	272	221	364	342	278
Rainfall		210	90	83	113	119	52	83	62	139	111	106
Irrigation		112	173	116	188	174	149	189	159	224	231	172

[1]Week in which the cover crops were sown.

on the irrigation canal during winter also caused irrigation water to be unavailable from the beginning of May to the end of June for a fortnight at a time, with one week in between during which the canal would be operational. This continued from July to

August, but the operational periods in between was a fortnight. The above–mentioned restrictions complicated irrigation scheduling for the cover crops and caused the total amount of irrigation that could be applied to vary considerably between years. For example, to help ensure that sufficient amounts of water would be available for the irrigation of the grapevines during the growing season, the irrigation of the cover crops had to be stopped prematurely five and six weeks before the end of August 2001 and 2002, respectively. As rainfall also varied considerably between years, different years in this study actually presented different scenarios (treatments) with regard to plant water availability.

The cover crops were sown during April, with the exception of 1993 (first week of May), at seeding rates suggested by Fourie *et al*. (2001). Seedbed preparation was done with a disc harrow approximately six weeks before the seeding date. The seeds were inoculated with a suitable *Rhizobium* strain just before it was sown by hand and covered with a cultivator. During 1995 and 1997, with the exception of pink Seradella in the latter year, no seeds were sown in the AB treatments, while during 1999 this management practice was restricted to grazing vetch and the two medics (Table 3).

Experiment lay-out

Twenty three treatments were applied (Table 3). Two cover crop management practices, namely chemical control before bud break (BB) and chemical control at the end of November (AB) were applied to eight cover crop species. Two treatments in which *Avena strigosa* L. v. Saia (‘Saia’ oats) and *Vicia dasycarpa* Ten. (grazing vetch) were controlled mechanically during bud break were applied as well. These eighteen treatments received 30 kg of P at the end of February (just before seedbed preparation), 30 kg of K and 14 kg of N during the second week of April (just after the cover crops were sown), as well as 28 kg of N at the two to four leaf stage of the grass cover crops. Two weeks after bud break (late September) 30 kg of K and 42 kg of N were applied. For the purpose of the study this will be referred to as the standard amount of fertiliser (SF). In the case of the N-fixing broadleaf cover crops the N was applied only to the vine row. In addition to these eighteen treatments, four treatments in which the amount of fertiliser applied to ‘Saia’ oats and grazing vetch deviated from SF, were applied as well. In two of these treatments (one for each species) all applications were restricted to the vine row up to the 1995/96 season, after which no fertiliser was applied (NF). The other

Table 3. The effect of five cover crop management practices, applied selectively to eight cover crop species, on the dry matter production (DMP), measured at the end of August.

Treatment	DMP (t/ha)										
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Average
Secale cereale L. v. Henog (rye), BB[1],SF[2].	3.94	4.28	1.71	4.06	2.92	1.01	2.56	2.67	4.82	4.97	3.29
Secale cereale L. v. Henog (rye) AB[3], SF.	2.10	3.24	0.09	3.60	1.00[8]	1.32	3.25	2.38	4.35	4.04	2.54
Triticale v. Usgen 18 (triticale), BB, SF.[4]	2.10	2.37	0.69	3.02	2.03	0.63	0.22	0.02	0.15	0.96	1.22
Triticale v. Usgen 18 (triticale), AB, SF.[5]	2.46	1.72	0.24[8]	2.12	0.18[8]	0.58	0.79	0.78	2.11	1.98	1.29
Avena sativa L. v. Overberg ('Overberg' oats), BB, SF.	0.80	1.78	0.42	2.68	2.04	0.97	1.67	1.58	2.58	2.90	1.74
Avena sativa L. v. Overberg ('Overberg' oats), AB, SF.	0.67	2.14	0.01[8]	1.92	0.06[8]	0.82	1.28	1.18	1.70	2.66	1.24
Avena strigosa L. v. Saia ('Saia' oats), BB, SF.	1.54	3.08	0.87	3.88	3.96	0.83	2.06	1.31	4.45	3.55	2.55
Avena strigosa L. v. Saia ('Saia' oats), AB, SF.	1.63	2.46	0.28[8]	4.14	1.01[8]	0.82	2.31	2.02	5.37	2.86	2.25
Medicago truncatula Gaertn. v. Parabinga ('Parabinga' medic), BB, SF.	2.77	2.16	0.30	2.13	2.07	1.16	2.09	1.09	3.14	2.28	1.92
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB, SF.	3.66	2.50	0.37[8]	2.25	1.23[8]	0.94	1.64[8]	1.21	2.49	1.96	1.83
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB, SF.	4.22	2.82	0.58	3.39	3.94	0.91	4.21	0.88	4.79	2.44	2.82
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB, SF.	3.00	3.07	0.17[8]	2.77	1.39[8]	0.35	1.25[8]	0.87	4.88	2.29	2.00
Ornithopus sativus L. v. Emena (pink Seradella), BB, SF.	5.02	2.21	1.03	4.61	3.40	1.54	3.78	1.01	4.88	4.08	3.06
Ornithopus sativus L. v. Emena (pink Seradella), AB, SF.	4.49	2.07	0.05[8]	3.76	4.99	1.07	2.72	0.86	5.99	3.73	2.97
Vicia dasycarpa Ten. (grazing vetch),BB, SF.	2.69	3.66	0.58	2.92	2.79	0.80	1.66	0.82	4.11	2.83	2.29
Vicia dasycarpa Ten. (grazing vetch), AB, SF.	3.01	2.55	1.01[8]	3.15	1.71[8]	1.40	0.62[8]	1.17	3.57	2.73	2.09
Avena strigosa L. v. Saia ('Saia' oats), BB,NF[6].	0.90	.98	0.27	0.61	0.40	0.22	0.37	0.43	0.43	0.89	0.55
Avena strigosa L. v. Saia ('Saia' oats), BB, SF x 2.	2.12	3.59	1.01	3.70	4.13	1.28	2.34	2.02	4.60	4.38	2.92
Vicia dasycarpa Ten. (grazing vetch), BB, NF.	2.48	2.83	0.81	3.01	2.35	0.58	1.67	0.98	2.50	2.85	2.01
Vicia dasycarpa Ten. (grazing vetch),BB, SF x 2	2.71	3.11	0.59	3.14	3.10	0.56	1.44	1.15	2.55	3.68	2.20
Avena strigosa L. v. Saia ('Saia' oats), MC[7], SF.	1.48	2.68	0.64	2.26	3.53	0.64	2.10	1.75	4.05	2.75	2.19
Vicia dasycarpa Ten. (grazing vetch),MC, SF.	3.49	3.31	0.38	2.52	2.73	0.47	0.87	0.82	3.40	2.29	2.03
Weeds, MC, SF (Control).	0.48	1.65	1.74	2.05	0.81	0.14	0.81	0.34	1.00	1.35	1.14
LSD ($p \leq 0.05$)	1.09	0.68	0.66	0.58	1.91	0.67	1.2	0.76	1.99	1.49	0.61

[1]BB = full surface chemical control before bud break. [2]SF = standard amount of fertiliser applied. [3]AB = full surface chemical control at the end of November. [4]*Triticale* v. Usgen replaced by *Lolium perenne* L. v. Derby Cochise from 1999. [5]*Triticale* v. Usgen replaced by Medicago mixture from 1999. [6]NF = no fertilizer applied in working row. [7]MC = chemical control in vine row, mechanical control in working row. [8]Cover crop left to re-establish.

two treatments received double the standard amount of fertiliser (SF x 2). A mechanically cultivated control in which no cover crop was sown and in which SF was applied, was included in the trial. The different weed control actions were executed two times per year, namely before bud break of the grapevines (first week of September) and when the berries reached pea size (end of November).

Measurements

Dry matter production (DMP) of both the cover crops and the associated weeds was determined at the end of August (just before bud break of the grapevines) and end of November (pea size berries). DMP was measured as described by Fourie *et al*. (2001).

To determine the number of viable seed present in the top 100 mm of the soil, including the seeds on the soil surface, an area of 0.25 m^2 was sampled at the end of February – six weeks before the seeding date. The soil was air-dried and sieved through a 850 micron sieve, to separate the organic matter and cover crop seeds from the soil. The cover crop seeds were separated from the organic matter by hand. The viability of the seeds was determined by means of the “between paper” method prescribed by the International Seed Testing Association (1999).

Statistical procedures

Twenty three treatment combinations were randomly allocated within each of three blocks. The treatment design was an (8x2)+7 factorial with factors eight cover crops, two management practices, as well as seven other practices. The experiment was repeated for 10 consecutive seasons (years). The size of each unit (plot) was 108 m^2. All variables were measured at random sites within each experiment unit at the end of August and end of November. Analyses of variance were performed for each season separately, using SAS (SAS, 1990). Student’s *t* least significant difference (LSD) was calculated at a 5% significance level to compare treatment means. The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965).

RESULTS AND DISCUSSION

DMP of cover crops

The DMP of the cover crops, as measured at the end of August, was (for the duration of the study) less than that reported by Fourie *et al.* (2001) under similar edaphic conditions (Table 3). In the study by Fourie *et al.* (2001) a DMP in excess of five t/ha was achieved at the end of August with the cover crops receiving weekly irrigations of 18 mm during the first 10 weeks after sowing, followed by 18 mm of water every fortnight, totaling 270 mm (rainfall, as well as irrigation applied) from the beginning of April to the end of August. The performance of the cover crops in the present study varied considerably between seasons (Table 3). This could be attributed *inter alia* to seeding date (1993), but to a greater extent to a continuous (1995, 1998, and 2000) or periodic (1994, 1996, 1997 and 1999 to 2002) shortage of rainfall and irrigation water during winter (Table 3), the latter being caused by restrictions in the water supply, preventing the application of the irrigation schedule suggested by Fourie *et al*. (2001).

Water deficits during six of the first ten weeks after sowing, followed by dry periods lasting up to six weeks (Table 2), limited the total amount of water received during 1995, 1998 and 2000 to between 49 mm and 143 mm less than the amount deemed necessary for sufficient cover crop growth (Van Bosch & Pieterse, 1995; Fourie *et al*., 2001; Anonymous, 2003). This caused extremely poor cover crop performance (Table 3). Although the cover crops were sown late during 1993 (Table 3), the relatively high winter rainfall and irrigation that could be applied regularly during the dry periods (Table 2) resulted in the cover crops, with the exception of *Triticale* v. Usgen 18 (triticale) and the two Avena (oat) species, producing acceptable amounts of dry matter (Table 3). *Secale cereale* L v. Henog (rye) and the two oat species produced more dry matter during 1994 compared to 1993 (Table 3), although they received less water (Table 2). This could be attributed to the growing period in 1994 being three weeks longer than that of 1993 (Table 3) and supported the results of Fourie *et al*. (2001), indicating the importance of establishing these species early in April under full surface irrigation. The dry spell that occurred during 1994 (the seventh to the eleventh week after planting), reduced the DMP of the two medic species and pink Seradella compared to that of 1993 (Table 2), despite the longer growing season. Although the cover crops received water at least once a week up to 15 weeks after planting during the winter of 2001 (Table 2), the following dry spell of five weeks seemed to restrict the species, with the exception of pink Seradella and ‘Saia’ oats, to a DMP of less than five t/ha (Table 3). The dry spell of six weeks experienced at the end of the winter of 2002 (Table 2), had a pronounced negative effect on the DMP of Saia oats and *Medicago truncatula* Gaertn. v. Paraggio (‘Paraggio’ medic). Although the cover crops received less water during 1996 than during 2002 (Table 2), the DMP was similar, with ‘Paraggio’ medic performing better during the first-mentioned season (Table 3). This could be attributed to the fact that the interval between rainfall events or irrigations during the winter of 1996 did not exceed a fortnight. It seems, therefore, that the interval between irrigations or rainfall events throughout winter should preferably not be allowed to exceed two weeks.

Rye and pink Seradella were, on average, the two most successful species (Table 3). This is in accordance with Gladstones & McKeown (1977) and Williams & De Lautour (1975) who found that *Ornithopus sativus* was capable of performing well on low fertility sands. The average DMP of ‘Paraggio’ medic and ‘Saia’ oats at the end of August was not significantly less than that of the first-mentioned species (Table 3). These two species could, therefore, also be considered for cover crop management in this region. Although the average DMP of ‘Paraggio’ medic was less than that reported by Fourie *et al*. (2001), it was similar to that produced on a sandy soil, under cool winter conditions and an average winter rainfall of 754 mm (Bolland,1997). This indicated that ‘Paraggio’ medic was well adapted to the climate of the Olifants River Valley. On average, grazing vetch did not perform as well as the above-mentioned species (Table 3), but showed the ability to produce in excess of four tons of dry matter per ha, if it received approximately 18 mm of water on a weekly basis (Table 2).

The average DMP of Saia oats BB, NF was only 21.6% compared to that of ‘Saia’ oats BB,SF and significantly lower than the DMP of the weeds in the control, indicating that fertiliser application during the establishment of a grain species on these infertile sandy soils is essential (Table 3). Doubling the amount of fertiliser applied, increased the average DMP of Saia oats BB, SFx2 by 14.5%, compared to that of the BB, SF treatment. The standard amount of fertiliser applied to ‘Saia’ oats in this study, was similar to the N and P applied to the species on a heavy clay soil with high organic matter (Assefa & Ledin, 2001). This also indicated that SF should be increased to maximise DMP on the sandy soils of the Olifants River valley. Doubling the amount of fertiliser applied during establishment of ‘Saia’ oats, however, seems luxurious, as it did not increase the DMP of Saia oats significantly. Irrespective of the amount of fertiliser applied, the DMP of the BB treatments of grazing vetch did not differ significantly. It seemed, therefore, that P and K at a level of 10 mg/kg and 78 mg/kg, respectively, in the top 300 mm soil layer, supplied in the needs of grazing vetch. This was much lower than the 15.5 mg/kg to 23.2 mg/kg P deemed necessary for near maximum yields by grazing vetch on a Manawatu fine sandy loam (De Ruiter, 1981).

All the species, except *Medicago truncatula* Gaertn. v. Parabinga (‘Parabinga’ medic), showed increased DMP from the end of August to the end of November (Table 4), depending on either seeding date or the amount and frequency of water received from April to August (Table 2). Rye, triticale and ‘Paraggio’ medic produced extra dry matter during 1998 only (Table 4), despite being sown early in comparison to the other seasons (Table 2). This additional growth from September to November (Table 4) was triggered by the irrigation during the growing season, because the growth of these three species was retarded during the winter of 1998, due to the smaller amount of water received compared to that of 1993, 1994, 1997 and 2001 (Table 2). The two oat species produced additional fibre from September to November during 1993 and 1998 (Table 4), because they were sown late and did not receive a sufficient amount of water to complete their life cycle (Table 2), respectively. Pink Seradella produced additional fibre from September to November (Table 4) if the total amount of water received regularly during winter was less than 300 mm (Table 2). Grazing vetch, with the exception of 2001, kept on growing after the end of August (Table 4). It seemed that the luxurious water supply on a weekly basis from the seeding date up to 15 weeks after planting during 2001(Table 2) enabled the species to complete growth by the end of August (Table 4).

Potential of species to re-establish themselves

Grazing vetch was the only species capable of producing an amount of viable seeds exceeding the seeding density used in the treatments in which the species were sown annually (Fig. 1). This resulted in the DMP of grazing vetch AB, SF being 174.1% compared to that of grazing vetch BB, SF at the end of August 1995 (Table 3), indicating that the species had the potential to re-establish successfully in the short-term. In the medium- term (end of August 1997), however, the DMP of grazing vetch AB, SF was

Table 4. Percentage change in dry matter production (DMP) of the different species from the end of August to the end of November, as determined in the treatments in which chemical control was applied at the end of November 1993 to 1998 and in mid-October 1999 to 2002.

Treatments	Change in DMP from the end of August to the end of November				
	1993	1994	1996	1998	2001[1]
Secale cereale L. v. Henog (rye)	-22	-48	-21	47	-0.1
Triticale v. Usgen (triticale)	-7	-28	-49	129	NA[2]
Avena sativa L. v. Overberg ('Overberg' oats)	72	-9	-7	66	-24
Avena strigosa L. v. Saia ('Saia' oats)	67	7	-42	76	-41
Vicia dasycarpa Ten. (grazing vetch)	15	35	18	114	-32
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic)	-59	-2	-50	-22	-65
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic)	-49	-20	-26	160	-20
Ornithopus sativus L. v. Emena (pink Seradella)	2	52	-50	50	-57
LSD ($p \leq 0.05$)	52	NS[3]	NS	NS	NS

[1]Cover crops controlled chemically mid-October. [2]*Triticale* v. Usgen replaced by mixture of Medicago species.

61.3% compared to that of grazing vetch BB, SF, although the number of viable seed present in the top 100 mm of the soil including the seeds on the soil surface of the first-mentioned treatment still exceeded the seeding density used in the BB, SF treatment (Fig. 1). The reason for this is not known. The poor growth of grazing vetch in the AB, SF treatment during 1997 and 1998 (Table 3), as well as the fact that approximately 17% of the seeds in the soil got damaged annually, could have resulted in the decline in the number of seeds over these two seasons (Fig. 1). This resulted in the re-establishment of the species during 1999 being only 37.3% successful (Table 3). It should, therefore, be possible to cut back at least 40% on the seeding density of grazing vetch after two seasons, if it was left to ripen its seeds.

'Parabinga' medic showed potential to re-establish itself as indicated by the continuous increase in the number of viable seed present in the top 100 mm of the soil including the seeds on the soil surface of the AB, SF treatment over time (Fig. 2), and the corresponding increase in the DMP at the end of August (Table 3). The species could not, however, produce enough seeds to re-establish itself successfully over a period of five years and would not likely do so in the long-term under similar edaphic conditions (Fig. 2). The AB, SF treatment of 'Paraggio' medic showed a similar trend. Although the amount of water the medic species received in the present study exceeded that deemed necessary for re-establishment (Tadmor *et al.*,1971; Tadmor *et al*., 1974), the seed density of the two medic species never reached the amounts deemed necessary for successful re-establishment (Carter & Lake, 1985). The number of viable seed present in the top 100 mm of the soil including the seeds on the soil surface (Fig. 2), as well as the DMP at the end of August (Table 3), indicated that it should be possible to cut back on the seeding density of both species by approximately 20% after they had been sown for five consecutive years and left to ripen their seeds.

The cereals did not re-establish successfully during both 1995 and 1997 (Table 3), as only a small number of undamaged, viable seeds were present in the top 100 mm of the soil including the seeds on the soil surface (Table 5). Although the number of seeds harvested from the above-mentioned soil layer in the AB, SF treatment of *Avena sativa* L. v. Overberg ('Overberg' oats) during 1995 and 1997 were as high as 55% and 61% of the seeding density used in the BB, SF treatment (250 seeds per m^2), respectively, less

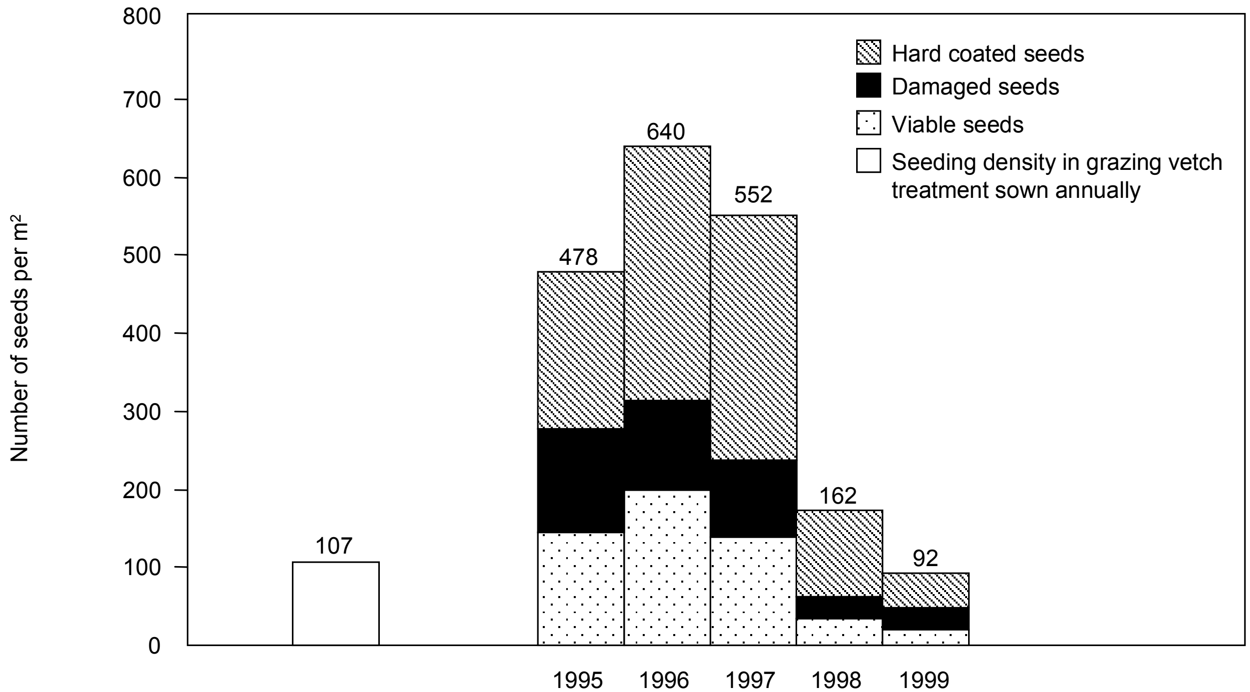

Figure 1. The number of seeds produced by *Vicia dasycarpa* over a period of five years on a sandy soil in the Olifants River Valley, if controlled chemically end of November.

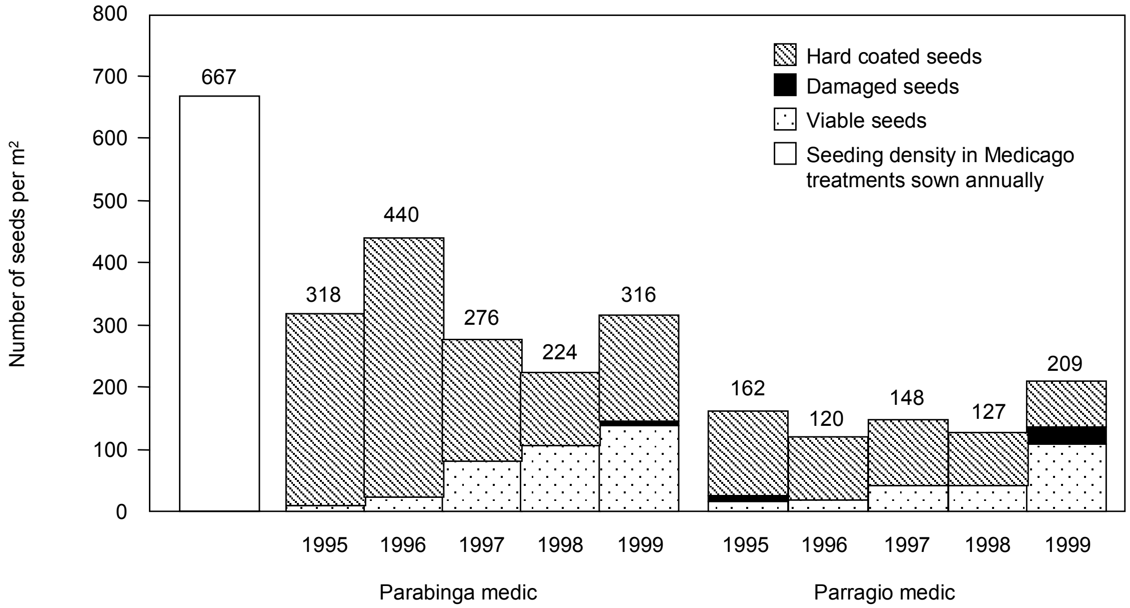

Figure 2.The number of seeds produced by *Medicago truncatula* v. Parabinga and *M. truncatula* v. Paraggio over a period of five years on a sandy soil in the Olifants River Valley, if controlled chemically end of November.

than 3% of the seeds were viable (Table 5). This resulted in practically no cover crop growth (Table 3). Rye produced 22% of the seeding density used in the corresponding BB, SF treatment (304 seeds per m^2) during 1997 (Table 4). This resulted in a DMP of one t/ha at the end of August 1997, which was significantly less than that of the corresponding BB, SF treatment and only 23% more than that produced by the weeds in the control (Table 3). A similar result was achieved with 'Saia' oats during 1997, although the number of viable seeds per m^2 was less than that of rye (Table 5) and only 10% of the amount sown in the BB, SF treatment (468 seeds per m^2). The number of viable seed present in the top 100 mm of the soil (including the seeds on the soil surface) of the AB, SF treatments of the grain species during 1999 indicated that no buildup of viable seeds occurred (Table 4) and that these species would not be able to re-establish under similar edaphic conditions. The cereals were, therefore, sown in the AB, SF treatments at the same seeding density used for the BB treatments from 1999 onwards.

No seeds could be found in the top 100 mm of soil (including the soil surface) of the pink Seradella AB, SF treatment from 1995 to 1999 (Table 5). The species being soft-seeded, could have resulted in all the seeds germinating because of irrigation applied regularly during December and January. Pink Seradella was, therefore, sown in the AB, SF treatment at the same seeding density used for the BB, SF treatment from 1997 onwards.

Weed control

The suppression of the winter growing weeds by the cover crops varied considerably between seasons and for most years the weed stand in the cover crop treatments did not differ significantly from that of the mechanically cultivated control (data not shown). This could mainly be attributed to the overall weed growth being poor during winter. The cover crops, however, suppressed the winter growing weeds significantly during 1996, 1999 and 2001 compared to that of the control (Table 6), indicating that it could compete effectively with the winter growing weeds in the region. The level of weed suppression achieved with the different species compared well with that reported by Fourie *et al*. (2001). Suppressing the winter growing weeds effectively, may result in a reduction in the dosage of herbicide applied at the end of August and may minimise the negative

Table 5. The number of seeds produced by the four grain species and *Ornithopus sativus* L. v. Emena over a period of four years on a sandy soil in the Olifants River Valley, if left to ripen its seeds.

Species	Number of seeds per m^2											
	1995			1996			1997			1998		
	Total	Viable	Damaged	Total	Viable	Damaged	Total	Viable	Damaged	Total	Viable	Damaged
Secale cereale L. v. Henog (rye)	62	8	54	0	0	0	164	67	97	1	1	0
Triticale v. Usgen 18 (triticale)	22	4	18	0	0	0	4	3	1	8	5	3
Avena sativa L. v. Overberg ('Overberg' oats)	138	0	138	36	0	36	152	4	148	2	1	1
Avena strigosa L. v. Saia ('Saia' oats)	34	4	30	0	0	0	82	46	36	1	1	0
Ornithopus sativus L. v. Emena (pink Seradella)	0	0	0	0	0	0	NA[1]	NA	NA	NA	NA	NA
LSD ($p \leq 0.05$)	62	22	35	138	46	12	82	26	31	61	15	12

[1]NA = Not applicable

effects caused by weeds, such as the harbouring of nematodes and mealy bug during winter.

The correlation between the DMP of the cover crops and the weeds are shown in Table 7. An increase in the growth of pink Seradella had the most significant negative impact on weed growth during winter. The growth of grazing vetch, 'Overberg' oats and 'Paraggio' medic, in order of merit, also had a significantly negative impact on weed growth during winter.

The growth of the summer growing weeds in the control from end of August to end of November was on average as little as 0.28 ton/ha (data not shown). Despite this, the correlation between the DMP of grazing vetch and weed dry matter, although not strong, was statistically significant at the 3% level.

The results indicated that grazing vetch was the only species for which an increase in DMP during winter would result in improved weed suppression during both winter and summer.

CONCLUSIONS

Rye and pink Seradella were the least sensitive to water deficits and should, therefore, be the preferred species for cover crop management in the sandy soils of the semi-arid Olifants River Valley. 'Paraggio' medic and 'Saia' oats could also be considered for cover crop management in this region. Although grazing vetch did not perform on average as well as the above-mentioned species, it could also be considered for cover crop management during years in which the water quota for the region is not reduced.

Indications are that both the total amount of water and the frequency of irrigations and/or rainfall, could affect the amount of dry matter produced by the cover crop species from April to August. The effect of different irrigation schedules on cover crop performance in this region should, therefore, be researched, to supply scientifically based guidelines for the optimal irrigation of cover crops on the sandy soils of the semi-arid Olifants River Valley.

Table 6. The effect of five cover crop management practices, applied selectively to eight cover crop species, as well as a mechanically cultivated soil, on the dry matter production (DMP) of winter growing weeds, measured end of August 1996, 1999 and 2001.

Treatment	DMP (t/ha)		
	1996	1999	2001
Secale cereale L. v. Henog (rye), BB[1], SF[2].	0.56	0.30	0.17
Secale cereale L (rye), AB[3], SF.	0.20	0.05	0.27
Triticale v. Usgen 18 (triticale), BB, SF.[4]	0.72	0.84	0.22
Triticale v. Usgen 18 (triticale), AB, SF.[5]	0.24	0.75	0.23
Avena sativa L. v. Overberg ('Overberg' oats), BB, SF.	0.34	0.43	0.01
Avena sativa L. v. Overberg ('Overberg' oats), AB, SF.	0.50	0.52	0.03
Avena strigosa L v. Saia ('Saia' oats), BB, SF.	0.10	0.32	0.08
Avena strigosa L. v. Saia ('Saia' oats), AB, SF.	0.21	0.30	0.04
Medicago truncatula Gaertn. v. Parabinga ('Parabinga' medic), BB, SF.	0.77	0.35	0.14
Medicago truncatula Gaertn.v. Parabinga ('Parabinga' medic), AB, SF.	0.20	0.24	0.05
Medicago truncatula Gaertn.v. Paraggio ('Paraggio' medic), BB, SF.	0.50	0.19	0.07
Medicago truncatula Gaertn.v. Paraggio ('Paraggio' medic), AB, SF.	0.32	0.52	0.30
Ornithopus sativus L. v. Emena (pink Seradella), BB, SF.	0.27	0.47	0.02
Ornithopus sativus L. v. Emena (pink Seradella), AB, SF.	0.94	0.50	0.05
Vicia dasycarpa Ten. (grazing vetch), BB, SF.	0.36	1.11	0.01
Vicia dasycarpa Ten. AB, SF.	0.17	0.58	0.03
Avena strigosa L. v. Saia ('Saia' oats), BB, NF[6].	0.06	0.07	0.00
Avena strigosa L. v. Saia ('Saia' oats), BB, SF x 2.	0.36	0.62	0.10
Vicia dasycarpa Ten. (grazing vetch), BB, NF.	0.20	0.58	0.09
Vicia dasycarpa Ten. (grazing vetch), BB, SF x 2	0.82	0.60	0.04
Avena strigosa L. v. Saia ('Saia' oats), MB[7], SF.	0.51	0.34	0.05
Vicia dasycarpa Ten. (grazing vetch), MB, SF.	0.90	0.50	0.28
Weeds, MB, SF.(Control).	2.05	1.81	1.00
LSD ($p \leq 0.05$)	0.77	0.54	0.47

[1]BB = full surface chemical control before bud break. [2]SF = standard amount of fertiliser applied. [3]AB = full surface chemical control at the end of November. [4]*Triticale* v. Usgen replaced by *Lolium perenne* L. v. Derby Cochise from 1999. [5]*Triticale* v. Usgen replaced by Medicago mixture from 1999. [6]NF = no fertilizer applied in working row. [7]MB = chemical control in vine row, mechanical control in working row. [8]Cover crop left to re-establish.

Table 7. The correlation between the dry matter production (DMP) of the cover crops and the weeds as measured at the end of August and the end of November over a period of 10 and 6 years, respectively.

Species	Number of replications	End of August		End of November[1]	
		Pearson correlation coefficient	Level of significance	Pearson correlation coefficient	Level of significance
Secale cereale L. v. Henog (rye)	12	-0.28	0.23	0.01	0.95
Triticale v. Usgen 18 (triticale)	12	-0.30[1]	0.20[1]	-0.15	0.64
Avena sativa L. v. Overberg ('Overberg' oats)	12	-0.39	0.09	-0.09	0.79
Avena. strigosa L. v. Saia ('Saia' oats)	32	-0.17	0.23	-0.29	0.12
Vicia dasycarpa Ten. (grazing vetch)	32	-0.36	0.01	-0.40	0.03
Medicago truncatula Gaertn. v. Parabinga ('Parabinga' medic)	12	-0.15	0.51	-0.33	0.29
Medicago truncatula Gaertn. v. Paraggio ('Paraggio' medic)	12	-0.38	0.10	-0.29	0.36
Ornithopus sativus L. v. Emena (pink Seradella)	12	-0.53	0.02	-0.25	0.43

[1]Pearson correlation coefficient determined with six years data (1993 to 1998).

It seemed that P and K at levels of 10 mg/kg and 78 mg/kg, respectively, in the top 300 mm soil layer, supplied in the needs of grazing vetch. ‘Saia’ oats, however, performed poorly if 30 kg of P was not broadcast just before seedbed preparation, followed by an application of 30 kg of K and 28 kg of N just after the cover crops were sown and 14 kg of N were not applied at the two to four leaf stages. Although it was luxurious to double the amount of fertiliser, the standard amount of fertiliser applied should be increased to maximize DMP. The specific amount should be determined by future research.

The cover crops (not controlled chemically at the end of August) did not produce additional dry matter from September to November if they received sufficient amounts of water on a regular basis during winter. If sown late (first week in May) the two oats species, grazing vetch and to a lesser extent pink Seradella should produce additional fibre if not controlled chemically at the end of August. Grazing vetch would most likely produce additional fibre under these edaphic conditions, if not controlled chemically at the end of August. The preceding winter, therefore, determines the cover crop management practice that should be applied end of August.

The cover crops did not produce enough seeds to re-establish themselves successfully over a period of five years. It may, however, be possible to cut back on the seeding density of the two *M. truncatula* varieties (20% after five seasons) and grazing vetch (40% after two seasons) if the species are allowed to ripen their seeds.

All the cover crops showed the ability to compete effectively with the winter growing weeds.

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CHAPTER 4

Cover crop management in a Sauvignon blanc/Ramsey vineyard in the semi-arid Olifants River Valley, South Africa. 2. Effect of different cover crops and cover crop management practices on grapevine performance.

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ABSTRACT

The trial was conducted over a period of ten years (1993/94 to 2002/03) on a sandy soil in a Sauvignon blanc/Ramsey vineyard near Lutzville (31°35'S, 18°52'E), situated in the semi-arid Olifants River Valley of the Western Cape. Fourteen treatments, consisting of

three cereals and four legumes, managed according to two cover crop management practices, were included. One management practice consisted of cover crops which were sown annually and full surface post-emergence chemical which was applied before bud break and when the berries reached pea size (BB). The second management practice consisted of the cover crops which were sown biennially. Post-emergence chemical control was applied to the vine row before bud break and full surface when the berries reached pea size (AB). From 1999/2000 to 2002/03 the cover crops were sown annually, while the full surface post-emergence control applied at the end of November was advanced to mid-October. Two treatments in which *Avena sativa* L. v. Saia ('Saia' oats) and *Vicia dasycarpa* Ten. (grazing vetch) were sown annually, controlled mechanically in the work row and chemically in the vine row from bud break to harvest (MC), were also applied. These treatments were compared to a control, in which no cover crop was sown and MC was applied. A treatment in which no cover crop was sown and BB was applied (weedchem), was also included. During the third growing season of the vines (1994/95), the shoot mass of the BB treatments of grazing vetch and *Medicago truncatula* Gaertn. v. Paraggio ('Paraggio' medic) was significantly more than that of the AB and MC treatments, with the exception of *Secale cereale* L. v. Henog (AB) and grazing vetch (MC). The first harvest (1994/95) from the grapevines in the BB treatments was significantly higher than that of weedchem and the MC treatments. The grape yield of the BB treatments, grazing vetch (AB) and *Ornithopus sativus* L. v. Emena (pink Seradella) (AB) was significantly more than that of weedchem and the control during the 1997/98 season. The NO_3-N concentration in the leaf petioles in all the cover crop treatments was, with the exception of the AB treatments of rye, *M. truncatula* Gaertn. v. Parabinga ('Parabinga' medic) and grazing vetch, significantly more than that in weedchem and the control, as measured during the 1994/95 season. The NO_3-N concentration in the leaf petioles of the BB and AB treatment of a species differed significantly. The N concentration in the juice of the cover crop treatments during the 1995/96 season was, with the exception of 'Saia' oats (MC) and 'Parabinga' medic (AB), significantly more than that of weedchem and the control. The N concentration of the juice in the BB and AB treatments of grazing vetch and pink Seradella was significantly higher than that of the MC treatments, the two rye treatments, weedchem, as well as the AB treatments of the other cover crop species, as measured during the 1998/99 season. The concentration of Ca in the juice of the cover crop treatments was, with the exception of the pink Seradella treatments, significantly higher than that of weedchem and the control. Wine quality did not differ between treatments.

INTRODUCTION

Cover crops are used as a non-specific method for the pre-emergence control of both winter and summer growing weeds in vineyards (Van Huyssteen *et al*., 1984; Fourie *et al*., 2001, Fourie *et al*., 2005; Fourie *et al*., 2006). The effective management of this biological method of weed control as an alternative for chemical weed control is of the utmost importance, because an increasing number of weed species are developing resistance towards herbicides (Anonymous, 1997; Henkes, 1997). Cover crop mulches facilitate a reduction in water runoff and erosion (Louw & Bennie, 1992) and reduce temperature fluctuations in the soil (Van Huyssteen *et al*., 1984). They also restrict evaporation from the soil surface (Van Huyssteen *et al*., 1984), thereby conserving soil water (Buckerfield & Webster, 1996).

Van Huyssteen & Weber (1980) and Fourie *et al*. (2006) observed that grape production and pruning mass were affected significantly by the soil cultivation practice applied to the medium textured soils of a non-irrigated and irrigated vineyard, respectively. The use of a permanent cover in the work row resulted in a reduction in grapevine vigour (Van Huyssteen & Weber, 1980; Soyer *et al*., 1984; Lombard *et al*., 1988; Pool *et al*., 1990; Sicher *et al*., 1995; Pinamonti *et al*., 1996; Ingels *et al*., 2005) and yield (Van Huyssteen & Weber, 1980; Soyer *et al*., 1984; Lombard *et al*., 1988; Sicher *et al*., 1995; Pinamonti *et al*., 1996) compared to grapevines grown under other soil cultivation practices. Ingels *et al*. (2005) observed that a permanent grass cover reduced grapevine vigour compared to grapevines in which a permanent mixed clover cover was used. According to Pool *et al*. (1990) and Ingels *et al*. (2005), grape yield was not affected by the soil cultivation practice applied, while Anonymous (1984) reported higher yields for grapevines with a permanent cover crop in comparison with grapevines in which other soil cultivation practices were applied. Grape yield under winter growing cover crops controlled chemically before bud break was significantly higher than that of grapevines in which clean cultivation was applied (Buckerfield & Webster, 1996; Fourie *et al*., 2006). Fourie *et al*. (2006) indicated that the performance of full bearing irrigated grapevines established on a medium textured soil, in which annual cover crops were allowed to grow in the work row until the vines reached the berry set stage, was similar to that of grapevines in which no cover crops were sown and the weeds were controlled mechanically or chemically from bud break to harvest.

A permanent grass cover crop significantly decreased the N concentration in the grapevine leaves compared to that of the vines in which full surface chemical control was applied to a bare soil (Soyer *et al*., 1984; Lombard *et al*., 1988; Tan & Crabtree, 1990; Sicher *et al*., 1995; Pinamonti *et al*., 1996). Ingels *et al*. (2005) observed a higher grapevine petiole N where a cover crop mix was disked in during early spring in comparison with grapevines in which weeds were disked in or cover crops were slashed. N-fixing species should, however, not be used as cover crops over the long-term on a medium textured soil, because they may lead to an early season over-supply of N which could cause vigorous grapevine growth (Fourie *et al*., 2006).

According to Lombard *et al*. (1988) and Ingels *et al*. (2005), soil cultivation did not affect the soluble solids content and acidity of grape juice at harvest. Van Huyssteen (1990) and Fourie *et al*. (2006), however, reported significant differences in total titratable acids of grapevine juice between soil cultivation treatments, which was probably caused by differences in crop size (Fourie *et al*., 2006) and vegetative growth (Conradie, 2001b; Fourie *et al*., 2006). A permanent green cover in the work row competed with the grapevines for nutrients during the growing season, which resulted in the must being low in ammonium-N (Dupuch, 1997) and N deficient (Van Huyssteen, 1990). This increased the time necessary to ferment all the sugar in the must (Dupuch, 1997) and caused stuck fermentation to occur (Van Huyssteen, 1990). According to Maigre (1997), a permanent grass cover in the work row had a negative effect on wine quality during years when the competition between the grass and the grapevines was high. Wine quality was, however, not affected negatively where annual cover crops were sown and full surface post-emergence chemical weed control was applied when the berries reached pea size (Fourie *et al*, 2006).

The reviewed literature indicated that soil cultivation practices impacted significantly on grapevine performance. The effect of annual cover crops controlled chemically during different stages of the grapevine growing season on the performance of both young and fully grown grapevines established on a medium textured soil was determined (Fourie *et* *al.*, 2006). Cover crop growth and N contributed by them depend on species, length of growing season, climate and soil conditions (Shennan, 1992). The effect of different cover crop management practices on the performance of grapevines established on a sandy soil in a semi-arid grapevine region should, therefore, also be clarified. This study was conducted to determine the effect of different cover crop management practices applied to three cereals and four legumes on the performance of Sauvignon blanc/Ramsey vines established on a sandy soil. The objective was to supply guidelines for sustainable cover crop management in vineyards on these soils in the Olifants River Valley.

MATERIALS AND METHODS

Experiment vineyard and layout

The detailed experiment procedures and layout have already been described in Fourie *et al*. (2005). The trial was conducted in a Sauvignon blanc/Ramsey vineyard trained on a hedge trellis system (Archer & Booysen, 1987) and established on a sandy soil (98.6% sand) at the Nietvoorbij research farm near Lutzville (31°35'S, 18°52'E). During winter (April to August) irrigation was scheduled as described by Fourie *et al.* (2005). During summer the soil water matric potential was measured by means of 11 sets of mercury manometer tensiometers, installed on the vine row at depths of 300 mm, 600 mm and 900 mm. Soil water retention curves and drainage curves, determined by Conradie & Myburgh (2000) for a similar soil adjacent to the trial site, were used to convert matric potential to soil water content. Field capacity was estimated at the point where the drainage rate began to decrease. Weekly tensiometer readings, taken before irrigation, were used to calculate the amount of water needed to restore the soil to field water capacity. The required amount of water was applied weekly from bud break (first week of September) to harvest (first week of February). The grapevines received 30 kg P/ha at the end of February (just before seedbed preparation), 30 kg K/ha and 14 kg N/ha during the second week of April (just after the cover crops were sown). At the two-to-four-leaf stage of the grass cover crops 28 kg N/ha was applied. Two weeks after bud break (late September), 30 kg K/ha and 42 kg N/ha were applied. The vines were spur pruned according to vigour and were suckered a few weeks after bud break. Shoot positioning was done and the vines tipped and topped as soon as the canes grew more than 100 mm past the highest line of the trellis system (approximately 1,1 m above the cordon of the vine).

Twenty three treatments were applied, of which 18 treatments are reported on with respect to grapevine performance (Table 1). The remaining five are not pertinent to the present trial. Two cover crop management practices were applied to seven cover crop species. One cover crop management practice consisted of cover crops being sown annually and full surface post-emergence chemical control being applied before bud break and when the berries reached pea size, i.e. end of November (BB). The other cover crop management practice consisted of the cover crops being sown biennially and post-emergence chemical control being applied to the vine row before bud break and full surface when the berries reached pea size (AB). From 1999/2000 to 2002/03 the cover crops in the AB treatments were sown annually and the full surface post-emergence chemical control applied end of November was advanced to mid-October, since the species have proved unable to re-establish successfully in previous seasons (Fourie *et al*., 2005). Two treatments in which *Avena strigosa* L. v. Saia ('Saia' oats) and *Vicia dasycarpa* Ten. (grazing vetch) were sown annually and controlled mechanically in the working row and chemically in the vine row from before bud break to harvest (MC), were also applied. The cover crop treatments were compared to a control treatment, in which no cover crop was sown and MC was applied. A treatment in which no cover crop was sown and full surface post-emergence chemical weed control was applied from before bud break to harvest (weedchem), was also included.

Statistical procedures

Twenty three treatments were randomly allocated within each of three blocks. The treatment design was an (8x2)+7 factorial with factors eight cover crops, two management practices, as well as seven other practices. The experiment was repeated for 10 consecutive seasons (years). The size of each unit (plot) was 108 m^2. Eight experimental grapevines were used for measurements. Individual plots were separated by one border grapevine row and five border grapevines within rows. Analyses of variance were performed for each season separately, using SAS (SAS, 1990). Student's *t* least significant difference (LSD) values were calculated at a 5% significance level to facilitate comparison between treatment means. The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965).

Measurements

Shoot mass and grape yield

Shoot mass and grape yield were measured for ten seasons (1993/94 to 2002/03) and nine seasons (1994/95 to 2002/03), respectively. All treatments were harvested on the same date.

Berry weight and volume

Berry weight and volume were determined during 1997/98 and 2002/03. One hundred berries were picked randomly from approximately 10 bunches for each treatment plot during harvest. The berries were weighed, after which the volume of these berries was determined volumetrically.

Leaf petiole analysis

Petiole analyses were carried out over nine seasons (1994/95 to 2002/03). Leaf petioles were collected at full bloom from locations which were directly opposite clusters. The leaves and petioles were separated immediately after sampling. Petiole samples were extracted with 1.0 M KCl and analysed colorimetrically for NO_3-N (The Non-affiliated Soil Analysis Work Committee, 1990).

Juice analysis

The grapes were harvested when the sugar concentration averaged 22°B. A representative sample (approximately one bunch per experimental vine) from each plot was crushed in a hydraulic press. Free run juice was analysed for sugar content (temperature compensated Abbé refractometer), pH (654 Metrohm pH meter) and titratable acidity (50 mL juice titrated with 0.333 M NaOH to pH 7.0 and expressed as g tartaric acid/L). These measurements were done for nine seasons (1994/95 to 2002/03). Total juice N was determined for eight consecutive years (1995/96 to 2002/03) using an automated colorimetric method (The Non-affiliated Soil Analysis Work Committee, 1990), following digestion with selenous acid/sulphuric acid. Total P, K, Ca and Mg concentrations in the juice were determined for five consecutive years (1995/96 to 1999/2000) by atomic absorption spectrophotometry, following digestion with nitric acid/perchloric acid.

Experimental wines

Experimental wines were prepared from the grapes of 13 of the 23 treatments over four consecutive seasons, namely from 1996/97 season to 1999/2000, as described by Fourie *et al*. (2006). The wines were stored at 14°C for three months before evaluation. Sensory evaluation was carried out by an experienced panel of 14 members on a nine point scorecard (Tromp & Conradie, 1979). The wines were presented in coded form and evaluated for overall wine quality, as well as for aroma and taste.

RESULTS AND DISCUSSION

Grape yield and shoot mass

The effect of the different management practices began to manifest during the first (1993/94) season (Table 1). The shoot mass of the two year old vines (1993/94) in the BB treatment of 'Saia' oats was significantly higher than that of the MC and AB treatments. Shoot mass in the AB treatments of the two Medicago varieties and the MC treatment of grazing vetch was also significantly lower than that of the BB treatment of *Secale cereale* L. v. Henog (rye) and *Avena sativa* L. v. Overberg ('Overberg' oats), as well as weedchem. During the third growing season of the vines (1994/95), the shoot mass of the BB treatments of grazing vetch and *Medicago truncatula* Gaertn. v. Paraggio ('Paraggio' medic) was significantly more than that of the AB and MC treatments, with the exception of rye (AB) and grazing vetch (MC). The shoot mass of the BB and AB treatment of a species differed significantly, with the exception of rye and 'Overberg' oats, with the shoot mass of the BB treatment constantly being the higher of the two. Results indicated that, in young vineyards, the cover crops should be controlled chemically before bud break. This corresponded with the observations of Fourie *et al.* (2006). The use of grazing vetch as cover crop in combination with post-emergence chemical control before bud break was the most effective soil management practice to be applied in young vineyards to enhance the development of the permanent structure of trellised grapevines established on sandy soils in the warmer climatic regions.

The first harvest (1994/95) from the grapevines in the BB treatments was significantly higher than that of weedchem and the MC treatments (Table 1). The grape yield in the BB treatments of *M. truncatula* Gaertn. v. Parabinga ('Parabinga' medic), *Ornithopus sativus* L. v. Emena (pink Seradella), grazing vetch and 'Saia' oats was significantly

Table 1. Effect of three cover crop management practices applied selectively to three cereals and four legumes on the shoot mass (SM) and grape yield (GY) of young and full-bearing Sauvignon blanc/Ramsey vines, on a sandy soil near Lutzville.

Treatment	1993/94	1994/95		1995/96		1997/98		2002/03	
	SM (t/ha)	SM (t/ha)	GY (t/ha)	SM (t/ha)	GY (t/ha)	SM (t/ha)	GY (t/ha)	SM (t/ha)	GY (t/ha)
Grain species:									
Secale cereale L. v. Henog (rye), BB[1].	0.62	2.11	6.54	3.29	12.51	3.02	11.32	2.89	13.09
Secale cereale L. v. Henog (rye) AB[2].	0.53	2.00	4.44	3.25[4]	12.02[4]	2.92[4]	10.67[4]	2.91	13.36
Avena sativa L. v. Overberg ('Overberg' oats), BB.	0.57	2.31	5.02	3.51	11.26	3.00	11.74	2.92	14.32
Avena sativa L. v. Overberg ('Overberg' oats), AB.	0.40	1.60	2.73	2.62[4]	10.31[4]	2.60[4]	9.09[4]	2.76	14.51
Avena strigosa L. v. Saia ('Saia' oats), BB.	0.84	2.53	7.76	4.01	12.31	3.25	11.13	2.78	13.45
Avena strigosa L. v. Saia ('Saia' oats), AB.	0.42	1.49	4.38	2.87[4]	10.44[4]	2.81[4]	9.33[4]	2.77	11.89
Avena strigosa L. v. Saia ('Saia' oats), MC[3].	0.40	1.62	1.47	3.03	10.56	2.38	9.83	2.39	12.00
N-fixing broadleaf species:									
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	0.58	2.77	6.20	3.30	13.09	2.98	11.89	2.95	13.42
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	0.27	1.24	4.12	3.33[4]	12.83[4]	2.57[4]	9.03[4]	2.81	13.84
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	0.62	2.53	8.26	3.39	11.86	3.07	12.08	3.13	14.83
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	0.24	1.31	4.88	2.84[4]	11.18[4]	2.52[4]	9.53[4]	2.76	13.40
Ornithopus sativus L. v. Emena (pink Seradella), BB	0.51	2.54	7.30	4.71	14.73	4.07	12.09	3.16	14.25
Ornithopus sativus L. v. Emena (pink Seradella), AB	0.40	1.56	5.55	3.82[4]	11.66[4]	3.81[4]	11.21[4]	3.19	14.01
Vicia dasycarpa Ten. (grazing vetch),BB.	0.56	2.91	8.19	4.65	15.37	4.08	11.35	2.72	14.49
Vicia dasycarpa Ten. (grazing vetch), AB.	0.44	1.78	5.32	3.60[4]	12.96[4]	4.04[4]	11.58[4]	3.11	13.65
Vicia dasycarpa Ten. (grazing vetch), MC.	0.33	2.16	3.29	4.57	10.82	3.13	11.49	2.39	12.05
Weeds, MC (control).	0.51	1.69	2.54	2.58	10.35	2.79	8.69	2.18	11.92
Weeds, BB (weedchem).	0.60	2.02	3.00	3.39	11.33	2.91	9.07	2.40	11.97
LSD ($p \leq 0.05$)	0.29	0.95	1.54	1.44	2.20	1.10	2.02	0.77	1.62

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]Cover crop left to re-establish.

more than that of AB treatments. A similar tendency was observed for rye (BB) and 'Paraggio' medic (BB). The grape yield of the latter two BB treatments was, however, not significantly more than that of grazing vetch (AB) and pink Seradella (AB). The grape yield of the BB and AB treatment of a species differed significantly, with the grape yield of the BB treatment being the higher of the two. This indicated that the cover crops which were controlled chemically before bud break, had a significant impact on the grape yield of the young Sauvignon blanc/Ramsey vines established on a sandy soil. This supported the results of Fourie *et al*. (2006). The grape yield of the AB treatments in which an N-fixing cover crop was established was, with the exception of 'Paraggio' medic, significantly more than that of weedchem and the MC treatments. The grape yield of 'Paraggio' medic (AB), rye (AB) and 'Saia' oats (AB) was significantly higher than that of the control and 'Saia' oats (MC), while that of 'Overberg' oats (AB) did not differ significantly from weedchem, the control and the two MC treatments in which a cover crop was established. These results differed from that reported by Fourie *et al.* (2006) for irrigated young Chardonnay/99 Richter vines and Van Huyssteen & Weber (1980) for non-irrigated full-bearing Chenin blanc vines, both of which were established on medium textured soils near Stellenbosch. The K and N applied two weeks after bud break in the present study could have reduced the impact that the cover crops, left to grow until berry set, might have had on the young Sauvignon blanc/Ramsey vines. Competition from summer growing weeds was low (Fourie *et al*., 2005), which seemed to benefit the AB treatments as well.

The cover crops performed poorly during the 1995/96 season (Fourie *et al*., 2005), the first season in which the grapevines were in full production (Table 1). This could have contributed to the differences in shoot mass and harvest mass between treatments not manifesting as clearly during the 1995/96 season as in the case of the 1994/95 season. Despite this, the shoot mass of the grapevines in pink Seradella (BB), grazing vetch (BB) and grazing vetch (MC) exceeded 4.5 t/ha. These results, as well as visual evaluation of the grapevine canopies during the growing season, indicated that the grapevines in these three treatments were developing dense canopies. Champagnol (1978), Hunter & Visser (1990) and Smart *et al*. (1990) indicated that increased vegetative growth may reduce yields due to excessive shading of fruiting zones, which may result in decreased fruitfulness of the buds in the following season. To prevent this from happening, the amount of N applied after bud break in these three treatments was reduced by 50% (21 kg of N/ha) from the 1996/97 season onwards. The grape yield of grazing vetch (BB) during the 1995/96 season was significantly more than that of the other treatments, with the exception of pink Seradella (BB). Pink Seradella yielded significantly more grapes than the other treatments, with the exception of the two 'Paraggio' medic treatments and the BB and AB treatments of grazing vetch. These results indicated that grazing vetch or pink Seradella controlled chemically before bud break should enhance the performance of grapevines on a sandy soil in the Olifants River Valley (Table 1), even when producing less than 1.1 tons of dry matter per hectare (Fourie *et al*., 2005). The grape yield of 'Paraggio' medic (BB) was significantly more than that of the MC treatments and exceeded that of weedchem and the AB treatments as well, although these differences were not always significant (Table 1). This indicated that 'Paraggio' medic, producing as little as 0.58 t/ha of dry matter (Fourie *et al*., 2005), could also enhance grapevine performance on a sandy soil.

Although the N applied after bud break in pink Seradella (BB) and grazing vetch (BB) was reduced by 50% from the 1996/97 season onwards, the shoot growth during the 1997/98 season (fifth season of the experiment) was still the highest and significantly more than that of the control, weedchem, 'Saia' oats (MC), as well as the AB treatments of the grain species and two Medicago species (Table 1). The grape yield/shoot mass ratio in the two BB treatments was less than 3. This was much lower than the ratio of 3.6 considered by Conradie (2001a) to indicate excessive growth for Bukettraube/Ramsey grapevines under supplementary irrigation on a duplex Kroonstad soil form (Soil Classification Working Group, 1991). From the 1998/99 season onwards, therefore, no N was applied after bud break in these two BB treatments. A similar result was obtained with grazing vetch (AB), indicating that the amount of N applied after bud break should be reduced for this treatment as well (Table 1). Although the shoot growth of the grapevines in pink Seradella (AB) was less than that of the above-mentioned BB treatments, the grape yield/shoot mass ratio was also less than three, indicating excessive shoot growth. The amount of N applied in grazing vetch (AB) and pink Seradella (AB) was, therefore, reduced by 50% (21 kg of N/ha) from the 1998/99 season onwards. The grape yield of the BB treatments, grazing vetch (AB) and pink Seradella (AB) was significantly more than that of weedchem and the control during the 1997/98 season, indicating that these treatments should preferably be applied over the medium term in full bearing vineyards established on sandy soils in the Olifants River Valley.

Although the grape yield of the AB treatments of the two Medicago species and 'Overberg' oats was significantly less than that of the BB treatments of these three species, indicating that these treatments impacted negatively on grapevine performance, it was similar to that of weedchem, the control and Saia (MC).

The cover crops in the AB treatments were controlled during mid-October from the 1999/2000 to the 2002/03 seasons (second phase of the trial). Results of the 2002/03 season (tenth season of the trial), which were representative of grapevine performance during this period, are shown in Table 1. The shoot growth in the two pink Seradella treatments, grazing vetch (AB) and 'Parabinga' medic (BB) was significantly more than that of weedchem, 'Saia' oats (MC) and the control. The shoot growth in these cover crop treatments were not excessive, however, as the yield/shoot mass ratios were between 4.36 and 4.73, which is similar to the ratios reported by Conradie (2001a) and Zeeman & Archer (1981) for grapevines considered to have a balanced growth pattern. The grape yield in the 'Overberg' oats and pink Seradella treatments, the BB treatments of 'Parabinga' medic and grazing vetch, as well as the AB treatments of 'Paraggio' medic and grazing vetch was significantly more than that of weedchem, 'Saia' oats (MC) and the control (Table 1). This indicated that these treatments should preferably be applied in vineyards established on the sandy soils of the Olifants River Valley, as they enhanced grapevine performance over the medium to long term. In the case of pink Seradella and grazing vetch the enhanced performance was achieved, despite a reduction (AB treatments) or omission (BB treatments) of the N fertilizer applied after bud break. Although the differences were not significant, the grape yield in the other minimum cultivated cover crop treatments, with the exception of 'Saia' oats (AB), exceeded that of weedchem by between 1.12 and 1.48 t/ha. In contrast with the 1997/98 season, the grape yield in the AB treatments of 'Overberg' oats and 'Paraggio' medic did not differ significantly from that of the BB treatments of the same species during the 2002/03 season (Table 1). This was attributed to the chemical control being applied six weeks earlier (mid-October instead of the end of November). Similar results were achieved with the other cover crop species during the 2002/03 season. This supported the results of Pool *et al*. (1990), who found that chemical weed control before bud break or at bloom, respectively, did not affect the vegetative growth or yield of 'Concord' grapevines.

Berry mass and volume

No significant differences in either berry mass or berry volume was observed (data not shown), which is similar to the results reported by Fourie *et al*. (2006).

Leaf petiole analysis

The trends between treatments differed significantly between years during both phases of the trial (1993/94 to 1998/99 and 1999/2000 to 2002/03). The NO_3-N concentration of the petioles for years selected to illustrate the impact that the cover crops and cover crop management practices had on grapevine nutrient status early in the grapevine growing season over time, are presented in Table 2. The NO_3-N concentration in the petioles of the young grapevines (1994/95 season) indicated that only the vines in the BB treatments of pink Seradella and grazing vetch were sufficiently supplied with N early in the grapevine growing season (Table 2), according to the norms of Conradie (1994). The NO_3-N concentration in the petioles of all the cover crop treatments was, with the exception of the AB treatments of rye, ‘Parabinga’ medic and grazing vetch, significantly more than that of weedchem and the control (Table 2). This indicated the importance of applying cover crop management, preferably with an N-fixing cover crop such as pink Seradella or grazing vetch, in young vineyards established on the sandy soils of the Olifants River Valley. The NO_3-N concentration in the petioles of the BB and AB treatment of a species differed significantly, with the NO_3-N concentration of the BB treatment being the higher of the two, making the latter the preferred cover crop management practice to be applied in young grapevines.

Although the cover crops performed poorly during the 1995/96 season (Fourie *et al*., 2006), the first season in which the grapevines were in full production (Table 1), the NO_3-N concentrations in the BB treatments and grazing vetch (MC) indicated that these grapevines were adequately supplied with N (Table 2), according to the norms of Conradie (1994). The growing cover crops in the AB treatments competed with the grapevines for N early in the growing season, causing the vines to be slightly, and in the case of ‘Parabinga’ medic (AB) severely, under-supplied with N (Table 2). ‘Saia’ oats (MC), weedchem and the control were also slightly under-supplied with N during the early grapevine growing season. This could be attributed to the inorganic N applied after bud break being fixed by the degradation process initiated by the incorporation of the ‘Saia’ oats fibre or weeds into the top soil, as well as leaching of N from the root zone of

Table 2. Effect of three cover crop management practices applied selectively to three cereals and four legumes on the NO_3-N concentration in leaf petioles during full bloom of young and full bearing Sauvignon blanc/Ramsey vines on a sandy soil near Lutzville.

Treatment	NO_3-N (mg/kg)				
	1994/95	1995/96	1997/98	1998/99	2002/03
Grain species:					
Secale cereale L. v. Henog (rye), BB[1].	550	735	771	753	983
Secale cereale L. v. Henog (rye) AB[2].	430	305[4]	537[4]	536	858
Avena sativa L. v. Overberg ('Overberg' oats), BB.	640	731	890	776	965
Avena sativa L. v. Overberg ('Overberg' oats), AB.	500	469[4]	534[4]	555	913
Avena strigosa L. v. Saia ('Saia' oats), BB.	597	742	917	837	994
Avena strigosa L. v. Saia ('Saia' oats), AB.	510	552[4]	442[4]	538	900
Avena strigosa L. v. Saia ('Saia' oats), MC[3].	495	597	533	471	661
N-fixing broadleaf species:					
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	550	727	1436	911	1300
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	496	428[4]	1184[4]	760	892
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	670	957	1504	847	1464
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	415	230[4]	887[4]	807	992
Ornithopus sativus L. v. Emena (pink Seradella), BB	816	1080	2020	996	984
Ornithopus sativus L. v. Emena (pink Seradella), AB	560	584[4]	2776[4]	939	1053
Vicia dasycarpa Ten. (grazing vetch),BB.	806	1205	1042	881	928
Vicia dasycarpa Ten. (grazing vetch), AB.	470	368[4]	2088[4]	976	1646
Vicia dasycarpa Ten. (grazing vetch), MC.	526	1009	1193	890	950
Weeds, MC (control).	426	516	715	626	617
Weeds, BB (weedchem).	422	504	704	628	651
LSD ($p \leq 0.05$)	68	130	176	85	171

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]Cover crop left to re-establish.

the grapevines promoted by the cultivation of the soil. The NO_3-N concentration in the BB treatments of 'Parabinga' medic, pink Seradella and grazing vetch, as well as grazing vetch (MC), was significantly higher than that of the BB treatments of the grain species. These N-fixing cover crops, therefore, supplied significant amounts of N to the grapevines during the early part of the growing season if controlled chemically or mechanically before bud break. According to the norms of Conradie (1994), this resulted in an over-supply of N in the case of pink Seradella and grazing vetch (Table 2), which led to excessive shoot growth (Table 1).

All the treatments sown with N-fixing cover crops, except 'Parabinga' medic (AB), were over-supplied with N during the early part of the 1997/98 grapevine growing season (Table 2), showing that 'Paraggio' medic, pink Seradella and grazing vetch impacted significantly on the N status of grapevines established on sandy soils in this region, irrespective of the management practice applied. Reducing the amount of N applied after bud break in the BB treatments of pink Seradella and grazing vetch, as well as grazing vetch (MC) by 50% for two seasons (1996/97 and 1997/98), therefore, did not suffice. In the case of the minimum cultivation treatments of grazing vetch and the pink Seradella, this over-supply of N led to excessive vegetative growth (Table 1). Reducing the amount of N applied after bud break in the AB treatments of grazing vetch and the pink Seradella by 50% and omitting the application of N after bud break in the BB treatments of these two species from the 1998/99 season onwards, normalized the N status of the grapevines during the early part of the growing season (Table 2). The amount of N applied after bud break in the two 'Paraggio' medic treatments and 'Parabinga' medic (BB), was not reduced, as the shoot growth in these treatments was not excessive during the 1997/98 season (Table 1). The normalization of the NO_3-N levels in these treatments in the following season was attributed to the poor performance of the cover crops, rendering them unable to supply the amount of N to the grapevines that caused the luxurious supply during the previous season. The cereals that were controlled chemically during berry set competed with the grapevines for nutrients throughout the first phase of the trial (1993/94 to 1998/99). This resulted in the grapevines in these treatments being slightly under-supplied with N early in the growing season (Table 2). Similar results were achieved with 'Saia' oats (MC), weedchem and the control. The NO_3-N concentration in the petioles of the grapevines in rye (AB), 'Saia' oats (AB) and ‘Saia’ oats (MC) was significantly less than that of weedchem and the control during the 1998/99 season (sixth season of the trial), indicating that the first-mentioned treatments had a significantly negative impact on the early season N status of the grapevines over the medium term. These treatments should not, therefore, be applied on the sandy soils of the Olifants River Valley.

During the second phase of the trial (1999/2000 to 2002/03) chemical control was applied mid-October in the AB treatments. The cover crops performed well during the 2001/02 and 2002/03 seasons (Fourie *et al.*, 2005), which resulted in the NO_3-N concentrations of the cover crop treatments, with the exception of ‘Saia’ oats (MC) being significantly higher than that of weedchem and the control (Table 2). The NO_3-N concentrations in the BB treatments of the Medicago species, as well as the AB treatments of pink Seradella and grazing vetch, however, indicated that the grapevines in these four treatments were over-supplied with N. The results suggest that the inorganic N applied in these four treatments should be reduced for the first-mentioned two treatments and omitted for the last-mentioned two species. The results indicated that pink Seradella and grazing vetch should preferably be controlled chemically during or before mid-October to optimize the supply of N to the grapevines during the early part of the growing season without the use of inorganic N during the growing season.

Juice analysis

The trends between treatments differed significantly between years as far as the sugar content, total acidity and pH were concerned. Trends between the BB and AB treatments within species, however, remained fairly consistent. The trend between weedchem and the control on the one hand and the cover crop management practices on the other also remained fairly consistent. To illustrate the trends that did occur, the results as measured during the fifth (1997/98) season of the experiment, a season during which the cover crops performed well, are presented in Table 3. The sugar content of the juice in the three MC treatments, weedchem, and ‘Parabinga’ medic (AB) was significantly higher than that of the two pink Seradella treatments, ‘Saia’ oats (BB), ‘Parabinga’ medic (BB) and grazing vetch (BB). The sugar content of the juice in the AB treatments also tended to be higher than that of the BB treatments, with the exception of pink Seradella. In the case of grazing vetch, this difference was significant. The total acidity of the juice in 'Parabinga' medic (BB) and pink Seradella (BB) was significantly higher than that of grazing vetch (MC), the AB treatments of the grain species and the AB treatments of the Medicago species. The total acidity of the juice in 'Saia' oats (BB), grazing vetch (BB) and pink Seradella (AB) was also higher than that of grazing vetch (MC), as well as the AB treatments of 'Overberg' oats, 'Saia' oats and 'Parabinga' medic. The total acidity of the juice in the BB treatments also tended to be higher than that of the AB treatments, with the exception of pink Seradella and grazing vetch, thus agreeing with the lower sugar contents. These trends were ascribed to crop sizes, as well as differences in vegetative growth and supported the results of Conradie (2001b) and Fourie *et al*. (2006).

The trends in the N concentration in the juice between treatments differed significantly between years during both phases of the trial (1993/94 to 1998/99 and 1999/2000 to 2002/03). The N concentration of the juice in the years selected to illustrate the impact that the cover crops and cover crop management practices had on the N concentration in the juice over time are presented in Table 4. The N concentration in the juice of the cover crop treatments during the 1995/96 season (the first season in which the grapevines were in full production) was, with the exception of 'Saia' oats (MC) and 'Parabinga' medic (AB), significantly more than that of weedchem and the control. The N concentration in the juice of pink Seradella (AB) was significantly higher than that of all the other treatments except 'Parabinga' medic (BB). This indicated that pink Seradella controlled chemically during berry set (end of November) supplied a significant amount of N to the grapevines from flowering to harvest. Although the grapevines in the BB treatments of pink Seradella and grazing vetch experienced an over-supply of N during the early part of the 1995/96 growing season of the grapevines (Table 2), excess N was not found in the juice (Table 4). The under-supply of N that the grapevines in 'Parabinga' medic (AB) experienced early in the 1995/96 growing season was also not apparent during harvest. With the exception of pink Seradella and grazing vetch, it tended to be beneficial for the N concentration of the juice of four year old grapevines if a cover crop species was controlled chemically before bud break on the sandy soils of the Olifants River Valley. The abnormally low values (W.J. Conradie, 2006 - personal communication) observed for the treatments in which no cover crops were sown, namely weedchem and the control (Table 4), indicated that cover crop management played an

Table 3. Effect of three cover crop management practices applied selectively to three cereals and four legumes on sugar, titratable acidity and pH of full bearing Sauvignon blanc/Ramsey vines on a sandy soil near Lutzville, during the fifth (1997/98) season.

Treatment	Sugar (˚B)	Total acids (g/L)	pH
Grain species:			
Secale cereale L. v. Henog (rye), BB[1].	22.5	8.17	3.13
Secale cereale L. v. Henog (rye) AB[2].	22.6[4]	7.70[4]	3.16[4]
Avena sativa L. v. Overberg ('Overberg' oats), BB.	22.3	7.87	3.14
Avena sativa L. v. Overberg ('Overberg' oats), AB.	22.6[4]	7.53[4]	3.15[4]
Avena strigosa L. v. Saia ('Saia' oats), BB.	22.0	8.53	3.04
Avena strigosa L. v. Saia ('Saia' oats), AB.	22.6[4]	7.40[4]	3.13[4]
Avena strigosa L. v. Saia ('Saia' oats), MC[3].	22.8	8.03	3.05
N-fixing broadleaf species:			
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	22.5	7.87	3.15
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	22.7[4]	7.70[4]	3.17[4]
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	22.0	8.70	3.11
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	22.9[4]	7.37[4]	3.09[4]
Ornithopus sativus L. v. Emena (pink Seradella), BB	21.6	8.77	3.14
Ornithopus sativus L. v. Emena (pink Seradella), AB	21.8[4]	8.53[4]	3.15[4]
Vicia dasycarpa Ten. (grazing vetch),BB.	21.5	8.57	3.17
Vicia dasycarpa Ten. (grazing vetch), AB.	22.3[4]	8.17[4]	3.15[4]
Vicia dasycarpa Ten. (grazing vetch), MC.	23.0	7.37	3.12
Weeds, MC (control).	22.8	7.83	3.10
Weeds, BB (weedchem).	22.8	8.0	3.09
LSD ($p \leq 0.05$)	0.7	0.97	NS[5]

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]Cover crop left to re-establish. [5]Values do not differ significantly at the 5% probability level.

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Table 4. Effect of three cover crop management practices applied selectively to three cereals and four legumes on the N concentration in the juice of Sauvignon blanc/Ramsey vines on a sandy soil near Lutzville.

Treatment	N (mg/L)			
	1995/96	1997/98	1998/99	2002/03
Grain species:				
Secale cereale L. v. Henog (rye), BB[1].	569	631	548	642
Secale cereale L. v. Henog (rye) AB[2].	557[4]	626[4]	543	649
Avena sativa L. v. Overberg ('Overberg' oats), BB.	625	649	573	652
Avena sativa L. v. Overberg ('Overberg' oats), AB.	538[4]	612[4]	401	586
Avena strigosa L. v. Saia ('Saia' oats), BB.	595	638	581	584
Avena strigosa L. v. Saia ('Saia' oats), AB.	557[4]	520[4]	386	653
Avena strigosa L. v. Saia ('Saia' oats), MC[3].	514	509	380	509
N-fixing broadleaf species:				
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	652	648	676	765
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	625[4]	653[4]	514	736
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	765	846	611	780
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	522[4]	624[4]	532	690
Ornithopus sativus L. v. Emena (pink Seradella), BB	659	757	615	640
Ornithopus sativus L. v. Emena (pink Seradella), AB	903[4]	866[4]	664	748
Vicia dasycarpa Ten. (grazing vetch),BB.	676	824[4]	705	829
Vicia dasycarpa Ten. (grazing vetch), AB.	732[4]	1165	730	1049
Vicia dasycarpa Ten. (grazing vetch), MC.	668	798	544	583
Weeds, MC (control).	391	604	513	597
Weeds, BB (weedchem).	360	565	554	601
LSD ($p \leq 0.05$)	149	81	68	100

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]Cover crop left to re-establish.

important role to help ensure that the grapevines were sufficiently supplied with N throughout the grapevine growing season on sandy soils.

The N concentration of the juice in 'Parabinga' medic (BB), as well as the treatments in which grazing vetch and pink Seradella was established, was significantly more than that of the other treatments during the 1997/98 season. These results were achieved with grazing vetch (BB) and pink Seradella (BB), despite a 50% reduction in the amount of inorganic N applied after bud break. This indicated that grazing vetch and pink Seradella supplied a significant amount of N to the grapevines from flowering to harvest irrespective of the management practice applied, while 'Parabinga' medic had to be controlled chemically before bud break to achieve similar results. The abnormally high concentration of N in the juice of the grazing vetch (AB) treatment indicated that the grapevines were not only over-supplied with N during the early part of the growing season (Table 2), but also from flowering to harvest (Table 4). The N concentration of the juice in the BB and AB treatments of grazing vetch and pink Seradella was significantly higher than that of the MC treatments, the two rye treatments, weedchem, as well as the AB treatments of the other cover crop species, as measured during the 1998/99 season. This was realized despite the fact that the BB treatments of grazing vetch and pink Seradella received no N after bud break and the amount of N applied after bud break in the AB treatments of these two species was reduced by 50%. This confirmed that pink Seradella and grazing vetch contributed significantly to the N status of the grapevines in the medium term (sixth season of the experiment) even when allowed to grow until the grapevines reached the berry set stage.

The N concentration in the juice of the grazing vetch (AB) treatment during the second phase of the trial was significantly higher than that of the other treatments and indicated that the inorganic N applied in this treatment should be withdrawn to prevent an over-supply of N to the grapevines in the period from flowering to harvest (Table 4). The N concentration in the juice of the BB treatments of grazing vetch and the two Medicago species was significantly higher than that of weedchem, the control and the treatments in which the grain species were sown. This indicated that grazing vetch and the two Medicago species combined with chemical control before bud break made a significant contribution towards the N status of the grapevines from flowering to harvest. As a high residual N content in the must may encourage microbial instability (Jiranek *et al*., 1995) and ethyl carbamate accumulation in wine (Ough, 1991; Henschke & Jiranek, 1993), the N status of the grapevines will need to be monitored annually if these treatments are applied over the long term in full bearing vineyards on sandy soils in the Olifants River Valley.

The P, K, Ca and Mg concentrations in the juice fluctuated from season to season, but trends remained fairly consistent. The mean values for the period 1995/96 to 1999/2000 are shown in Table 5. The concentration of K in the juice of the AB treatments of the two Medicago species was significantly lower than that of weedchem, indicating that these two species competed with the grapevines for K during the growing season if controlled chemically after bud break. The concentration of P in the juice of grazing vetch (BB) was significantly more than that of the other treatments. The concentration of Ca in the juice of the cover crop treatments was, with the exception of the pink Seradella treatments, significantly higher than that of weedchem and the control. The concentration of Mg in the juice of the BB and AB treatments of grazing vetch was significantly more than that of weedchem, the control and the AB treatments of the two Medicago species and pink Seradella. This could be attributed to these minerals being consumed by the relevant cover crops during its growing season and released from its fibre during the growing season of the grapevines.

Wine quality

Wine quality was not influenced by the different soil cultivation treatments (data not shown). This was similar to the results reported by Fourie *et al*. (2006) for Chardonnay/99 Richter vines established on a medium textured soil near Stellenbosch.

CONCLUSIONS

The effect of the different soil management practices started manifesting as early as the first season in which the treatments were applied. The annual sowing of a cover crop, preferably grazing vetch, in combination with post-emergence chemical control from just before bud break (BB), proved to be the soil management practice that should be applied in young vineyards on sandy soils in the warmer climatic regions. This will enhance the development of the permanent structure of trellised grapevines, while maximizing the harvest. When the grapevines reached full production (fourth growing

Table 5. Effect of three cover crop management practices applied selectively to three cereals and four legumes on the P, K, Ca and Mg concentrations in the juice of Sauvignon blanc/Ramsey vines on a sandy soil near Lutzville.

Treatment	P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
Grain species:				
Secale cereale L. v. Henog (rye), BB[1].	94	1324	53	92
Secale cereale L. v. Henog (rye) AB[2].	91	1308	52	87
Avena sativa L. v. Overberg ('Overberg' oats), BB.	97	1281	62	90
Avena sativa L. v. Overberg ('Overberg' oats), AB.	100	1297	62	89
Avena strigosa L. v. Saia ('Saia' oats), BB.	98	1166	57	89
Avena strigosa L. v. Saia ('Saia' oats), AB.	104	1365	60	91
Avena strigosa L. v. Saia ('Saia' oats), MC[3].	96	1316	66	90
N-fixing broadleaf species:				
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	85	1155	55	87
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	88	1024	52	80
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	98	1198	61	88
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	101	1058	59	85
Ornithopus sativus L. v. Emena (pink Seradella), BB	95	1327	46	86
Ornithopus sativus L. v. Emena (pink Seradella), AB	92	1258	36	78
Vicia dasycarpa Ten. (grazing vetch),BB.	116	1395	67	95
Vicia dasycarpa Ten. (grazing vetch), AB.	100	1256	58	96
Vicia dasycarpa Ten. (grazing vetch), MC.	92	1214	62	92
Weeds, MC (control).	93	1240	41	84
Weeds, BB (weedchem).	97	1303	40	85
LSD ($p \leq 0.05$)	13	157	10	9

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002).
[3]MC = chemical control in vine row, mechanical control in working row.

season, third season of the trial), the yield of the BB treatments in which grazing vetch, pink Seradella and 'Paraggio' medic was established, were superior to that of the grapevines in which the cover crops or weeds were mechanically incorporated into the top soil during bud break, as well as those in which the weeds were controlled chemically from just before bud break. Allowing the cereals and Medicago species to complete its life cycle had a negative effect on grapevine performance both in the short and medium term (treatments applied for six consecutive years). Mechanical control of weeds and a cereal cover crop from bud break or chemical control of weeds from just before bud break also impacted negatively on grapevine performance. The performance of full bearing grapevines established on a sandy soil was not affected negatively, if the cover crops were controlled chemically during mid-October.

It should be possible to reduce the inorganic N applied after bud break on sandy soils in the warmer climatic regions in the short term (approximately after three years) or even stop the application in the medium term (after approximately five years) when using pink Seradella or grazing vetch with BB as soil management practice. Indications are that it may also be possible to reduce the inorganic N applied after bud break over the medium to long term with the BB treatments of the two Medicago species, as well as that of grazing vetch and pink Seradella controlled chemically during berry set. The impact that the cover crops have on the N status of the grapevines will be dependant on the performance of the cover crop. Pink Seradella and grazing vetch had a positive effect on the N concentration in the juice of the grapevines, irrespective of the soil management practice applied. A similar result could probably be achieved with the two Medicago species if they were controlled chemically before bud break.

Although the different soil management practices affected grape yield significantly over the 10 year period, they did not affect berry volume or wine quality.

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CHAPTER 5

Cover crop management in a Sauvignon blanc/Ramsey vineyard in the semi-arid Olifants River Valley, South Africa. 3. Effect of different cover crops and cover crop management practices on organic matter and inorganic N content of a sandy soil.

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ABSTRACT

The trial was conducted over a period of ten years (1993/94 to 2002/03) on a sandy soil in a Sauvignon blanc/Ramsey vineyard near Lutzville (31°35'S, 18°52'E), situated in the

semi-arid Olifants River Valley of the Western Cape. Fourteen treatments, consisting of three grain species and four legumes, managed according to two cover crop management practices, were included. One management practice consisted of cover crops which were sown annually and full surface post-emergence chemical which was applied before bud break and when the berries reached pea size (BB). The second management practice consisted of the cover crops which were sown biennially. Post-emergence chemical control was applied to the vine row before bud break and full surface when the berries reached pea size (AB). From 1999/2000 to 2002/03 the cover crops were sown annually, while the full surface post-emergence control applied at the end of November (berries reached pea size) was advanced to mid-October. Two treatments in which *Avena sativa* L. v. Saia ('Saia' oats) and *Vicia dasycarpa* Ten. (grazing vetch) were sown annually, controlled mechanically in the work row and chemically in the vine row from bud break to harvest (MC), were also applied. These treatments were compared to a control, in which no cover crop was sown and MC was applied. A treatment in which no cover crop was sown and BB was applied (weedchem), was also included. After five years (1997/98), the soil organic matter (SOM) in the 0-150 mm soil layer of the BB and AB treatments of grazing vetch was significantly higher than that of the control and weedchem. During March 2003, the SOM content in the 0-600 mm soil layer of grazing vetch (AB), as well as the 0-150 mm soil layer of *Ornithopus sativus* L. v. Emena (pink Seradella) (AB) and *Secale cereale* L. v. Henog (rye) (BB), was significantly higher than that of the control and weedchem. The total inorganic N concentration (TIN) of pink Seradella (BB) was the highest in the 0-150 mm soil layer during the full bloom stage of the grapevines in 1995/96 and significantly higher than that of the other treatments in the 150-300 mm soil layer. The TIN in the AB treatments of grazing vetch and pink Seradella, as measured after the grapevine harvest (1995/96), was significantly higher than that of the control, weedchem and grain treatments in the 0-300 mm and 0-150 mm soil layers, respectively. The TIN in the 0-150 mm soil layer of the N-fixing broadleaf species was, with the exception of pink Seradella (BB), significantly more than that of the control, weedchem and the BB treatments of the grain species during March 2003. The TIN in the 150-300 mm soil layers of the AB treatments of pink Seradella and the two *Medicago truncatula* Gaertn. varieties, namely, Parabinga and Paraggio, was significantly higher than that of the control, weedchem and the grain treatments. Potassium concentrations in the 0-150 mm soil layer of the two pink

Seradella treatments, the AB treatment of rye,. *Medicago truncatula* Gaertn. v. Paraggio and grazing vetch, as well as the 150-300 mm soil layer of grazing vetch (BB) and pink Seradella (BB), were significantly higher than that of the control, weedchem and 'Saia' oats (MC) during March 1997.

INTRODUCTION

Maintenance and improvement of soil quality is critical to sustaining agricultural productivity (Reeves, 1997). Sicher *et al*. (1995) and *Fourie et al*. (2007a) observed that the effect of soil surface management on the organic matter content was restricted mainly to the 0-300 mm soil layer. Intensive clean cultivation reduced the organic matter content of the top soil over both the medium (Merwin & Styles, 1994) and long term (Laker, 1990). Fourie *et al*. (2007a), however, observed that the organic matter content of a medium textured soil could be maintained over a period of five years by allowing the weeds to grow during winter and by applying post-emergence control during the growing season of the grapevines. According to Gallaher & Ferrer (1987), the soil from no-tillage treatments averaged 27% more organic matter than that of the mechanically cultivated treatment in the 0-150 mm soil layer after a period of six years indicating that the latter management practice had a negative effect on the soil organic matter (SOM) content in the top soil. This was confirmed by Fourie *et al*.(2007a) who reported that the SOM of chemically clean cultivated soils decreased by 16% in the 0-300 mm soil layer over a period of six years. Larson *et al*. (1972) and Rasmussen *et al*. (1980) indicated that approximately 5 to 6 t/ha of plant residue is necessary to maintain the organic C levels in soils. Cover crop management increased the SOM of the soil over time to a greater or lesser extent (Kuo *et al*., 1997; Sanderson, 1998; Fourie *et al*., 2007a). Conradie (1994) indicated that it may not be necessary to apply fertilizer N to vineyards established on soils with a clay content of 6% or more, if the organic matter content exceeded the 1.5% level.

The growth and N contribution of cover crops depend on the species, length of the growing season, climate and soil conditions (Shennan, 1992). Dou *et al*. (1994) indicated that total N availability was also influenced by the tillage method applied. Under no-till a gradual increase, which lasted for approximately eight weeks after the legumes were controlled, was followed by a leveling off phase until the end of the season. Amato *et al*. (1987) observed that more N was mineralized from legume tops than from wheat straw. Van Huyssteen *et al*. (1984) found that *Vicia sativa* L. (broadleaf purple vetch) had 5.86% N available for recycling compared to the 2.05% N of *Lolium multiflorum* lam. (Wimmera ryegrass). The amount of N fixed by annual medics is closely associated with the total amount of dry matter produced (Holford, 1989; Peoples & Baldock, 2001) and, therefore, determines the N benefits to subsequent crops. Between 10% and 29% of the fixed N of temperate legumes are retained by the roots (Oke, 1967; Whiteman, 1971; Musa & Burhan, 1974; Jenkinson, 1981), indicating that the roots could also make a significant contribution towards the supply of N to subsequent crops. The N concentration of a cover crop varies with the stage of growth (Kuo *et al*., 1996), with the highest amount of N fixed by legumes occurring at the flowering stage or during pod fill (Imsande & Edwards, 1988; Imsande, 1989; Imsande & Touraine, 1994). The extent of mineralization would, therefore, also depend on the growth stage at which the cover crop was incorporated into the soil (Kuo *et al.*, 1996). Raised soil nitrate levels were detected three weeks after the incorporation of 'Paraggio' medic into the soil, at their highest five to 11 weeks and returning to low levels at 14 weeks (Sanderson & Fitzgerald, 1999). Chemical control of the cover crop also caused an increase in soil nitrate. Although the nitrate levels were not as high in the early breakdown and release phase, nitrate was still detectable in mid-December up to a depth of 500 mm, while it was absent in the cultivated plots. Cover crops that were sown biennially and left to grow until the berry set stage of the grapevines did not have a significantly negative impact on the N status of the soil early in the growing season of the grapevines (Fourie *et al.*, 2007a). Chemical control of cover crops during mid-October resulted in more N being available to the grapevines after harvest, while chemical control before bud break resulted in more N being available during full bloom on a medium textured soil situated in the relatively cool Coastal wine grape region of South Africa (Fourie *et al.*, 2007a). The effect of these management practices on the organic matter content and nutrient status of less fertile sandy soils in the warmer grapevine regions of South Africa is, however not known.

This study was conducted to determine the effect of two cover crop management practices applied to three cereals and four legumes on the organic matter and macro-

macro-nutrient content of a sandy soil in the semi-arid Olifants River Valley.

MATERIALS AND METHODS

Experiment vineyard and layout

The detailed experiment procedures and layout have already been described in Fourie *et al*. (2005). The trial was conducted in a Sauvignon blanc/Ramsey vineyard trained on a hedge trellis system (Archer & Booysen, 1987) and established on a sandy soil (98.6% sand) at the Nietvoorbij research farm near Lutzville (31°35'S, 18°52'E). During winter (April to August) irrigation was scheduled as described by Fourie *et al.* (2005) and during summer as described by Fourie *et al.* (2007b). The grapevines received 30 kg P/ha at the end of February (just before seedbed preparation), 30 kg K/ha and 14 kg N/ha during the second week of April (just after the cover crops were sown). At the two-to-four-leaf stage of the grass cover crops 28 kg N/ha was applied. Two weeks after bud break (late September), 30 kg K/ha and 42 kg N/ha were applied. The vines were spur pruned according to vigour and were suckered a few weeks after bud break. Shoot positioning was done and the vines tipped and topped as soon as the canes grew more than 100 mm past the highest line of the trellis system (approximately 1,1 m above the cordon of the vine).

Twenty three treatments were applied, of which 18 treatments are reported on with respect to soil reaction (Table 1). The remaining five are not relevant to the present trial. Two cover crop management practices were applied to seven cover crop species. One cover crop management practice consisted of cover crops being sown annually and full surface post-emergence chemical control being applied before bud break and when the berries reached pea size, i.e. the end of November (BB). The other cover crop management practice consisted of the cover crops being sown biennially and post-emergence chemical control being applied to the vine row before bud break and full surface when the berries reached pea size (AB). From 1999/2000 to 2002/03 the cover crops in the AB treatments were sown annually and the full surface post-emergence chemical control applied end of November was advanced to mid-October, since the species have proved unable to re-establish successfully in previous seasons (Fourie *et* *al*., 2005). Two treatments in which *Avena strigosa* L. v. Saia ('Saia' oats) and *Vicia dasycarpa* Ten. (grazing vetch) were sown annually and controlled mechanically in the working row and chemically in the vine row from before bud break to harvest (MC), were also applied. The cover crop treatments were compared to a control treatment, in which no cover crop was sown and MC was applied. A treatment in which no cover crop was sown and full surface post-emergence chemical weed control was applied from before bud break to harvest (weedchem), was also included.

Statistical procedures

Twenty three treatments were randomly allocated within each of three blocks. The treatment design was an (8x2)+7 factorial with factors eight cover crops, two management practices, as well as seven other practices. The experiment was repeated for 10 consecutive seasons (years). The size of each unit (plot) was 108 m^2. Eight experimental grapevines were used for measurements. Individual plots were separated by one border grapevine row and five border grapevines within rows. Analyses of variance were performed for each season separately, using SAS (SAS, 1990). Student's *t* least significant difference (LSD) values were calculated at a 5% significance level to facilitate comparison between treatment means. The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965).

Measurements

Soil was sampled annually from two positions in approximately the middle of the work row. Samples were drawn when the grapevines reached full bloom (early November) and after harvest, just before seedbed preparation was done (early March). The composite samples were analysed for pH (1.0 M KCl), P and K (Bray II), exchangeable K, Ca, Mg and Na (extracted with 0.2 M ammonium acetate) and organic carbon by means of the Walkley-Black method (The Non-affiliated Soil Analysis Work Committee, 1990). The NH_4-N and NO_3-N (extracted with 1.0 M KCl) were determined by means of the colorimetric method described by The Non-affiliated Soil Analysis Work Committee (1990).

RESULTS AND DISCUSSION

Soil organic matter (SOM)

The SOM (%C x 1.717) measured before the treatments commenced (March 1993), did not differ significantly between treatments in the 0-300 mm soil layer (Table 1). After five years, the SOM in the 0-150 mm soil layer of the BB and AB treatments of grazing vetch was significantly higher than that of weedchem and the control. The SOM in the 0-150 mm soil layer of all the cover crop treatments increased over the five year period, while that of weedchem did not change. This supported the observations of Fourie *et al*. (2007a) in a trial conducted on a medium textured soil in the Coastal region. The SOM in the minimum cultivated cover crop treatments increased with between 23% and 94% in the 0-300 mm soil layer, depending on species and management practice applied (Table 1). This supported the results of Gallaher & Ferrer (1987) and Fourie *et al*. (2007a). The 24% and 53% increases in SOM reported for the BB and AB treatments of ‘Paraggio’ medic, respectively (Table 1), were lower than the 75% increase reported by Sanderson (1998). The differences in SOM increase was attributed to the differences in average dry matter production (DMP) which was 2.99 t/ha/yr and 2.08 t/ha/yr for the BB and AB treatments of ‘Paraggio’ medic (Fourie *et al*., 2005), respectively, which were much lower than the 4.2 t/ha/yr of dry matter reported by Sanderson (1998). The SOM content in the 0-300 mm soil layer of grazing vetch (MC) increased by 35% over the five year period, while that of ‘Saia’ oats (MC) showed a slight increase of 5%. The SOM in the 0-150 mm soil layer of grazing vetch (MC) was significantly lower than that of grazing vetch (AB) as measured during March 1998 (Table 1), despite the fact that the average DMP of the species was similar for both treatments (Fourie *et al*., 2005). Although not significant, it was also 27% lower than that of the BB treatment of grazing vetch (Table 1). The SOM of the MC treatment of ‘Saia’ oats in the 0-300 mm soil layer also tended to be lower (between 15% and 26%) than that of the BB and AB treatments. The lower SOM observed in the MC treatments of a species compared to that of the AB and BB treatments of the same species, was attributed to accelerated breakdown caused by aerating the soil during mechanical cultivation. No significant differences or tendencies between treatments could be detected in the SOM of the 300-600 mm soil layer before the treatments commenced or after the treatments were applied for five seasons (data not shown).

During March 2003, the SOM content in the 0-600 mm soil layer of grazing vetch (AB) was significantly higher than that of the control and weedchem, indicating that this species/management combination made a significant impact on the SOM of this sandy soil (Table 2). The increase in the SOM content of the 0-300 mm soil layer in this treatment was 188%. In the case of *Ornithopus sativus* L. v. Emena (pink Seradella) (AB) and *S. cereale* L. v. Henog (rye) (BB) the SOM content of the 0-150 mm soil layer was significantly higher than that of the control and weedchem. The increase in the SOM content of the 0-300 mm soil layer of pink Seradella (AB) and rye (BB) was 59% and 71%, respectively. The increase in the SOM content of the 0-300 mm soil layer of the BB treatments of grazing vetch, pink Seradella and 'Saia' oats, as well as that of 'Saia' oats (AB), was more than 60%. These results indicated that grazing vetch, pink Seradella, rye and 'Saia oats have the ability to significantly increase the organic matter content of a sandy soil in the warmer climatic regions over the long term. After a period of ten years, the SOM in the 0-600 mm soil layer of the AB and the 150-300 mm soil layer of the BB treatment of grazing vetch was significantly higher than that of the MC treatment of the species (Table 1). Although not significant, the SOM in the 0-150 mm soil layer of grazing vetch (BB) was also 30% higher than that of grazing vetch (MC). The SOM of the MC treatment of 'Saia' oats in the 0-300 mm soil layer also tended to be lower (between 14% and 31%) than that of the BB and AB treatments of the species. This once again indicated that the mechanical incorporation of grazing vetch and 'Saia' oats into the soil led to accelerated breakdown of its fibre.

Total inorganic N

The trends between treatments differed significantly between years during both phases of the trial (1993/94 to 1998/99 and 1999/2000 to 2002/03). The total inorganic N (NH_4-N + NO_3-N) concentration in the soil during the full bloom stage of the grapevines and after harvest for years selected to illustrate the impact that the cover crops and cover crop management practices had on the N status of the soil over time are presented in Tables 3 to 5.

The 42 kg/ha inorganic N applied in the BB and MC treatments of grazing vetch and the BB treatment of pink Seradella was reduced by 50% from the 1995/96 season onwards, because of excessive vegetative growth observed in these treatments (Fourie *et al*., 2007b). Despite this, the total inorganic N concentration of pink Seradella (BB) was the highest in the 0-150 mm soil layer during the full bloom stage of the grapevines and significantly higher than that of the other treatments in the 150-300 mm soil layer during the third (1995/96) season of the trial (Table 3). This indicated that pink Seradella compensated sufficiently for the reduction in inorganic N applied after bud break in this treatment. The total inorganic N concentration in the 0-150 mm soil layer of the BB and MC treatments of grazing vetch also tended to be higher than that of the grain treatments, 'Paraggio' medic, *Medicago* truncatula Gaertn. v. Parabinga ('Parabinga' medic), weedchem and the control, indicating that grazing vetch could also compensate for the reduction in inorganic N applied. During the fifth season of the trial, the total inorganic N concentration in the 0-150 mm soil layer of the BB and AB treatments of grazing vetch and pink Seradella was significantly higher than that of the control, weedchem and grain treatments. This was also true for the 150-300 mm soil layer of grazing vetch (BB) and pink Seradella (AB). These results indicated that these two species could supply additional inorganic N to the grapevines during full bloom over the medium term, irrespective of the management practice applied. Although not significant, the total inorganic N concentration in the 0-300 mm soil layer of 'Paraggio' and 'Parabinga' medic tended to be higher than that of the control, weedchem and grain treatments. The above-mentioned results supported the findings of Amato *et al*. (1987) who indicated that more N was mineralized from legume tops than from wheat straw.

The 42 kg/ha inorganic N applied in the AB treatments of grazing vetch and pink Seradella after bud break was reduced by 50%, while no inorganic N was applied in the BB treatments of these two species from the 1998/99 season onwards. This was done to curb the excessive vegetative growth observed in these treatments during the 1997 season (Fourie *et al*., 2007b). Despite the reductions in inorganic N applied, the total inorganic N concentration in the 0-150 mm soil layer of the grazing vetch and pink Seradella treatments was significantly higher than that of the control, weedchem and grain treatments, as measured during the full bloom stage of the grapevines (Table 3). The total inorganic N concentration in the 150-300 mm soil layer of grazing vetch treatments was also significantly higher than that of the control, weedchem and grain species, with the exception of the AB treatments of rye and *Avena sativa* L. v. Overberg ('Overberg' oats). This indicates that grazing vetch and pink Seradella have the ability

Table 1. Effect of three cover crop management practices applied selectively to three cereals and four legumes on the soil organic matter (SOM) content in the 0-300 mm soil layer of a sandy soil near Lutzville , during march 1993 (before the treatments commenced) and March 1998 (fifth season of applying treatments).

Treatment	SOM (%)			
	March 1993	March 1998		
	0-300 mm soil layer	0-150 mm soil layer	150-300 mm soil layer	Average 0-300 mm soil layer
Grain species:				
Secale cereale L. v. Henog (rye), BB[2].	0.21	0.36	0.26	0.31
Secale cereale L. v. Henog (rye) AB[3].	0.22	0.22[5]	0.33[5]	0.27
Avena sativa L. v. Overberg ('Overberg' oats), BB.	0.21	0.26	0.24	0.26
Avena sativa L. v. Overberg ('Overberg' oats), AB.	0.19	0.34[5]	0.21[5]	0.27
Avena strigosa L. v. Saia ('Saia' oats), BB.	0.17	0.26	0.17	0.22
Avena strigosa L. v. Saia ('Saia' oats), AB.	0.19	0.27[5]	0.19[5]	0.24
Avena strigosa L. v. Saia ('Saia' oats), MC[4].	0.17	0.22	0.14	0.19
N-fixing broadleaf species:				
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	0.21	0.27	0.22	0.26
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	0.19	0.34[5]	0.24[5]	0.29
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	0.22	0.34	0.26	0.31
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	0.17	0.22[5]	0.21[5]	0.22
Ornithopus sativus L. v. Emena (pink Seradella), BB	0.19	0.34	0.24	0.29
Ornithopus sativus L. v. Emena (pink Seradella), AB	0.22	0.29[5]	0.24[5]	0.27
Vicia dasycarpa Ten. (grazing vetch),BB.	0.21	0.38	0.22	0.31
Vicia dasycarpa Ten. (grazing vetch), AB.	0.17	0.41[5]	0.22[5]	0.33
Vicia dasycarpa Ten. (grazing vetch), MC.	0.17	0.27	0.19	0.24
Weeds, MC (control).	0.17	0.22	0.14	0.19
Weeds, BB (weedchem).	0.22	0.24	0.19	0.22
LSD ($p \leq 0.05$)	NS[6]	0.12	0.10	NA[7]

[1]SOM = 1.717 x %C. [2]BB = full surface chemical control before bud break. [3]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [4]MC = chemical control in vine row, mechanical control in working row. [5]Cover crop left to re-establish. [6]NS = Data do not differ significantly on the 10% level. [7]NA = not applicable

Table 2. Effect of three cover crop management practices applied selectively to three cereals and four legumes on the soil organic matter (SOM) content in the 0-150 mm and 150-300 mm soil layers of a sandy soil near Lutzville during March 2003 (tenth season of applying the treatments).

Treatment	SOM (%)			
	0-150 mm soil layer	150-300 mm soil layer	300-600 mm soil layer	Average 0-300 mm soil layer
Grain species:			SOM (%)	
Secale cereale L. v. Henog (rye), BB[2].	0.43	0.29	0.22	0.36
Secale cereale L. v. Henog (rye) AB[3].	0.29	0.19	0.12	0.24
Avena sativa L. v. Overberg ('Overberg' oats), BB.	0.29	0.24	0.21	0.27
Avena sativa L. v. Overberg ('Overberg' oats), AB.	0.27	0.22	0.22	0.26
Avena strigosa L. v. Saia ('Saia' oats), BB.	0.33	0.26	0.22	0.29
Avena strigosa L. v. Saia ('Saia' oats), AB.	0.39	0.22	0.14	0.31
Avena strigosa L. v. Saia ('Saia' oats), MC[4].	0.27	0.19	0.15	0.24
N-fixing broadleaf species:				
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	0.33	0.24	0.14	0.29
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	0.29	0.24	0.15	0.27
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	0.27	0.21	0.12	0.24
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	0.27	0.21	0.14	0.24
Ornithopus sativus L. v. Emena (pink Seradella), BB	0.36	0.27	0.17	0.33
Ornithopus sativus L. v. Emena (pink Seradella), AB	0.43	0.27	0.15	0.36
Vicia dasycarpa Ten. (grazing vetch),BB.	0.41	0.31	0.12	0.36
Vicia dasycarpa Ten. (grazing vetch), AB.	0.57	0.41	0.31	0.50
Vicia dasycarpa Ten. (grazing vetch), MC.	0.29	0.12	0.09	0.21
Weeds, MC (control).	0.22	0.17	0.14	0.21
Weeds, BB (weedchem).	0.22	0.14	0.12	0.19
LSD ($p \leq 0.05$)	0.19	0.15	0.10	NA[5]

[1]SOM = 1.717 x %C. [2]BB = full surface chemical control before bud break. [3]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [4]MC = chemical control in vine row, mechanical control in working row. [5]NA

to make sufficient amounts of N available in the soil during the early part of the growing season over the medium term, to replace the inorganic N normally applied in the sandy soils of the Olifants River Valley. No significant differences or tendencies between treatments could be detected for the 300-600 mm soil layer during the 1995/96, 1997/98 and 1998/99 seasons (data not shown).

The total inorganic N concentration in the AB treatments of grazing vetch and pink Seradella, as measured after the grapevines were harvested during the 1995/96 season (third season of applying the treatments), was significantly higher than that of the control, weedchem and grain treatments in the 0-300 mm and 0-150 mm soil layers, respectively (Table 4). The total inorganic N concentration in the 150-300 mm soil layer of pink Seradella was also significantly higher than that of the control, weedchem, the two rye treatments and the BB treatments of the two oats species. These results indicated that these two species should be controlled during berry set, to improve the supply of inorganic N to the grapevines in the after harvest period. The total inorganic N concentration in the 0-300 mm soil layer of grazing vetch (AB) was significantly higher than that of the BB treatment. This significant difference also occurred in the 150-300 mm soil layer of the pink Seradella treatments. In the case of pink Seradella, this corresponded with a high level of N in the juice of the grapevines (Fourie *et al*., 2007b). Although not always significant, the total inorganic N concentration in the 0-600 mm soil layer of the AB treatment of a species always exceeded that of the BB treatment of the species, with the exception of 'Paraggio' and 'Parabinga' medic (Table 4). This supports the observations of Fourie *et al*. (2007a) in a trial conducted on a medium textured soil in the Coastal wine grape region of South Africa.

During the second phase of the trial (1999/2000 to 2002/03) the cover crops were controlled during mid-October in the AB treatments. No significant differences in total inorganic N concentrations were observed between treatments during the full bloom stage of the grapevines as indicated by the results of the 0-300 mm soil layer accumulated during the 2002/03 season (Table 5). Although the cover crops were controlled mid-October in the AB treatments during this season, the total inorganic N concentrations in the 0-300 mm soil layer of the AB treatment of a species still tended to be lower than that of the BB treatment of that species during full bloom, with the

Table 3. Effect of three cover crop management practices applied selectively to three cereals and four legumes on the total inorganic N (NH_4-N + NO_3-N) concentration in the 0-150 mm and 150-300 mm soil layers of a sandy soil near Lutzville during full bloom (early November), as measured during the third (1995/96), fifth (1997/98) and sixth (1998/99) seasons.

Treatment	Total inorganic N (mg/kg)					
	1995/96		1997/98		1998/99	
	0-150 mm soil layer	150-300 mm soil layer	0-150 mm soil layer	150-300 mm soil layer	0-150 mm soil layer	150-300 mm soil layer
Grain species:						
Secale cereale L. v. Henog (rye), BB[1].	3.96	2.27	3.40	2.35	1.79	1.55
Secale cereale L. v. Henog (rye) AB[2].	2.40[4]	2.51[4]	2.40[4]	2.67[4]	1.67	2.72
Avena sativa L. v. Overberg ('Overberg' oats), BB.	3.13	2.28	2.10	2.82	2.23	1.43
Avena sativa L. v. Overberg ('Overberg' oats), AB.	3.13[4]	2.83[4]	2.14[4]	1.56[4]	1.61	1.80
Avena strigosa L. v. Saia ('Saia' oats), BB.	3.14	2.19	3.80	3.69	2.01	1.28
Avena strigosa L. v. Saia ('Saia' oats), AB.	2.01[4]	1.79[4]	2.20[4]	1.47[4]	1.36	1.30
Avena strigosa L. v. Saia ('Saia' oats), MC[3].	2.37	2.35	1.30	2.02	1.75	1.41
N-fixing broadleaf species:						
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	2.53	2.04	5.26	4.44	3.36	2.37
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	2.72[4]	2.66[4]	5.60[4]	3.92[4]	3.00	2.71
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	2.63	2.33	5.43	4.19	2.17	2.02
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	2.71[4]	1.45[4]	4.92[4]	3.90[4]	2.60	2.38
Ornithopus sativus L. v. Emena (pink Seradella), BB	9.31	9.10	8.97	7.11	6.47	3.30
Ornithopus sativus L. v. Emena (pink Seradella), AB	5.06[4]	4.16[4]	9.83[4]	3.79[4]	5.92	2.89
Vicia dasycarpa Ten. (grazing vetch),BB.	6.18	3.96	7.63	4.28	5.22	5.36
Vicia dasycarpa Ten. (grazing vetch), AB.	4.98[4]	2.41[4]	14.20[4]	11.88[4]	5.34	5.04
Vicia dasycarpa Ten. (grazing vetch), MC.	6.08	2.91	6.88	4.81	6.65	5.61
Weeds, MC (control).	1.27	1.99	2.56	1.93	0.90	0.58
Weeds, BB (weedchem).	1.56	1.44	2.95	2.24	0.75	1.02
LSD ($p \leq 0.05$)	NS[5]	3.73[6]	4.48	3.24[6]	2.98	3.28[6]

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]Cover crop left to re-establish. [5]NS = Data do not differ significantly on the 10% level. [6]Data differ significantly on the 10% level.

exception of grazing vetch and pink Seradella. This was similar to the trends observed by Fourie *et al*. (2007a) on a medium textured soil in the Coastal grapevine region of South Africa. The difference in trend observed for the latter two treatments can be ascribed to the fact that no inorganic N was applied in the BB treatments of these two species during the 2002/03 season, while the AB treatments received 21 kg/ha inorganic N after bud break. The average total inorganic N concentration in the 0-300 mm soil layer of 'Paraggio medic (BB), 'Parabinga' medic (BB) and pink Seradella (AB) was higher than the 10 mg/kg level at which Conradie (1994) would usually deem it unnecessary to apply N fertilizer to grapevines. This also corresponded with elevated NO_3-N levels measured in the leaf stems of the grapevines in these treatments (Fourie *et al*., 2007b).

The total inorganic N concentration in the 0-150 mm soil layer of the N-fixing broadleaf species was, with the exception of pink Seradella (BB), significantly more than that of the control, weedchem and the treatments in which the grain species were controlled before bud break (Table 5). The total inorganic N concentration in the 150-300 mm soil layer of the AB treatments of pink Seradella, 'Parabinga' medic and 'Paraggio' medic was significantly higher than that of the control, weedchem and the cereal treatments. The legumes, therefore, showed the ability to supply significant amounts of inorganic N to the grapevines after harvest, especially if chemical control was applied during mid-October. In the case of the BB treatments of grazing vetch, 'Parabinga' medic and 'Paraggio' medic and the AB treatment of grazing vetch the elevated levels of inorganic N in the soil corresponded with abnormally high N concentrations in the grape juice (Fourie *et al*., 2007b).

Exchangeable K, Ca and Mg

Although significant differences in the P concentration and exchangeable Ca and Mg did occur between some treatments, no significant tendencies was detected in the measuring years, namely 1997, 2000 and 2003 (data not shown). The K concentration in the 0-150 mm soil layer of the two pink Seradella treatments and the AB treatments of rye, 'Paraggio' medic and grazing vetch was significantly higher than that of the control, weedchem and 'Saia' oats (MC) (Table 6). The K concentration in the 150-300 mm soil

Table 4. Effect of three cover crop management practices applied selectively to three cereals and four legumes on the total inorganic N (NH_4-N + NO_3-N) concentration in the 0-150 mm, 150-300 mm 300-600 mm soil layers of a sandy soil near Lutzville after harvest (March) during the third (1995/96) season of applying the treatments.

Treatment	Total inorganic N (mg/kg)		
	0-150 mm soil layer	150-300 mm soil layer	300-600 mm soil layer
Grain species:			
Secale cereale L. v. Henog (rye), BB[1].	3.24	1.48	1.45
Secale cereale L. v. Henog (rye) AB[2].	3.90	2.00	2.04
Avena sativa L. v. Overberg ('Overberg' oats), BB.	2.57	1.36	1.78
Avena sativa L. v. Overberg ('Overberg' oats), AB.	3.80	3.14	2.47
Avena strigosa L. v. Saia ('Saia' oats), BB.	2.75	2.13	1.56
Avena strigosa L. v. Saia ('Saia' oats), AB.	3.29	2.68	2.06
Avena strigosa L. v. Saia ('Saia' oats), MC[3].	2.20	1.65	1.09
N-fixing broadleaf species:			
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	3.83	2.27	1.89
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	3.70	2.21	2.17
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	3.52	1.80	1.63
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	3.06	1.60	1.49
Ornithopus sativus L. v. Emena (pink Seradella), BB	4.51	2.30	2.41
Ornithopus sativus L. v. Emena (pink Seradella), AB	6.30	4.79	5.61
Vicia dasycarpa Ten. (grazing vetch),BB.	4.38	2.80	2.51
Vicia dasycarpa Ten. (grazing vetch), AB.	7.21	6.37	4.72
Vicia dasycarpa Ten. (grazing vetch), MC.	4.20	1.87	1.76
Weeds, MC (control).	2.41	1.66	1.73
Weeds, BB (weedchem).	2.70	1.11	1.56
LSD ($p \leq 0.05$)	2.37	2.15	NS[5]

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]Cover crop left to re-establish. [5]NS = Data do not differ significantly on the 10% level.

Table 5. Effect of three cover crop management practices applied selectively to three cereals and four legumes on the total inorganic N (NH_4-N + NO_3-N) concentration in the 0-150 mm and 150-300 mm soil layers of a sandy soil near Lutzville during full bloom (early November) and after harvest (March), as measured during the tenth (2002/03) season of applying the treatments.

Treatment	Total inorganic N (mg/kg)			
	Full bloom		After harvest	
	0-150 mm soil layer	150-300 mm soil layer	0-150 mm soil layer	150-300 mm soil layer
Grain species:				
Secale cereale L. v. Henog (rye), BB[1].	8.30	8.34	6.88	4.33
Secale cereale L. v. Henog (rye) AB[2].	7.95	5.58	11.69	5.44
Avena sativa L. v. Overberg ('Overberg' oats), BB.	8.43	5.25	6.23	5.20
Avena sativa L. v. Overberg ('Overberg' oats), AB.	6.81	4.27	10.63	5.55
Avena strigosa L. v. Saia ('Saia' oats), BB.	8.09	5.59	5.25	5.24
Avena strigosa L. v. Saia ('Saia' oats), AB.	7.37	4.55	9.38	5.68
Avena strigosa L. v. Saia ('Saia' oats), MC[3].	5.22	3.41	6.74	4.22
N-fixing broadleaf species:				
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	11.18	9.23	19.45	11.01
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	8.34	7.88	22.38	21.51
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	12.02	9.13	17.63	9.72
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	9.56	7.35	17.36	15.80
Ornithopus sativus L. v. Emena (pink Seradella), BB	13.94	7.84	13.31	11.56
Ornithopus sativus L. v. Emena (pink Seradella), AB	17.14	10.88	17.60	19.91
Vicia dasycarpa Ten. (grazing vetch),BB.	7.41	6.40	18.53	4.11
Vicia dasycarpa Ten. (grazing vetch), AB.	10.93	8.18	18.73	12.12
Vicia dasycarpa Ten. (grazing vetch), MC.	7.71	4.32	16.16	4.96
Weeds, MC (control).	4.87	2.51	7.28	5.16
Weeds, BB (weedchem).	5.03	2.97	7.67	4.03
LSD ($p \leq 0.05$)	NS[4]	NS	7.33	7.27

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]NS = Data do not differ significantly on the 10% level.

Table 6. Effect of three cover crop management practices applied selectively to three cereals and four legumes on the K concentration in the 0-600 mm soil layer of a sandy soil near Lutzville after harvest (March), as measured during the fourth (1996/97) season of the trial.

Treatment	K (mg/kg)		
	0-150 mm soil layer	150-300 mm soil layer	300-600 mm soil layer
Grain species:			
Secale cereale L. v. Henog (rye), BB[1].	89	91	86
Secale cereale L. v. Henog (rye) AB[2].	101	85	81
Avena sativa L. v. Overberg ('Overberg' oats), BB.	85	82	83
Avena sativa L. v. Overberg ('Overberg' oats), AB.	92	94	75
Avena strigosa L. v. Saia ('Saia' oats), BB.	87	89	75
Avena strigosa L. v. Saia ('Saia' oats), AB.	89	97	89
Avena strigosa L. v. Saia ('Saia' oats), MC[3].	67	67	68
N-fixing broadleaf species:			
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	82	96	83
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	113	92	96
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), BB.	93	97	84
Medicago truncatula Gaertn v. Parabinga ('Parabinga' medic), AB.	85	82	84
Ornithopus sativus L. v. Emena (pink Seradella), BB	109	115	85
Ornithopus sativus L. v. Emena (pink Seradella), AB	107	96	94
Vicia dasycarpa Ten. (grazing vetch),BB.	84	94	86
Vicia dasycarpa Ten. (grazing vetch), AB.	105	105	89
Vicia dasycarpa Ten. (grazing vetch), MC.	88	84	85
Weeds, MC (control).	72	78	70
Weeds, BB (weedchem).	78	77	69
LSD ($p \leq 0.05$)	22	24	NS[4]

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]NS = Data do not differ significantly on the 10% level.

layer of grazing vetch (AB) and pink Seradella (BB) was also significantly higher than that of the last-mentioned three treatments. No significant differences were observed in the 300-600 mm soil layer. Although not significant, the K concentration in the 0-600 mm soil layer of the other cover crop treatments exceeded that of the control, weedchem and 'Saia' oats (MC). This is an indication that the cover crops must have incorporated some of the fertilizer K applied after bud break into their fibre, which was released back into the soil during breakdown to be available for consumption by the grapevines after harvest. Similar trends occurred during the 2000 and 2003 seasons (data not shown).

CONCLUSIONS

Grazing vetch, pink Seradella, rye and 'Saia' oats have the ability to significantly increase the organic matter content of a sandy soil in the Olifants River Valley over the long term. The SOM content of the 0-300 mm soil layer was improved to a greater extent if grazing vetch and 'Saia oats were controlled chemically and the top growth left on the soil surface than when these species were incorporated mechanically into the top soil during bud break.

The 42 kg/ha of inorganic N applied to the grapevines after bud break could be reduced by 50% after three seasons and omitted after six seasons where pink Seradella and grazing vetch was sown annually and controlled chemically before bud break (BB). The application of inorganic N to the grapevines after bud break could be reduced by 50% after six seasons where these two species were sown biennially and controlled chemically after bud break (AB). The application of these four practices did not affect the inorganic N concentration in the soil during the full bloom stage of the grapevines negatively over the long term. Pink Seradella and grazing vetch should be controlled chemically during berry set to improve the supply of inorganic N to the grapevines in the after harvest period. BB applied to 'Paraggio' and 'Parabinga' medic over the long term, increased the inorganic N concentration in the 0-300 mm soil layer to a level where a cut back in the application of inorganic N on these soils could be considered. The N-fixing broadleaf species showed the ability to supply significant amounts of inorganic N to the grapevines after harvest, especially if chemical control was applied during mid-October. The different cover crops and cover crop management practices had no significant effect on the P concentration or the exchangeable Ca and Mg of the 0-600 mm soil layer. Rye, 'Paraggio' medic and grazing vetch controlled chemically during the berry set stage of the grapevines had a significantly positive impact on the K concentration in the top soil layer after harvest. Pink Seradella increased the K concentration in the top soil irrespective of the management practice applied. These cover crops could, therefore, serve as catch crops for K on sandy soils.

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CHAPTER 6

Cover crop management in a Chardonnay/99 Richter vineyard in the Coastal wine grape region, South Africa. 1. Effect of two management practices on selected grass and broadleaf species.

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ABSTRACT

The trial was conducted over a period of 10 years (1993/94 to 2002/03) on a medium textured soil in a Chardonnay/99 Richter vineyard near Stellenbosch (33°55'S, 18°52'E), situated in the Coastal wine grape region of the Western Cape. Sixteen treatments, consisting of three cereals and five legumes managed according to two cover crop management practices, were included. These treatments were compared to a control treatment, in which no cover crop was sown and the weeds were controlled mechanically in the work row and chemically in the vine row from the first week of September to the end of March (grapevine growing season). A treatment in which no cover crop was sown and full surface post-emergence chemical control was applied during the grapevine growing season was also included. The different weed control actions were carried out during the first week of September and/or at the end of November, as well as mid October (1999/00 to 2002/03). *Secale cereale* L. v. Henog (rye), *Avena sativa* L. v. Overberg ('Overberg' oats), *Avena strigosa* L. v. Saia and *Vicia faba* L. v. Fiord (only if sown annually and controlled chemically before bud break (BB)), showed the ability to produce, on average, significantly more dry matter during winter than the weeds in the region. The dry matter production of all the cover crops increased from the end of August to the end of November if left to complete their life cycles, with the exception of rye and 'Overberg' oats sown in early April. None of the cover crop species were able to re-establish successfully. Continuous effective suppression of winter growing weeds (less than 20% of the weed stand in the control) was achieved with 'Overberg' oats (BB) and 'Saia' oats (BB), while total suppression was achieved for six and five of the 10 years, respectively. Effective, long-term control of the summer growing weeds was obtained with rye (BB), 'Overberg' oats (BB) and 'Saia' oats (BB).

INTRODUCTION

An increasing number of weed species are developing resistance to herbicides and even to groups of herbicides with different modes of action (LeBaron, 1991; Anonymous, 1997; Henkes, 1997). Certain weed species can be controlled with biological agents (Cullen *et al*., 1973; Daniel *et al*., 1973; Woodhead, 1981; Phatak *et al*., 1983). The vacated niche will, however, be filled by other species not susceptible to the agent (Putnam, 1990). Cover crop management is a non-specific biological method of pre-emergence weed control, which has many advantages (Van Huyssteen *et al*., 1984; Khan *et al*., 1986, Radcliffe *et al.*, 1988; Roth *et al*., 1988; Louw & Bennie, 1992; Buckerfield & Webster, 1996).

The difference in climate between regions, as well as the spectrum of winter growing weeds in a specific region, has an effect on the performance of a cover crop species (Fourie *et al*., 2001). A selection of species suitable for cover crop management in the different grapevine regions is required to apply this environment friendly practice in a sustainable manner, as part of an integrated production strategy (Fourie *et al*., 2001). In this regard it was indicated that *Secale cereale* L. (rye), two *Avena* (oat) species and *Triticale* v. Usgen 18 (triticale) could be considered for cover crop management on the medium textured soils of the Coastal wine grape region, situated in the Winter Rainfall region of South Africa (Fourie *et al*., 2001). They also indicated that three *Trifolium subterraneum* (subterranean clover) species, four *Medicago* (medic) species, three *Vicia* (vetch) species and *Ornithopus sativus* L. v. Emena (pink Seradella) should be included in further studies to determine whether the norm of eight t/ha of dry matter considered necessary by Van Huyssteen *et al*. (1984) for the effective control of summer growing weeds, was applicable to these species under the edaphic conditions of the Coastal region.

This study was carried out to determine the effect of two cover crop management practices on eight selected cover crop species, with the objective of supplying the wine grape industry with guidelines for sustainable cover crop management in vineyards established on medium textured soils in the Coastal wine grape region.

MATERIALS AND METHODS

Experiment vineyard and layout

The trial was carried out in a Chardonnay/99 Richter vineyard trained on a seven strand double lengthened Perold trellis system (Booysen, Steenkamp & Archer, 1992) and established on a medium textured soil (Table 1) at the Nietvoorbij research farm near Stellenbosch during November 1992. The soil used in the trial is representative of the top soil of medium textured soils found in the vineyards of the Coastal wine grape region of the Western Cape. Stellenbosch (33^{o}55'S, 18^{o}52'E) is situated in the Coastal wine grape region of the Western Cape. Mean annual rainfall amounts to 705 mm, of which approximately 73% precipitates during the autumn and winter (March to August). The vines were spaced 1.5 m in the row and 2.75 m between rows. The soil was analysed for pH (1.0 M KCl), P and K (Bray II), exchangeable K, Ca, Mg and Na (extracted with 0.2 M ammonium acetate) and organic carbon by means of the Walkley-Black method (The Non-affiliated Soil Analysis Work Committee, 1990). These analyses were done during March 1993 for the 0-300 mm and 300-600 mm soil layers, before the treatments were initiated (Table 1). The pH and P (Bray II) analyses were repeated during March 1997 and March 2000 on the 0-300 mm soil layer (Table 2).

Eighteen treatments were applied as shown in Table 3. Two cover crop management practices, namely full surface post-emergence chemical control from the first week in September (bud break) to the end of March (BB), which is the growing season of the grapevines, and full surface post-emergence chemical control from the stage when the berries reached pea size at the end of November to the end of March (AB), were applied to eight cover crop species. These treatments were compared to a control treatment, in which no cover crop was sown and the weeds were controlled mechanically in the work row and chemically in the vine row over the period from bud break to the end of March. A treatment in which no cover crop was sown and full surface post-emergence chemical control was applied during the growing season of the vines (weeds, BB) was also included. Weed control was carried out twice each year, namely just before bud break and at the end of November. From 1999 to 2002 all the species in the AB treatments were controlled chemically during mid October. Post-emergence weed control was applied with glyphosate at a rate of 1.44 kg/ha by means of a tractor sprayer.

The vineyard was irrigated by means of 25.7 L/h micro-sprinklers which had a 360^{o} wetting pattern. The micro-sprinklers were installed on the irrigation line in the upright position at 1.5 m intervals. Irrigation of the cover crops was scheduled as described by Fourie *et al.* (2001) for the first 10 weeks after sowing (April to mid June). Following this period, the cover crops were dependent on the rainfall, which is normally *ca* 109 mm, 127 mm and 121 mm for June, July and August, respectively, in this region. The cover crops were sown annually in early April (seeding dates varying between 4-15 April) at seeding densities suggested by Fourie *et al*. (2001), with the exception of 1993 when infra-structural work delayed sowing until 24 May. Seedbed preparation was done with a disc harrow approximately six weeks before the seeding date. The legume seeds were inoculated with a suitable *Rhizobium* strain just before the seeds were sown by hand and covered using a rotary harrow. During 1995 and 1997, no seeds were sown in the AB treatments to determine if the species would be able to re-establish themselves, while during 1999 this management practice was restricted to the N-fixing broadleaf species. From 2000 onwards, all the treatments were sown annually.

Table 1. Analyses of the medium textured soil near Stellenbosch determined before the treatments commenced (sampled March 1993).

Soil depth (mm)	Clay (%)	Silt (%)	Sand (%)	pH (KCl)	Electrical conductivity (mS/m)	Organic C (%)	P (mg/kg)	K (mg/kg)	Exchangeable cations (cmol(+)/kg)			
									Ca	Mg	K	Na
0-300	17.06	12.68	70.26	6.3	20	0.53	22	111	3.56	0.33	0.30	0.04
300-600	18.73	14.06	67.21	6.5	19	0.41	15	51	3.28	0.38	0.16	0.06

Table 2. Phosphorous concentration and pH in the 0-300 mm soil layer of the medium textured soil near Stellenbosch, as measured at the end of February 1993, 1997 and 1999.

Treatment	1993		1997			1999		
	0-300 mm		0-300 mm	0-150 mm	150-300 mm	0-300 mm	0-150 mm	150-300 mm
	pH (KCl)	P (mg/kg)	pH (KCl)	P (mg/kg)	P (mg/kg)	pH (KCl)	P (mg/kg)	P (mg/kg)
Grain species:								
Secale cereale L. v. Henog (rye), BB[1].	6.5	23	5.9	16	11	5.7	31	24
Secale cereale L. v. Henog (rye) AB[2].	6.8	23	6.1	19	10	5.9	30	22
Avena sativa L. v. Overberg ('Overberg' oats), BB.	6.7	22	5.9	17	11	6.0	27	24
Avena sativa L. v. Overberg ('Overberg' oats), AB.	6.9	27	5.9	17	8	5.8	30	23
Avena strigosa L. v. Saia ('Saia' oats), BB.	6.5	23	5.9	19	9	5.8	29	32
Avena strigosa L. v. Saia ('Saia' oats), AB.	6.6	22	6.2	23	18	6.0	27	26
N-fixing broadleaf species:								
Vicia dasycarpa Ten. (grazing vetch),BB.	6.8	26	6.3	19	10	6.1	26	26
Vicia dasycarpa Ten. (grazing vetch), AB.	6.8	22	6.3	15	10	6.1	28	27
Vicia faba L. v. Fiord (faba bean), BB.	6.7	23	6.1	16	10	6.0	27	22
Vicia faba L. v. Fiord (faba bean), AB.	6.7	24	5.9	13	7	5.6	30	20
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	6.7	29	5.8	22	19	5.6	29	22
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	6.8	30	5.9	21	16	5.8	26	28
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), BB.	6.3	27	6.0	18	9	5.9	32	20
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), AB.	6.8	27	6.1	18	14	5.7	30	18
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), BB.	6.8	25	6.0	15	11	5.8	24	24
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), AB.	6.9	25	5.9	20	15	6.0	30	24
LSD ($p \leq 0.05$)	NS[3]	NS	NS	9	7	NS	NS	NS

[1]BB = full surface post-emergence chemical control from just before bud break. [2]AB = full surface chemical control from the end of November (1993 to 1998) and from mid October (1999 to 2002). [3]Data do not differ significantly on the 5% level.

Table 3. Effect of two cover crop management practices on dry matter production (DMP) by three cereals and five legumes, measured at the end of August.

Treatment	DMP (t/ha)										
	1993[1]	1994	1995	1996	1997	1998	1999	2000	2001	2002	Average
Grain species:											
Secale cereale L. v. Henog (rye), BB[2].	1.37	5.13	4.56	5.51	3.42	3.90	1.53	3.22	2.22	2.38	3.32
Secale cereale L. v. Henog (rye) AB[3].	1.38	6.15	0[5]	8.50	0[5]	2.50	1.36	3.89	2.31	2.27	2.84
Avena sativa L. v. Overberg ('Overberg' oats), BB.	2.24	9.49	6.48	7.23	4.48	4.48	2.09	3.38	3.60	5.19	4.87
Avena sativa L. v. Overberg ('Overberg' oats), AB.	1.12	5.60	1.48[5]	7.21	0[5]	3.99	2.37	3.50	4.14	3.29	3.27
Avena strigosa L. v. Saia ('Saia' oats), BB.	0.97	6.13	4.83	5.90	4.13	3.98	2.08	2.79	3.26	3.44	3.75
Avena strigosa L. v. Saia ('Saia' oats), AB.	1.50	4.71	0.62[5]	6.17	0[5]	2.71	2.52	3.38	3.66	3.65	2.89
N-fixing broadleaf species:											
Vicia dasycarpa Ten. (grazing vetch),BB.	1.10	3.71	2.51	2.45	0	0.45	1.05	2.43	0.05	0	1.38
Vicia dasycarpa Ten. (grazing vetch), AB.	1.47	4.15	0.20[5]	2.35	0[5]	0.89	0.23[5]	4.22	0	0	1.35
Vicia faba L. v. Fiord (faba bean), BB.	1.60	3.34	3.53	5.16	1.57	3.42	0.46	5.10	3.55	2.41	3.04
Vicia faba L. v. Fiord (faba bean), AB.	2.57	3.26	0[5]	5.07	0.15[5]	3.56	0.79[5]	1.73	3.64	2.33	2.28
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	1.76	4.17	3.65	3.66	1.55	4.03	1.00	2.60	2.84	1.82	2.71
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	1.42	3.60	1.19[5]	2.23	0[5]	3.15	0.04[5]	1.73	2.22	1.41	1.70
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), BB.	1.78	4.18	4.44	5.05	1.01	1.38	1.35	2.64	1.99	2.04	2.59
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), AB.	2.14	4.01	0.20[5]	4.21	0.11[5]	1.33	0.38[5]	2.30	2.00	1.92	1.86
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), BB.	0.79	2.01	1.25	1.14	0.37	0.30	0.67	2.69	2.00	1.50	1.27
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), AB.	1.37	3.46	0[5]	1.64	0[5]	0.26	0[5]	2.11	2.15	1.38	1.24
Weeds, MC[4] (Control).	0.98	5.83	3.06	1.58	1.83	0.87	1.71	1.03	0.83	1.11	1.88
Weeds, BB.	0.59	4.01	3.57	2.95	1.70	0.98	1.15	0.65	1.34	1.33	1.73
LSD ($p \leq 0.05$)	0.76	2.97	1.76	1.11	NS[6]	0.74	1.04	1.90	1.47	0.99	NA[7]

[1]Cover crops established 24 May instead of early April. [2]BB = full surface post-emergence chemical control from just before bud break. [3]AB = full surface post-emergence chemical control from the end of November (1993 to 1998) and from mid October (1999 to 2002). [4]MC = chemical control in vine row, mechanical control in working row. [5]Cover crop left to re-establish. [6]Data do not differ significantly on the 5% level. [7]Not applicable

All the treatments received 14 kg/ha of N during seedbed preparation, as well as at the two to four leaf development phases of the grass cover crops. In the case of the N-fixing broadleaf cover crops, the N was applied to the vine row only, while in the other treatments it was broadcasted. From the 1998 season onwards, 19.5 kg of P/ha was broadcasted over all treatments at the end of February, just before seedbed preparation. This was intended to restore and maintain the P concentrations in the 0 to 300 mm soil layer at approximately 30 mg/kg (Table 2). This P concentration is the norm for grapevines established on these soils (Conradie, 1994), which is also the level that would help to ensure adequate growth rates with *Medicago* species (Sanderson, 1998). Calcitic lime was applied at a rate of 2.5 t/ha to the top soil layer at the end of February 2000, in order to enhance growth of the broadleaf species without exceeding the requirements for grapevines (W.J. Conradie, 2000 - personal communication). Dimethoate (150 ml/ha) was applied post-emergence to the two *Medicago* species and *Vicia dasycarpa* Ten. (grazing vetch) during 1999 in reaction to damage to the above-ground growth. From 2000 onwards the seeds of all the N-fixing broadleaf species were treated with dimethoate (600 ml/100 kg seed) to protect the emerging seedlings.

Measurements

Dry matter production (DMP) by both the cover crops and the associated weeds was determined at the end of August and again at the end of November, according to the procedure described by Fourie *et al*. (2001). To determine the number of viable seeds present in the top 100 mm of the soil, including the seeds on the soil surface, a square quadrat with an area of 0.25 m^2 was sampled at the end of February – six weeks before the seeding date. The soil was air dried and passed through an 850 micron sieve, to separate the organic matter and cover crop seeds from the soil. The cover crop seeds were then separated from the organic matter by hand. The viability of the seeds was determined by means of the “between paper” method prescribed by the International Seed Testing Association (1999).

Statistical procedures

The eighteen treatments were randomly allocated within each of three blocks. The design was an (8x2)+2 factorial with factors eight cover crops, two management practices, as well as two other practices. The experiment was repeated for 10 consecutive seasons (years). The size of each unit (plot) was 165 m^2. All variables were measured at random sites within each experiment unit at the end of August and end of November. Analyses of variance were performed for each season separately, using SAS (SAS, 1990). Student's *t* least significant difference (LSD) was calculated at a 5% significance level to facilitate comparison between treatment means. The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965).

RESULTS AND DISCUSSION

Dry matter production of cover crops

The DMP of the cover crop species in all the treatments, as measured before bud break (end of August), was lower during 1993 compared to that of the 1994 and 1996 seasons, the following two seasons during which the species were also established in all the treatments (Table 3). This was attributed to the fact that the cover crops could only be sown as late as 24 May during 1993, compared to early April during 1994 and 1996. This supports the results of Fourie *et al*. (2001) which indicated that these cover crops should be established before the second week of April in this region.

The long-term average DMP of the BB treatment of *Avena sativa* L. v. Overberg ('Overberg' oats) was the highest of all the treatments, and comparable to the values reported by Fourie *et al*. (2001) in a trial on open land. Although the long-term average DMP of the two *Medicago* species was less than that of the grain species, it was similar to production obtained on a sandy soil (Bolland, 1997; Fourie *et al.*, 2005), but approximately 35% less than production on open soil under similar edaphic conditions (Fourie *et al*., 2001). The long-term average DMP of grazing vetch and *Trifolium subterraneum* L. v. 'Woogenellup' subterranean clover was less than that of the weeds in the control and the weeds (BB) treatment, indicating that it is risky to use these two species as cover crops under conditions similar to that of the trial.

Ignoring seasonal fluctuations in performance, the DMP of rye (BB) at the end of August declined progressively from the 1996 season onwards (Table 3). The DMP in the BB treatments of the two *Avena* species showed a similar tendency to that observed in the BB treatment of rye. The decline in DMP was, however, more pronounced and occurred especially from 1997 to 1999. The application of P from the 1998 season onwards did not result in a significant increase in the DMP of the grain species. The tendency to produce less dry matter in 1997 as compared to that in 1998 (Table 3) was attributed to the much colder average daily temperatures in April 1997 and relatively low rainfall during July 1997 compared to that of 1998 (Table 4). The poor performance of the grain species during 1999 as compared to that in 1998 and 2000 (Table 2) could be attributed to the absence of rain in June 1999, followed by a relatively dry July (Table 4). This supports the data of Van Bosch & Pieterse (1995) who found that a reduction in the irrigation rate from 18 mm per week to 13 mm per week significantly reduced the DMP of rye, 'Overberg' oats and *Avena strigosa* L. v. Saia ('Saia' oats) by 1.2, 1.4 and 2 t/ha, respectively. The application of calcitic lime at a rate of 2.5 t/ha during seedbed preparation in 2000 seemed to have improved the DMP of the grain species slightly, but only in the short term and not to the levels measured from 1994 to 1996 (Table 3). The inability of the grain species to recover in full could have been caused by a gradual buildup of soil-borne diseases against these species as a result of the same species being sown year after year (Lamprecht *et al*., 1988; Lamprecht *et al*., 1990). This, however, was beyond the scope of this study. Overshadowing by the fully grown grapevines in the period from harvest to leaf-fall, might have contributed to the observed decline as well.

The DMP of grazing vetch in the period from 1994 to 1996 was similar to that reported by Fourie *et al*. (2001) under similar edaphic conditions (Table 3). From the 1997 season onwards, however, the performance of the species was exceptionally poor except in the 2000 season. The application of P from 1998 onwards, restored the level of P in the 0 to 300 mm soil level to approximately 30 mg/kg (Table 3), which was more than sufficient to supply the needs of the species employed (De Ruiter, 1981). Despite this, the DMP of the species did not improve. The increase in DMP that occurred from 1998 to 1999 (Table 3), despite the absence of rain in June 1999 (Table 4), could be attributed to the post-emergence application of dimethoate in reaction to damage to the above-ground growth. The drastic increase in the DMP of grazing vetch from 1999 to 2000 was attributed to the application of 2.5 t/ha of calcitic lime during seedbed preparation, as well as to the seeds having been treated with dimethoate (Table 3). During 2001 and 2002 the species was continuously grazed to the ground. This damage must have been caused by larger herbivores, selectively feeding on the grazing vetch.

Table 4. Average daily temperature and monthly rainfall as measured near the trial site at Nietvoorbij Research farm near Stellenbosch from April to August (Data supplied by ARC Institute for Soil, Climate and Water).

Month	Measurement	1994	1995	1996	1997	1998	1999	2000	2001	2002
April	Average daily temperature (°C)	19.5	17.7	18.2	15.9	17.9	17.9	18.2	17.6	17.7
	Total monthly rainfall (mm)	59	23	53	60	37	59	14	50	65
May	Average daily temperature (°C)	14.5	16.5	15.3	15.0	14.5	15.0	15.1	15.2	14.0
	Total monthly rainfall (mm)	47	95	58	82	197	59	107	174	124
June	Average daily temperature (°C)	11.6	13.5	12.7	11.6	12.6	14.1	14.3	13.0	11.7
	Total monthly rainfall (mm)	279	137	187	155	60	0	108	94	135
July	Average daily temperature (°C)	12.4	11.3	11.1	13.1	11.5	12.7	12.7	13.2	11.0
	Total monthly rainfall (mm)	96	147	96	30	77	79	118	288	182
August	Average daily temperature (°C)	12.9	12.6	11.6	12.8	12.8	13.6	14.0	12.6	12.6
	Total monthly rainfall (mm)	39	124	121	91	56	178	102	184	113
	Total winter rainfall (mm)	520	526	515	418	427	375	449	790	619

The DMP of *Vicia faba* L. v. Fiord (faba bean) differed considerably between seasons (Table 3) and was on average appreciably lower than that reported by Fourie *et al*. (2001). The performance of faba bean was exceptionally poor in the BB treatments during 1997 and 1999, despite the fact that the rainfall during both winters (Table 4) exceeded the minimum of 350 mm deemed necessary for sufficient growth by Lochner (1989). The relatively cold average daily temperatures in April, combined with a relatively low rainfall during July (Table 4) could, however, have had a negative effect on the performance of the cover crop in 1997. The application of P from 1998 onwards improved the DMP of faba bean initially (Table 3). Faba bean germinated poorly during 1999 (visual observation). This might have been caused by soil-borne pests attacking the emerging seedlings. The performance of the plants that did germinate, seemed to be further restricted by the absence of rain in June 1999, followed by a relatively dry July (Table 4). Treatment of the seeds with dimethoate, as well as the application of 2.5 t/ha of calcitic lime during seedbed preparation, resulted in faba bean producing more than five t/ha of dry matter at the end of August 2000 (Table 3). The exceptionally high rainfall during July 2001 and 2002 compared to that of July 2000 (Table 4) could have created conditions favourable for soil-borne diseases, which might have been responsible for the reduction in DMP during 2001 and 2002 compared to that of 2000 (Table 3).

The DMP of *Medicago scutellata* (L.) Mill. v. Kelson ('Kelson' medic) and *Medicago truncatula* Gaertn. v. Paraggio ('Paraggio' medic) in the BB treatments from 1994 to 1996 (Table 3) was similar to that reported by Fourie *et al.* (2001). The climatic conditions during 1997 (as described above), as well as the level of P in the 0-300 mm soil layer (Table 2) being lower than the level deemed necessary for good growth rates with the *Medicago* species (De Ruiter, 1981; Sanderson, 1998), could have contributed towards the poor performance of the two *Medicago* species during that year. The application of P during seedbed preparation in 1998 improved the DMP of 'Kelson' medic and 'Paraggio' medic in the BB treatments by 38% and 260%, respectively, compared to the DMP measured in these treatments in 1997 (Table 3). This supported the results of Nnadi & Haque (1988). The control of the pests must also have contributed towards the drastic increase in the DMP of 'Paraggio' medic. Despite the application of dimethoate and P, the species performed poorly during 1999. Although the pH of the soil measured in 1999 was lower than that at the beginning of the trial (Table 3), it still exceeded the minimum levels at which suppression of growth can be expected (Helyar & Anderson, 1971; Evans *et al*., 1990; Bordeleau & Prévost, 1994). Clarkson *et al*. (1987) reported that the amount of rainfall/irrigation received had a highly significant effect on the DMP of *M*. *truncatula* Gaertn v. Jemalong. The absence of rain in June 1999, followed by a relatively dry July, therefore, must have had a negative impact on the DMP of 'Paraggio' medic. The application of 2.5 t/ha of calcitic lime during seedbed preparation in 2000 approximately doubled the DMP of the two *Medicago* species, but could not restore it to the levels produced from 1994 to 1996. This was probably the result of an increase in soil-borne diseases suffered by these two species after being planted on the same plots for 10 consecutive years in the absence of a rotation system with grain species (Lamprecht *et al*., 1988; Lamprecht *et al*., 1990).

The DMP of *Trifolium subterraneum* L. v. Woogenellup ('Woogenellup' subterranean clover) followed much the same pattern as that of grazing vetch (Table 3). The application of 2.5 t/ha of calcitic lime during seedbed preparation and the treatment of the seeds with dimethoate in 2000 improved its performance to the same levels produced in 1994. The reduction in DMP from 2000 to 2002 was probably due to an increase in soil-borne diseases against the species after using it on the same soil for 10 consecutive years. The exceptionally high rainfall measured during July 2001and 2002 compared to that of July 2000 might also have affected cover crop growth negatively.

In 1993, when the cover crops were sown as late as 24 May, the DMP of all the cover crops increased from the end of August to the end of November (Table 5). If sown during early April, rye and 'Overberg' oats did not produce additional dry matter if left to die back naturally. The same results were obtained with 'Saia' oats, with the exception of 1998, when a considerable amount of additional growth took place from the end of August to the end of November. The lower rainfall during July and August 1998 compared to that of 1994, 1996, and 2000 (Table 4), might have retarded growth during this period, resulting in more growth from September to November in order for the species to complete its life cycle. 'Kelson' medic produced significantly more dry matter from the end of August to mid-October/end of November, with the exception of 1994, if it was allowed to complete its life cycle (Table 5). These results indicate that, in order to

Table 5. Percentage change in dry matter production (DMP) of the different cover crop species, from the end of August to the end of November, as determined in the treatments in which chemical control was applied at the end of November 1993 to 1998, and in mid - October 1999 to 2002.

Treatments	Change in DMP				
	1993[1]	1994[1]	1996[1]	1998[1]	2000[2]
Grain species:					
Secale cereale L. v. Henog (rye)	231	-40	-67	-58	-42
Avena sativa L. v. Overberg ('Overberg' oats)	263	-11	2	-53	-40
Avena strigosa L. v. Saia ('Saia' oats)	451	-13	-6	171	-38
N-fixing broadleaf species:					
Vicia dasycarpa Ten. (grazing vetch)	118	-52	-57	120	-4
Vicia faba L. v. Fiord (faba bean)	254	-39	-12	133	186
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic)	242	-15	-2	-24	116
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic)	250	-2	102	129	155
Trifolium subterraneum L. v. Woogenellup ('Woogenellup subterranean clover)	234	-28	183	-96	120
LSD ($p \leq 0.05$)	55	15	38	48	42

[1]Cover crops controlled chemically end of November. [2]Cover crops controlled chemically mid - October.

maximize DMP, 'Kelson' medic should rather be allowed to grow until mid-October than be controlled chemically at the end of August. Depending on the year, faba bean, and to a lesser extent 'Paraggio' medic and grazing vetch, also produced more dry matter when not controlled chemically at the end of August.

Potential of species to re-establish themselves

'Paraggio' medic showed the potential to re-establish in the 1995 season, as indicated by the dry matter in the AB treatment being 33% of that measured in the BB treatment (Table 3). The DMP of 1.19 t/ha (Table 3) achieved with 81 viable seeds per m^2 (Fig. 1), was similar to that reported by Fourie *et al*. (2005). Both the total and viable amount of seeds did not increase from 1995 onwards (Fig. 1). This could be attributed to the poor performance of the species during 1995 and 1997 in this treatment, due to poor re-establishment (Table 3), as well as the less favourable climatic conditions during 1997 described previously (Table 4), thereby not adding more seeds to the seedbed. The untimely germination of seeds during the summer could also have contributed to the observed decline. A large number of seeds were damaged during 1997 (Fig. 1), probably by soil-borne pests. The inability of the species to re-establish at all during 1997 and 1999 (Table 3) was probably due to the destruction of the germinating plants by soil-borne pests (Moulds, 1986; Porter, 1998). 'Kelson' medic, when left to die back naturally, produced considerably more seed than the seeding density used in the treatments in which the species were sown annually (Fig. 1). Most of these seeds were, however, hard-coated, with too small a percentage being viable in any season. Similar to 'Paraggio' medic, both the total and viable amount of seed did not increase from 1996 onwards. This could be attributed to both the poor performance of the species during 1997, thereby failing to sustain the seedbed, as well as to the probability of untimely germination of seeds during summer. Although the amount of water the two *Medicago* species received in the present study exceeded that deemed necessary for re-establishment (Tadmor *et al*., 1971; Tadmor *et al*., 1974) the seed density could not reach the amounts deemed necessary for successful re-establishment (Carter & Lake, 1985).

During 1999 the amount of viable seed produced by faba bean was 193% of the seeding density used in the treatment in which the species was sown annually (Table 6). This

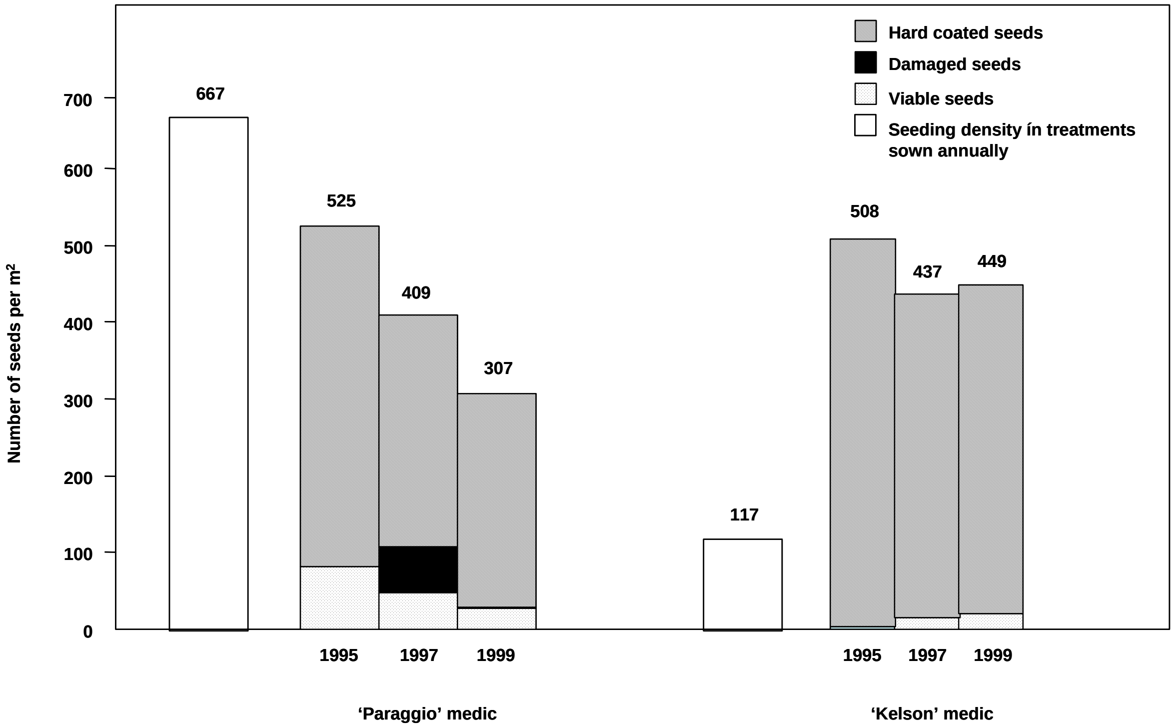

Figure 1. The number of seeds produced by *Medicago truncatula* Gaertn. v. Paraggio ('Paraggio' medic) and *M. scutellata* (L.) Mill. v. Kelson ('Kelson' medic) on a medium textured soil in Stellenbosch (Coastal wine grape region), if left to ripen.

resulted in the DMP of faba bean (AB) being 172% compared with that of faba bean (BB) as determined at the end of August 1999 (Table 3), indicating that the species had the ability to re-establish successfully in the short term. The DMP of grazing vetch (AB) was, however, only 22% compared with that of grazing vetch (BB) at the end of August 1999 (Table 3). This was despite the fact that the amount of viable seed produced was 50% of the seeding density used in the treatment in which the species was sown annually (Fig. 2). These results indicated that the species would not be able to re-establish successfully under similar edaphic conditions. The inability of 'Woogenellup' subterranean clover to re-establish (Table 3) was attributed to the species not producing significant amounts of viable seed over time. The considerable decline in the amount of seed from 1997 to 1999 (Fig. 2) could be attributed to the poor performance of this cover crop in the AB treatment during this period (Table 2). Damage to the seeds (Fig. 2), probably caused by soil-borne pests, might have contributed to the reduction in the amount of seed.

Table 6. Number of seeds produced by the cover crop species over a period of six years on a medium textured soil near Stellenbosch (Coastal wine grape region), if left to ripen.

Species	Number of seeds per m^2									
	Seeding density	1995			1997			1999		
		Total	Viable	Damaged	Total	Viable	Damaged	Total	Viable	Damaged
Grain species:										
Secale cereale L. v. Henog (rye)	304	13	5	8	115	26	89	12	3	9
Avena sativa L. v. Overberg ('Overberg' oats)	250	149	41	108	0	0	0	14	5	9
Avena strigosa L. v. Saia ('Saia' oats)	468	73	10	63	0	0	0	7	0	7
N-fixing broadleaf species:										
Vicia faba L. v. Fiord (faba bean)	14	0	0	0	13	3	10	36	27	9
LSD ($p \leq 0.05$)		224	23	13	139	54	65	77	25	6

The cereals could not re-establish successfully (Table 2). Although the number of seeds present in ‘Overberg’ oats (AB) was as high as 60% of the seeding density used in the BB treatment of the species during 1995 (Table 4), the species did not establish itself successfully (Table 2). This was attributed to the fact that only a relatively small fraction of these seeds (28%) was viable. The same phenomenon occurred in ‘Saia’ oats (AB) during 1995 and rye (AB) during 1997. This supported the results of Fourie *et al*. (2005). The number of viable seeds present in these three AB treatments during 1999, indicated that no buildup of viable seed occurred over time (Table 4). From 1999 onwards, the grain species were, therefore, sown in the AB treatments at the same seeding density used for the BB treatments.

Control of winter growing weeds

In the first year following the establishment of the vineyard in 1993, DMP of the winter growing weeds in the control and weeds (BB) treatments amounted to less than one t/ha (Table 7). This suggested that the deep pre-plant soil preparation during 1992 could have had a negative impact on the weed seed population in the top soil. The DMP of the winter growing weeds measured in these two treatments during 1994 was an indication that the weeds in this region have the ability to re-establish successfully within two years after initial deep soil preparation. The sharp decline in DMP of winter growing weeds measured in the control from 1994 to 1996, indicated that mechanical control, applied at the correct time from bud break to harvest, could reduce the stand of winter growing weeds in this region by as much as 73% within two seasons. The weed stand in the weeds (BB) treatment was reduced by 58% within three seasons (from 1994 to 1997). The foregoing results indicated that a large number of the winter growing weed species must have been prevented from producing seeds, thereby reducing the amount of seeds available for germination in the following seasons.

Continuous effective suppression of the winter growing weeds (less than 20% of the weed stand in the control) was only achieved with the BB treatments of the two *Avena* species (Table 7). Total suppression of the winter growing weeds was achieved with ‘Overberg’ oats (BB) and ‘Saia’ oats (BB) for six and five of the ten years, respectively. This enabled a 50% reduction in the amount of glyphosate that was applied for post-emergence weed control at the end of August during those years. Although the winter

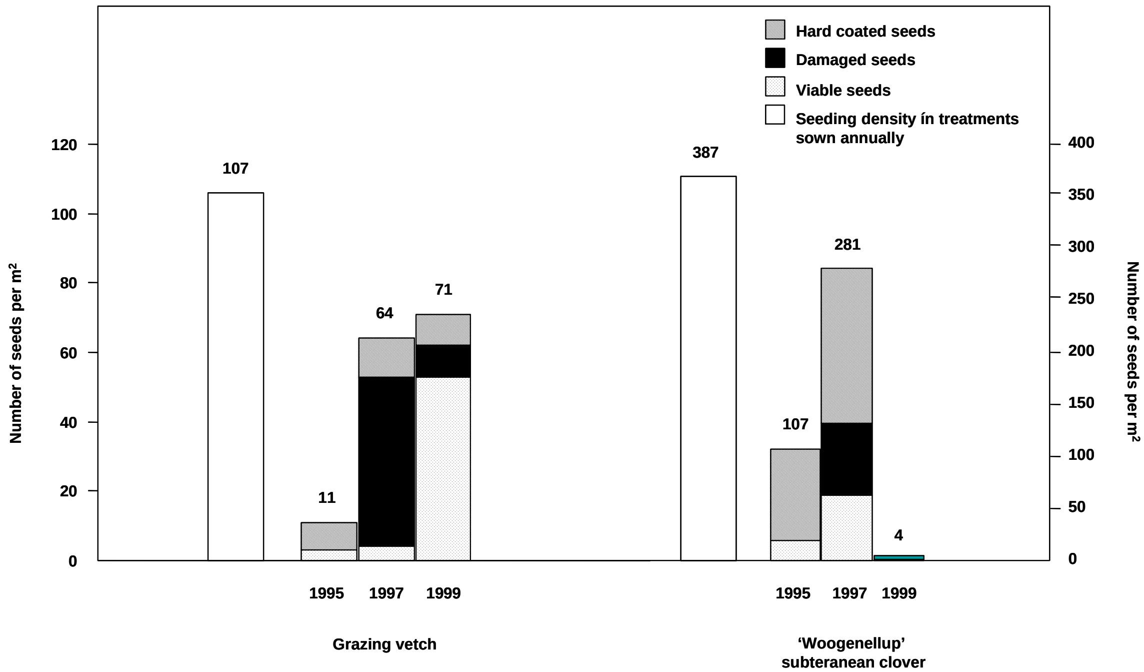

Figure 2. The number of seeds produced by *Vicia dasycarpa* Ten. (grazing vetch) and *Trifolium subterraneum* L. v. Woogenellup ('Woogenellup subterranean clover) on a medium textured soil in Stellenbosch (Coastal wine grape region), if left to ripen.

weed suppression by rye (BB) was not effective in some years, total suppression of the winter growing weeds was nevertheless achieved during 1996 and 1997, while effective weed suppression occurred during 1993, 1994 and 1998. A DMP in excess of four t/ha by rye at the end of August 1994, 1995 and 1996 (Table 2), combined with post-emergence chemical weed control during the first week of September, could have contributed towards the total weed suppression achieved with less than four t/ha of dry matter during 1997 (Table 7). This was probably caused by the prevention of weed seed production during the first-mentioned seasons. The exceptionally high amounts of dry matter produced at the end of August by the grain species in the AB treatments during 1996 (Table 3), prevented the winter growing weeds from germinating, although the weeds proliferated in these treatments during the previous winter (Table 7). This indicated a high weed seed density in these treatments. 'Saia' oats sown annually from 1998 onwards, in combination with chemical control in mid October from 1999 onwards, resulted in total winter weed suppression in 2001 and 2002. This management practice could, therefore, be applied if 'Saia' oats is used as cover crop, without the danger of increasing the competition from winter growing weeds over time.

Table 7. Effect of two cover crop management practices, applied to three cereals and five legumes, as well as two treatments in which no cover crops were sown and full surface chemical control and mechanical control was applied from bud break, respectively, on the dry matter production (DMP) of winter growing weeds, as measured end of August.

Treatment	DMP (t/ha)									
	1993[1]	1994	1995	1996	1997	1998	1999	2000	2001	2002
Grain species:										
Secale cereale L. v. Henog (rye), BB[2].	0.08	1.11	0.94	0	0	0.12	0.87	0.52	0.24	0.65
Secale cereale L. v. Henog (rye) AB[3].	0.20	1.10	3.87[5]	0	1.29[5]	1.40	1.22	0.20	0.85	0.76
Avena sativa L. v. Overberg ('Overberg' oats), BB.	0.01	0.40	0	0	0	0.01	0	0.20	0	0
Avena sativa L. v. Overberg ('Overberg' oats), AB.	0.06	0.54	3.34[5]	0	1.15[5]	1.24	0.55	0.30	0.23	0.97
Avena strigosa L. v. Saia ('Saia' oats), BB.	0.03	0.79	0	0	0.06	0.08	0.33	0	0	0
Avena strigosa L. v. Saia ('Saia' oats), AB.	0.01	0.82	4.21[5]	0	1.44[5]	0.26	0.02	0.62	0	0
N-fixing broadleaf species:										
Vicia dasycarpa Ten. (grazing vetch),BB.	0.15	0.81	0.45	1.22	1.24	0.54	0.94	0.38	0.49	1.04
Vicia dasycarpa Ten. (grazing vetch), AB.	0.11	0.99	3.33[5]	1.07	1.80[5]	1.09	0.96[5]	0.87	0.98	1.39
Vicia faba L. v. Fiord (faba bean), BB.	0.15	1.58	0.63	1.34	1.26	0.47	0.62	0.42	0.61	1.51
Vicia faba L. v. Fiord (faba bean), AB.	0.15	1.84	3.67[5]	1.34	1.32[5]	0.63	1.63[5]	0.81	0.43	1.51
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	0.14	2.00	1.04	0.06	1.42	0.47	1.41	0.19	0.41	1.99
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	0.05	1.87	2.04[5]	0.51	1.15[5]	0.53	0.63[5]	0.64	0.32	1.50
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), BB.	0.04	1.06	0.83	0	1.12	0.97	0.91	0.10	1.00	1.23
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), AB.	0.10	0.66	2.89[5]	0.14	1.51[5]	0.87	0.69[5]	0.14	0.80	1.85
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), BB.	0.02	1.45	1.65	0.34	1.57	0.60	0.26	0.30	1.13	0.64
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), AB.	0.19	1.42	2.77[5]	0.91	1.41[5]	1.01	0.84[5]	0.50	1.12	1.51
Weeds, MC[4] (Control).	0.98	5.83	3.06	1.58	1.83	0.87	1.71	1.03	0.83	1.11
Weeds, BB.	0.59	4.01	3.57	2.95	1.70	0.98	1.15	0.65	1.34	1.33
LSD ($p \leq 0.05$)	0.20	2.29	1.83	1.11	NS[6]	0.74	NS	0.67	NS	1.03

[1]Cover crops established 24 May instead of early April. [2]BB = full surface post-emergence chemical control from just before bud break. [3]AB = full surface post-emergence chemical control from the end of November (1993 to 1998) and from mid October (1999 to 2002). [4]MC = chemical control in vine row, mechanical control in working row. [5]Cover crop left to re-establish. [6]Data do not differ significantly on the 5% level.

Grazing vetch (BB) competed effectively with the winter growing weeds during the first three seasons of the trial (Table 7), with the DMP of the species still exceeding 2.5 t/ha if sown during April (Table 3). 'Kelson' medic suppressed the winter growing weeds effectively in both the BB and AB treatments during 1993, 1994, 1996 and 2000 (Table 7). This was achieved from 1994 onwards with dry matter productions exceeding 2.3 t/ha (Table 3). 'Paraggio' medic also showed the ability to effectively suppress the winter growing weeds during 1993, 1996 and 2000 (Table 7). This did not, however, correspond with the DMP of the species (Table 3).

Control of summer growing weeds

Long term effective control of the summer growing weeds, as measured at the end of November, was achieved with the BB treatments of the cereals (Table 8). This was achieved with dry matter productions of 2.22, 3.60 and 3.26 t/ha for rye, 'Overberg' oats and 'Saia' oats, respectively. This was considerably lower than the 5 t/ha deemed necessary by Van Huyssteen *et al*. (1984) for effective season-long weed control in an intensively irrigated vineyard in the warmer Klein Karoo wine grape region of South Africa. Effective control was also achieved with the 'Saia' oats (AB) treatment during the 1993, 1994 and 1996 seasons and the 'Overberg' oats (AB) treatment during 1993 and 1994. The results indicated, however, that 'Saia' oats (AB) and 'Overberg' oats (AB) should not be applied for longer than two consecutive years, as it may allow the weeds to produce seeds, and in doing so, promote a buildup in the weed population. No post-emergence weed control was necessary at the end of November in the treatments in which no summer weeds occurred. 'Overberg' oats (AB) and 'Saia' oats (AB) were, therefore, managed without the application of any herbicides during 1994 and 1996, respectively.

The legumes reduced the DMP of the summer growing weeds significantly over the long-term, if post-emergence chemical control was applied before bud break. Effective control was achieved in most years with the faba bean (BB) treatment. Initially, as well as when producing more than four tons of dry matter per ha (Table 2), 'Kelson' medic (BB) suppressed the summer growing weeds effectively (Table 8). Grazing vetch (BB) suppressed the summer weeds acceptably during the first three seasons only. Weed suppression with 'Paraggio' medic (BB) was erratic, with effective control being achieved during 1994, 1995 and 1997 only. 'Woogenellup' subterranean clover (BB)

Table 8. Effect of two cover crop management practices, applied to three cereals and five legumes, as well as two treatments in which no cover crop were sown and full surface chemical control and mechanical control was applied from bud break, respectively, on the dry matter production (DMP) of summer growing weeds, as measured end of November.

Treatment	DMP (t/ha)						
	1993[1]	1994	1995	1996	1997	1998	2001
Grain species:							
Secale cereale L. v. Henog (rye), BB[2].	0	0	0.22	0	0	0	0.06
Secale cereale L. v. Henog (rye) AB[3].	2.23	2.26	3.06[5]	1.83	2.72[5]	2.31	2.28
Avena sativa L. v. Overberg ('Overberg' oats), BB.	0	0	0.26	0	0	0	0.01
Avena sativa L. v. Overberg ('Overberg' oats), AB.	0.66	0	3.84[5]	0.70	3.59[5]	1.24	0.46
Avena strigosa L. v. Saia ('Saia' oats), BB.	0.01	0	0.22	0	0	0.08	0
Avena strigosa L. v. Saia ('Saia' oats), AB.	0.26	0.01	4.34[5]	0	0.95[5]	1.11	0.34
N-fixing broadleaf species:							
Vicia dasycarpa Ten. (grazing vetch),BB.	0.09	1.09	0.56	0.83	1.23	1.54	2.11
Vicia dasycarpa Ten. (grazing vetch), AB.	1.25	4.37	2.92[5]	0.41	1.02[5]	1.56	0.96
Vicia faba L. v. Fiord (faba bean), BB.	0.01	0.67	1.51	0.24	0.23	0.89	0.06
Vicia faba L. v. Fiord (faba bean), AB.	0.38	2.13	3.78[5]	3.30	2.17[5]	1.10	0.58
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	1.19	0	0.63	0.78	0.27	0.75	0.47
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	2.30	3.19	5.69[5]	4.12	2.64[5]	2.38	1.32
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), BB.	0.08	0	0.65	0.06	0.47	0.82	0.58
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), AB.	1.40	2.07	2.57[5]	2.24	1.32[5]	2.18	0.26
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), BB.	1.00	0.99	0.93	1.72	1.35	0.94	0.64
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), AB.	1.26	3.99	3.69[5]	6.14	2.59[5]	2.99	1.13
Weeds, MC[4] (Control).	3.43	4.76	3.32	2.05	1.84	1.82	1.78
Weeds, BB.	0.90	2.70	1.78	1.60	1.61	1.28	1.13
LSD ($p \leq 0.05$)	2.40	1.94	2.34	3.11	1.45	1.59	NS[6]

[1]Cover crops established 24 May instead of early April. [2]BB = full surface post-emergence chemical control from just before bud break. [3]AB = full surface post-emergence chemical control from the end of November (1993 to 1998) and from mid October (2001). [4]MC = chemical control in vine row, mechanical control in working row. [5]Cover crop left to re-establish itself on the AB treatments. [6]Data do not differ significantly on the 5% level.

could not suppress the summer growing weeds effectively, although it reduced the DMP of the weeds significantly during the first three seasons.

CONCLUSIONS

None of the cover crop species could re-establish successfully under the conditions prevalent in the trial. The cereals had the ability to produce significant amounts of dry matter over the long-term, despite the fact that they have been planted on the same soil for 10 consecutive years. The decline in DMP after four seasons, however, indicated that they should be rotated with other cover crop species. The cereals, with the exception of 'Saia' oats during one season, did not produce significantly more dry matter when left to complete its life cycle, if sown before mid April. It is, therefore, not worthwhile to allow these species to complete their life cycle if they were established before mid-April. The two oat species suppressed the winter growing weeds common to the Coastal grapevine region significantly, irrespective of the management practice applied. To achieve similar results with rye, however, post-emergence chemical control should be applied before bud break. To obtain effective suppression of the winter growing weeds in the region, the two oat species should be established annually and controlled chemically before bud break. The cereals controlled the summer growing weeds effectively if sown annually and controlled chemically before bud break. It seems, therefore, that this management practice should preferably be applied to the cereals on a well drained medium textured soil in this region.

'Woogenellup' subterranean clover should not be considered for cover crop management in this region. The other legumes also performed poorly over the long-term on this medium-textured soil. Faba bean, grazing vetch and the two *Medicago* species must not be established on the same soil for more than four consecutive years, since this would necessitate the use of additional chemicals as protection against pests and diseases. This defeats the purpose of reducing the use of chemicals in grapevine cultivation. The legumes produced more dry matter if allowed to complete their life cycle, irrespective of seeding date. To achieve effective weed control with these species, however, post-emergence chemical control must be applied before bud break. The preference for the use of legumes in a rotation system with cereals on medium textured soils in this region should be 'Kelson' medic > faba bean > grazing vetch > Paraggio medic.

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CHAPTER 7

Cover crop management in a Chardonnay/99 Richter vineyard in the Coastal region, South Africa. 2. Effect of different cover crops and cover crop management practices on grapevine performance.

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ABSTRACT

The trial was conducted over a period of 10 years (1993/94 to 2002/03) on a medium textured soil in a Chardonnay/99 Richter vineyard near Stellenbosch (33°55'S, 18°52'E), situated in the Coastal wine grape region of the Western Cape. Sixteen treatments, consisting of three cereals and five legumes, managed according to two cover crop

management practices, were included. The one cover crop management practice consisted of cover crops being sown annually and full surface post-emergence chemical control being applied before bud break and when the berries reached pea size (BB). The other management practice consisted of cover crops being sown biennially and post-emergence chemical control applied to the vine row before bud break and full surface when the berries reached pea size (AB). From 1999/2000 to 2002/03 the cover crops were sown annually, while the full surface post-emergence chemical control applied end of November was advanced to mid-October. These treatments were compared to a control, in which no cover crop was sown and the weeds were controlled mechanically in the work row and chemically in the vine row from bud break to harvest (approximately the first week of February). A treatment in which no cover crop was sown and full surface post-emergence chemical weed control was applied from before bud break to harvest (weedchem), was also included. During the 1994/95 season, the shoot mass of the two year old grapevines in the BB treatments was significantly higher than that of the control and the AB treatments. In the following season, the shoot mass and grape yield of the BB treatments was, with the exception of *Vicia faba* L. v. Fiord (faba bean) and *Avena sativa* L. v. Overberg, significantly higher than that of the control and weedchem. The grape yield of the control and AB treatments was significantly less than that of weedchem. Although significant differences in shoot mass (2000/01 and 2002/03) and grape yield (2002/03) were detected between treatments, no significant differences could be detected between the BB and AB treatments, with the exception of the shoot mass of *Medicago scuttelata* v. Kelson ('Kelson' medic). The mean petiole NO_3-N concentration for the period 1994/95 to 1998/99 tended to be lower in the AB treatment of a cover crop species compared to that of the BB treatment of the same species. In the case of 'Kelson' medic (BB) the petiole NO_3-N and juice N concentrations were significantly higher than that of the control and weedchem. The juice N concentration of the control and weedchem was significantly less than that of the faba bean treatments during 2000/01 and 2001/02, the *Vicia dasycarpa* Ten (grazing vetch) and 'Kelson' medic treatments during 2000/01, as well as that of *Medicago truncatula* Gaertn. (BB) and *Trifolium subterraneum* L. v. Woogenellup (BB) during the 2001/02 season. Wine quality did not differ between treatments.

INTRODUCTION

Maintenance and improvement of soil quality is critical if agricultural productivity and environmental quality is to be sustained for future generations (Reeves, 1997). The use of cover crops in vineyards reduces water runoff and erosion (Louw & Bennie, 1992), restricts evaporation from the soil surface (Van Huyssteen *et al*., 1984), conserves soil water (Buckerfield & Webster, 1996) and reduces temperature fluctuations in the soil (Van Huyssteen *et al*., 1984). It is also a non-specific method of pre-emergence weed control (Van Huyssteen *et al*., 1984; Fourie *et al*., 2001) and has the ability to suppress both winter and summer growing weeds (Fourie *et al*., 2005; Fourie *et al*., 2006).

Van Huyssteen & Weber (1980) found that grape production and pruning mass was affected significantly by the soil cultivation practice applied in a non-irrigated Chenin blanc vineyard established on a medium textured soil. The use of a permanent cover crop or a naturally established permanent cover (sward) in the work row resulted in a reduction in grapevine vigour compared to grapevines grown under mulch (Van Huyssteen & Weber, 1980; Soyer *et al*., 1984; Lombard *et al*., 1988; Pool *et al*., 1990). A permanent grass cover crop or sward also reduced the pruning weight of grapevines in comparison with grapevines in which a clover mix was used as permanent cover crop (Ingels *et al*., 2005), in which the weeds were disked in during early spring (Van Huyssteen & Weber, 1980; Pool *et al*., 1990; Ingels *et al*., 2005) and in which full surface chemical control was applied (Van Huyssteen & Weber, 1980; Sicher *et al*., 1995; Pinamonti *et al*., 1996). The use of a permanent cover crop or sward in the work row resulted in a significant reduction in grape yield compared to grapevines grown under other soil cultivation practices (Van Huyssteen & Weber, 1980; Soyer *et al*., 1984; Lombard *et al*., 1988; Sicher *et al*., 1995; Pinamonti *et al*., 1996). Pool *et al*. (1990) and Ingels *et al*. (2005), however, reported no difference, whereas Anonymous (1984) reported higher yields for grapevines with a permanent cover crop in comparison with grapevines in which other soil cultivation practices were applied. Buckerfield & Webster (1996) observed that the yields of grapevines under total straw or of grapevines in which the cover crop was slashed and thrown in the vine row and controlled chemically before bud break in the work row, were significantly higher than those of grapevines in which clean cultivation was applied.

A permanent grass cover crop significantly decreased the N concentration in the leaves of young *Vitis vinifera* L. cv. Chardonnay vines compared to that of the vines in which full surface chemical control was applied to a bare soil (Tan & Crabtree, 1990; Pinamonti *et al*., 1996). Similar results were reported by Soyer *et al*. (1984), Lombard *et al*. (1988) and Sicher *et al*. (1995). The P and K concentrations in the leaves of grapevines grown under a permanent grass cover crop were also significantly higher than that of grapevines grown under full surface chemical weed control or mechanical soil cultivation (Soyer *et al*., 1984; Sicher *et al*., 1995). Grapevine petiole N was significantly higher where a cover crop mix was disked in during early spring compared to grapevines in which weeds were disked in during early spring or where the cover crops were slashed (Ingels *et al*., 2005).

Soil management did not affect the soluble solids content and acidity of the grape juice at harvest (Lombard *et al*., 1988; Ingels *et al*., 2005). A straw mulch cover and full surface chemical control, however, induced a higher total titratable acid in the juice of non-irrigated Chenin blanc vines compared to vines in which a permanent cover crop was grown (Van Huyssteen, 1990). Stuck fermentation occurred for three consecutive years in the musts of non-irrigated Chenin blanc vines in which a permanent cover crop was grown in the work row. Dupuch (1997) indicated that must from a vineyard with green cover in the inter row took much longer to ferment all the sugar, compared to the must from a vineyard with no green cover. This was attributed to the musts being low in ammonium-N (Dupuch, 1997) and an N deficiency in the musts (Van Huyssteen, 1990), respectively, as a result of competition with the grapevines for nutrients during the growing season. Wine quality was affected by the bouquet being masked or denatured and the occurrence of marked bitterness and astringency to the palate in years when the competition of the grass growing in the inter rows with the grapevines was high (Maigre, 1997).

The reviewed literature indicated that a permanent grass cover crop competes with grapevines for water and nutrients. The effect of annual cover crops controlled chemically during different stages of the grapevine growing season on the performance of both young and fully grown vines, requires clarification. The growth and N contribution of cover crops depend on species, length of the growing season, climate and soil conditions (Shennan, 1992). The effect of different cover crop management practices on the ability of cover crops to contribute towards the N status of the vines must, therefore, also be clarified. This study was carried out to determine the effect of two cover crop management practices, applied to three grain and five N-fixing cover crop species, on the performance of Chardonnay/99 Richter vines established on a medium textured soil. The objective was to supply guidelines for sustainable cover crop management in vineyards on these soils in the Coastal grapevine region.

MATERIALS AND METHODS

Experiment vineyard and layout

The detailed experiment procedures and layout were previously described in Fourie *et al*. (2006). The trial was conducted in a Chardonnay/99 Richter vineyard trained on a hedge trellis system (Booysen, Steenkamp & Archer, 1992) and established on a medium textured soil (18% clay) at the Nietvoorbij research farm near Stellenbosch (33°55'S, 18°52'E). Irrigation was scheduled according to the guideline supplied by Fourie *et al.* (2001) for the first ten weeks (April to mid-June) after the cover crops were sown. No irrigation was applied from mid-June to mid-September. During summer the soil water content was determined weekly with a neutron moisture probe (CPN, series number H340502024). The neutron moisture probe was calibrated against gravimetric soil water content. Plant available water (PAW) was defined as water retained between field water capacity and -0.1 MPa and the grapevines were irrigated to field water capacity when approximately 60% PAW was depleted (P.A. Myburgh, 1993 - personal communication). The grapevines received 14 kg N/ha during seedbed preparation (first week of March) and 14 kg N/ha at the two to four leaf stage of the grass cover crops. From the 1998/99 season onwards, 19.5 kg P/ha was applied at the end of February. During the 2000/01 season, 2.5 t/ha of calcitic lime was applied at the end of February. The vines were spur pruned according to vigour and suckered a few weeks after bud break. Shoot positioning was done and the vines tipped and topped as soon as the canes grew more than 100 mm past the highest line of the trellis system (approximately 1,1 m above the cordon of the vine).

Eighteen treatments were applied (Table 1). Two cover crop management practices were applied to eight cover crop species. One cover crop management practice consisted of the cover crops being sown annually and full surface post-emergence chemical control being applied before bud break (first week of September) and when the berries reached pea size (end of November) (BB). The second management practice consisted of the cover crops being sown biennially and post-emergence chemical control being applied to the vine row before bud break and full surface when the berries reached pea size (AB). From 1999/2000 to 2002/03 the cover crops in the AB treatments were sown annually and the full surface post-emergence chemical control scheduled for the end of November was advanced to mid-October, since the species have proved unable to re-establish successfully in previous seasons (Fourie *et al*., 2006). The cover crop treatments were compared to a control, in which no cover crop was sown and weeds were controlled mechanically in the work row and chemically in the vine row just before bud break and at the end of November. A treatment in which no cover crop was sown and full surface post-emergence chemical control was applied just before bud break and at the end of November (weedchem), was also included in the trial.

Statistical procedures

Eighteen treatments were randomly allocated within each of three blocks. The treatment design was an (8x2)+2 factorial. Factors were eight cover crops, two management practices, plus two other practices. The experiment was repeated over 10 consecutive seasons (years). The size of each unit (plot) was 165 m^2. Ten experimental grapevines were used for measurements. Individual plots were separated by two border grapevine rows and five border grapevines within rows. Analyses of variance were performed for each season separately, using SAS (SAS, 1990). Student's *t* least significant difference (LSD) was calculated at the 5% significance level to facilitate comparison between treatment means. The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965).

Measurements

Shoot mass and grape yield

Shoot mass and grape yield were measured for ten seasons (1993/94 to 2002/03 and nine seasons (1994/95 to 2002/03), respectively. All treatments were harvested on the same date.

Table 1. Effect of two cover crop management practices applied to three cereals and five legumes, on the shoot mass (SM) and grape yield (GY) of young and full-bearing Chardonnay/99 Richter vines, established on a medium textured soil near Stellenbosch.

Treatment	1993/94	1994/95		1995/96		1998/99	
	SM (t/ha)	SM (t/ha)	GY (t/ha)	SM (t/ha)	GY (t/ha)	SM (t/ha)	GY (t/ha)
Grain species:							
Secale cereale L. v. Henog (rye), BB[1].	0.18	2.30	2.46	2.99	9.57	2.99	10.65
Secale cereale L. v. Henog (rye) AB[2].	0.13	0.61	1.67	2.06[4]	6.52[4]	2.97	8.22
Avena sativa L. v. Overberg ('Overberg' oats), BB.	0.18	1.81	2.33	2.74	8.69	3.06	11.77
Avena sativa L. v. Overberg ('Overberg' oats), AB.	0.11	0.36	1.28	1.41[4]	5.25[4]	2.87	9.57
Avena strigosa L. v. Saia ('Saia' oats), BB.	0.23	2.08	2.40	2.80	10.23	3.07	10.63
Avena strigosa L. v. Saia ('Saia' oats), AB.	0.12	0.80	1.48	2.03[4]	5.35[4]	2.68	8.92
N-fixing broadleaf species:							
Vicia dasycarpa Ten. (grazing vetch),BB.	0.23	1.96	3.20	2.87	10.57	3.54	11.25
Vicia dasycarpa Ten. (grazing vetch), AB.	0.14	0.69	1.36	2.17[4]	5.08[4]	3.01	9.69
Vicia faba L. v. Fiord (faba bean), BB.	0.16	2.01	1.79	2.71	7.69	3.67	11.41
Vicia faba L. v. Fiord (faba bean), AB.	0.16	0.52	1.50	2.32[4]	5.91[4]	3.15	9.24
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	0.26	2.38	2.96	2.97	10.11	3.66	11.52
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	0.09	0.44	1.50	2.09[4]	4.44[4]	3.02	8.26
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), BB.	0.20	2.21	2.67	3.09	9.48	3.52	11.37
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), AB.	0.09	0.52	1.67	2.28[4]	5.27[4]	2.85	9.16
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), BB.	0.23	2.11	2.57	3.03	9.65	3.62	11.97
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), AB.	0.10	0.67	1.16	2.03[4]	5.64[4]	2.89	9.67
Weeds, MC[3] (control).	0.11	0.50	1.62	1.89	5.96	3.06	9.95
Weeds, BB (weedchem).	0.17	2.04	2.42	2.39	7.79	3.00	9.83
LSD ($p \leq 0.05$)	0.08	0.41	0.99	0.57	0.97	0.69	NS[5]

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]Cover crop left to re-establish. [5]Data do not differ significantly on the 5% level.

Berry weight and volume

Berry weight and berry volume were determined from 1996/97 to 2002/03. One hundred berries were picked randomly from approximately 10 bunches for each treatment plot during harvest. The berries were weighed, after which the volume of these berries was determined volumetrically.

Petiole analysis

Petiole analyses were carried out over nine seasons (1994/95 to 2002/03). Leaf petioles were collected at full bloom from locations which were directly opposite the clusters. The leaves and petioles were separated immediately after sampling. Petiole samples were extracted with 1.0 M KCl and analysed colorimetrically for NO_3-N (The Non-affiliated Soil Analysis Work Committee, 1990).

Juice analysis.

The grapes were harvested when the sugar concentration averaged 22°B. A representative sample (approximately one bunch per experimental vine) from each plot was crushed in a hydraulic press. Free run juice was analysed for sugar content (temperature compensated Abbé refractometer), pH (654 Metrohm pH meter) and titratable acidity (50 mL juice titrated with 0.333 M NaOH to pH 7.0 and expressed as g tartaric acid/L). These measurements were done for nine seasons (1994/95 to 2002/03). Total juice N was determined for eight consecutive years (1995/96 to 2002/03) by means of an automated colorimetric method (The Non-affiliated Soil Analysis Work Committee, 1990), following digestion with selenous acid/sulphuric acid. Total P, K, Ca and Mg concentrations in juice were determined for four consecutive years (1995/96 to 1998/99) by means of atomic absorption spectrophotometry, following digestion with nitric acid/perchloric acid.

Experimental wines

Experimental wines were prepared from nine of the 18 treatments for four consecutive seasons, namely from 1996/97 to 1999/2000. Forty kg of grapes were harvested for each replication of the selected treatments. The grapes were crushed, de-stemmed and immediately pressed to 100 kPa in a small-scale pneumatic press. Sulfur dioxide was adjusted to 50 mg/L and 0.5 g/hL of Ultrazyme® was added. The juice was allowed to settle overnight at a temperature of 14°C. Clear juice was drawn off into 20 L stainless steel canisters and inoculated with 30 g/hL of *Saccharomyces cerevisiae* (VIN 7 from 1996 to 1998 and Vin 13 during 2000). Fermentation took place at 14°C. Diammonium phosphate (50 g/hL) was added to ensure a sufficient supply of N during fermentation. Bentonite (75 g/hL) was added two days after fermentation commenced. The wines were fermented to dryness, as tested with a Clinistix™ strip (Bayer, Cape Town), whereafter 50 mg/L of SO_2 was added. The wines were cold stabilised at 0°C for a minimum of one week, after which they were racked, filtered through K700 and EK filter sheets and bottled in 750 ml bottles. Free SO_2 was adjusted to 40 mg/L at bottling. The wines were stored at 14°C for three months before they were evaluated. Sensory evaluation was carried out by an experienced panel of 14 members on a nine point scorecard (Tromp & Conradie, 1979). The wines were presented in coded form and evaluated for overall wine quality, as well as for aroma and taste.

RESULTS AND DISCUSSION

Grape yield and shoot mass

The effect of the different management practices became apparent during the first season (1993/94) (Table 1). The shoot mass of the two year old vines (1993/94 season) in the BB treatments of *Avena strigosa* L. v. Saia ('Saia' oats), *Medicago scutellata* L. v. Kelson ('Kelson' medic), *Vicia dasycarpa* Ten. (grazing vetch) and *Trifolium subterraneum* L. v. Woogenellup ('Woogenellup' subterranean clover) was significantly higher than that of the mechanically cultivated control. The shoot mass of the grapevines in the BB treatment of *Medicago truncatula* Gaertn. v. Paraggio ('Paraggio' medic) was significantly more than both that of the control and weedchem, indicating that this treatment should preferably be applied in young vineyards. The trends that manifested during the second growing season of the vines (1993/94) became even more prominent in the following season (1994/95), the first season in which the permanent structure of the grapevines was developed in full and the grapevines produced their first harvest. During the 1994/95 season, the shoot mass of the grapevines in the BB treatments and weedchem was significantly higher (between 1.00 and 2.02 t/ha) than that of the control and AB treatments. These results indicated that minimum cultivation with post-emergence chemical control before bud break, preferably combined with the use of 'Paraggio' medic as cover crop, was the most effective soil management practice to be applied in young vineyards to enhance the development of the permanent structure of trellised vines. The first harvest from the grapevines in the BB treatments of grazing vetch and the two *Medicago* species was significantly higher than that of the control, indicating that these legumes had a positive impact on grape yield of young grapevines. The BB treatments of *Avena sativa* L. 'Overberg' ('Overberg' oats), grazing vetch and 'Paraggio' medic yielded significantly more grapes than the AB treatments of the corresponding species. This trend also occurred between the BB and AB treatments of the other cover crop species, although it did not manifest as strongly. The grape yield of the AB treatments was not, however, significantly lower than that of the control and weedchem, with the exception of the AB treatment of 'Woogenellup' subterranean clover in which the grapevines produced significantly less grapes than vines of the weedchem treatment. The annual cover crops, growing actively from bud break to when the berries reached pea size, reduced the growth of the irrigated young grapevines by between 61% and 82% compared to that of weedchem. The harvest was also reduced by between 31% and 47%. This corresponds with the results of Van Huyssteen & Weber (1980), who reported that a permanent sward in the work row reduced the growth and harvest of non-irrigated Chenin blanc vines established on a medium textured soil by 75% and 35%, respectively, compared to the grapevines in which full surface weed control was applied from bud break.

During the 1995/96 season, the first season in which the grapevines were in full production, the difference in shoot mass between the BB treatments on the one hand and the AB treatments and the control on the other was less than that observed in the 1994/95 season (Table 1). The shoot mass of the grapevines in the BB treatments, with the exception of *Vicia faba* L. v. Fiord (faba bean) and the two *Avena* species, were, however, still significantly higher than that of the grapevines in the control and AB treatments. The grape yield of the BB treatments, with the exception of faba bean and 'Overberg' oats, was significantly higher than that of the two treatments in which no cover crop was sown. The shoot mass and grape yield of the BB treatment of a cover crop was also significantly higher than that of the AB treatment of the same species. This indicated that most of the cover crops increasingly enhanced the performance of the grapevines on the medium textured soil, if controlled chemically before bud break. The grape yield in the mechanically cultivated control, being significantly less than that of the BB treatments, indicated that mechanical soil cultivation had a negative effect on grapevine production compared to minimum soil cultivation practices, if post-emergence chemical control was applied before bud break. The grape yield of the AB treatments was significantly less than that of weedchem, indicating that the cover crops had an increasingly negative effect on the young grapevines if left to complete their life cycles during the growing season of the grapevines. These results accentuated the importance of applying the correct cover crop management practice in young vineyards established on medium textured soils in the Coastal region of South Africa.

The impact of the different soil management practices on the full bearing grapevines seemed to become less over the medium term, as indicated by the shoot mass and grape yield measured during the 1998/99 season (Table 1). Although the shoot mass of some of the treatments still differed significantly, the differences were not as prominent as in the previous seasons. Grapevine growth in the treatments in which the grain species were sown, as well as that in the AB treatments of the N-fixing broadleaf species, was similar to that of the control and weedchem during the 1998/99 season. The growth of the grapevines in the BB treatments of the N-fixing cover crops tended to be vigorous compared to that of the foregoing treatments. Canopy density in the BB treatments of the N-fixing cover crops did not, however, affect grape yield negatively. Despite this, these treatments showed the potential to over-stimulate shoot growth on these medium textured soils in the Coastal region, with the danger of creating a dense canopy, especially under circumstances where the trellising system is smaller than that used in this trial. Although grape yield did not differ significantly between treatments, the yield of the BB treatments exceeded that of the control, weedchem and AB treatments by between 0.68 t/ha and 3.55 t/ha. The foregoing results indicated that the performance of full bearing irrigated grapevines in which annual cover crops were allowed to grow in the work row until the vines reached the berry set stage, was similar to that of grapevines in which mechanical weed control or full surface chemical control was applied from bud break to harvest. A cereal cover crop combined with full surface chemical control from bud break to harvest, however, enhanced grapevine performance and was the preferred soil management practice to be applied in the medium term on these medium textured soils in the Coastal grapevine region.

The cover crops in the AB treatments were controlled during mid-October from the 1999/2000 to the 2002/03 seasons. The results of the 2000/01 and 2002/03 seasons, which were representative of grapevine performance during this period, are shown in

Table 2. Although significant differences in shoot mass (2000/01 and 2002/03) and grape yield (2002/03) were detected between treatments, no significant differences were observed between the BB and AB treatments, with the exception of the shoot mass of 'Kelson' medic (Table 2). This supported the results of Pool *et al*. (1990), who found that chemical weed control before bud break or at bloom, respectively, did not affect the vegetative growth or yield of 'Concord' grapevines. Grapevine shoot mass in the BB treatment of 'Kelson' medic was significantly higher than most treatments during 2000/01 and all the treatments during 2002/03 (Table 2). Although not significant, the excessive shoot growth in this treatment seemed to have a negative effect on grape production during 2002/03. These results indicated that 'Kelson' medic should not be used continuously over the long term on medium textured soils in the Coastal grapevine region, since it could lead to excessive vegetative growth and eventually affect grape yield negatively. Although not significant, the grape yield of the cover crop treatments, with the exception of the faba bean treatments in 2000/01 and 'Kelson' medic (BB) in 2002/03, exceeded that of the control and weedchem. Faba bean, the two *Medicago* species and 'Woogenellup' subterranean clover controlled chemically during mid-October showed the ability to produce additional fibre between bud break and mid-October (Fourie *et al*., 2006). This management practice could, therefore, be applied to maximise dry matter production with these species, without compromising the performance of irrigated grapevines (Table 2).

Berry mass and volume

Although the grape yield differed significantly between treatments, no difference in either berry mass or berry volume was observed (data not shown).

Leaf petiole analysis

The NO_3-N concentration of the petioles fluctuated from season to season, but trends remained fairly consistent during the first phase (1994/95 to 1998/99) or medium term. The mean values for the medium term are shown in Table 3. The trends between treatments differed significantly between years during the second phase of the trial (1999/2000 to 2002/03). The trend between the BB and AB treatments of a species was, however, fairly consistent. The cover crops performed the best during the 2000/01 and 2001/02 seasons (Fourie *et al*., 2006). Data from these two seasons are, therefore,

Table 2. Effect of two cover crop management practices applied to three cereals and five legumes, on the shoot mass (SM) and grape yield (GY)of Chardonnay/99 Richter vines established on a medium textured soil near Stellenbosch, as measured during the eighth (2000/01) and tenth (2002/03) season of the experiment.

Treatment	2000/01		2002/03	
	SM (t/ha)	GY (t/ha)	SM (t/ha)	GY (t/ha)
Grain species:				
Secale cereale L. v. Henog (rye), BB[1].	3.18	13.00	2.85	12.62
Secale cereale L. v. Henog (rye) AB[2].	3.04	12.10	3.02	12.29
Avena sativa L. v. Overberg ('Overberg' oats), BB.	2.77	12.13	2.87	12.43
Avena sativa L. v. Overberg ('Overberg' oats), AB.	2.72	12.08	2.78	12.66
Avena strigosa L. v. Saia ('Saia' oats), BB.	2.92	12.59	2.81	12.55
Avena strigosa L. v. Saia ('Saia' oats), AB.	2.94	12.19	2.89	12.49
N-fixing broadleaf species:				
Vicia dasycarpa Ten. (grazing vetch),BB.	2.90	12.10	3.28	12.50
Vicia dasycarpa Ten. (grazing vetch), AB.	3.11	12.63	3.49	12.59
Vicia faba L. v. Fiord (faba bean), BB.	3.38	11.16	3.48	12.09
Vicia faba L. v. Fiord (faba bean), AB.	3.36	10.16	3.49	12.24
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	3.18	12.20	3.40	13.46
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	3.01	12.12	3.33	12.45
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), BB.	3.70	12.23	4.11	10.23
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), AB.	2.98	11.97	3.37	12.88
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), BB.	3.10	13.37	3.15	11.05
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), AB.	3.03	13.33	3.06	11.53
Weeds, MC[3] (control).	2.82	11.86	3.24	10.16
Weeds, BB (weedchem).	2.95	11.74	3.28	10.94
LSD ($p \leq 0.05$)	0.58	2.08	0.59	NS[4]

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]Data do not differ significantly on the 5% level.

presented to illustrate the impact the cover crops and cover crop management practices had on grapevine nutrient status early in the grapevine growing season during the second phase or long term (Table 3). The medium term NO_3-N concentration in the petioles indicated that the grapevines in the control and weedchem treatments, as well as those in AB treatments of faba bean, 'Paraggio' medic and 'Woogenellup' subterranean clover could have been slightly under-supplied with N from bud break to bloom, according to the norms of Conradie (1994). This was attributed to competition from summer growing weeds proliferating in these treatments from bud break to when the berries reached pea size (Fourie *et al*., 2006). The poor performance of the N-fixing cover crops in the AB treatments of the above-mentioned three cover crop species during the 1995 and 1997 seasons (Fourie *et al*., 2006) could have caused a reduction in the amount of N fixed. This, as well as untimely release of N by these species, could have contributed towards the insufficient supply of N during this period. The medium term NO_3-N concentration tended to be lower in the petioles of the AB treatment of a cover crop species compared to that of the BB treatment of the same species (Table 3). This illustrated that the cover crops and weeds growing in the AB treatments after bud break competed with the grapevines for N, to a greater or lesser extent, during the early part of the grapevine growing season. The NO_3-N concentration in the petioles of the BB treatment of 'Kelson' medic was significantly higher than that of the treatments in which no cover crop was sown (Table 3) and indicated a slight over-supply of N according to the norms of Conradie (1994). This trend became more pronounced during the 2000/01 and 2001/02 seasons (Table 3). Luxurious supply of N to the grapevines during the early part of the season resulted in excessive shoot growth over the long term (Table 2). The NO_3-N concentration in the petioles of 'Paraggio' medic (BB) and 'Kelson' medic (AB) indicated a luxurious supply of N to the grapevines during this period (Table 3). Grazing vetch caused an over-supply of N to the grapevines during the 2000/01 season, irrespective of the management practice applied. The poor performance of this cover crop during the 2001/02 season (Fourie *et al*., 2006), however, must have prevented this early season trend from re-occurring. The NO_3-N concentration in the petioles of the two faba bean treatments and 'Woogenellup' subterranean clover (BB) during 2001/02 indicated that these species also had the ability to create a luxurious supply of N to the grapevines at full bloom (Table 3). The N fixed by faba bean, grazing vetch and 'Kelson' medic became available in time for consumption by the grapevines if the species were controlled chemically not later than mid-October on these medium textured soils. The foregoing results indicate that N-fixing species should not be used continuously as cover crops over the long-term under conditions similar to that of the present trial, as it may lead to an early season over-supply of N which may cause vigorous grapevine growth.

Juice analysis

The mean sugar content of the juice in the BB treatments of the different cover crops tended to be lower than that of the AB treatments, the control and weedchem (Table 4). The mean total acidity of the BB treatment of a cover crop species tended to be higher and the pH lower than that of the AB treatment of the same species, thus agreeing with the lower sugar contents. In the case of 'Paraggio' medic and the subterranean clover, the differences in total acids were significant. This was ascribed to differences in crop size, as well as differences in vegetative growth. This supported the results of Conradie (2001), which indicated that increased vegetative growth delayed maturity.

The N concentration in the juice fluctuated from season to season, but trends remained fairly consistent over the medium term. The mean values for the medium term are shown in Table 5. The trends between treatments differed significantly between years during the second phase or long term. The cover crops performed best during the 2000/01 and 2001/02 seasons (Fourie *et al*., 2006). Data from these two seasons are, therefore, presented to illustrate the impact the cover crops and cover crop management practices had on grapevine nutrient status during harvest over the long term (Table 5). The N concentration in the juice of 'Kelson' medic (BB) was significantly higher than that of the control and weedchem over the medium term. This indicated that 'Kelson' medic supplied additional N to the grapevines from flowering to harvest over the medium term, if controlled chemically before bud break. The juice N concentration of the treatments in which the *Vicia* species and 'Kelson' medic were sown, was significantly higher than that of the control and weedchem during 2000/01. Similar results were obtained with the two faba bean treatments, 'Paraggio' medic (BB) and 'Woogenellup' subterranean clover (BB) during 2001/02. The N concentration in the juice of grazing vetch (BB) tending to be lower than that of grazing vetch (AB) during the 2000/01 and 2001/02 seasons was attributed to the cover crop dry matter production being considerably higher in the latter treatment than in the former treatment (Fourie *et al*., 2006), rather than to the effect of the two management practices. In the case of faba bean, however, the juice N concen-

Table 3. Effect of two cover crop management practices applied to three cereals and five legumes, on the NO_3-N concentration in leaf petioles during full bloom of Chardonnay/99 Richter vines established on a medium textured soil near Stellenbosch.

Treatment	Mean NO_3-N (mg/kg)	NO_3-N (mg/kg)	
	1994/95 to 1998/99	2000/01	2001/02
Grain species:			
Secale cereale L. v. Henog (rye), BB[1].	906	600	992
Secale cereale L. v. Henog (rye) AB[2].	700	687	825
Avena sativa L. v. Overberg ('Overberg' oats), BB.	791	433	993
Avena sativa L. v. Overberg ('Overberg' oats), AB.	762	667	600
Avena strigosa L. v. Saia ('Saia' oats), BB.	888	492	717
Avena strigosa L. v. Saia ('Saia' oats), AB.	740	450	767
N-fixing broadleaf species:			
Vicia dasycarpa Ten. (grazing vetch),BB.	874	1475	783
Vicia dasycarpa Ten. (grazing vetch), AB.	709	1567	933
Vicia faba L. v. Fiord (faba bean), BB.	928	842	1692
Vicia faba L. v. Fiord (faba bean), AB.	641	742	1633
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	749	1117	1242
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	604	517	892
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), BB.	1003	1142	1500
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), AB.	771	1308	1392
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), BB.	818	617	1084
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), AB.	627	542	967
Weeds, MC[3] (Control).	665	633	633
Weeds, BB.	686	608	942
LSD ($p \leq 0.05$)	261	311	343

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row.

Table 4. Effect of two cover crop management practices applied to three cereals and five legumes, on sugar, titratable acidity and pH of juice for Chardonnay/99 Richter vines established on a medium textured soil near Stellenbosch (means for 1994/95 to 2002/03).

Treatment	Sugar (°B)	Total acids (g/L)	pH
Grain species:			
Secale cereale L. v. Henog (rye), BB[1].	21.9	8.69	3.21
Secale cereale L. v. Henog (rye) AB[2].	22.0	8.49	3.27
Avena sativa L. v. Overberg (‘Overberg’ oats), BB.	21.9	8.97	3.19
Avena sativa L. v. Overberg (‘Overberg’ oats), AB.	22.4	8.79	3.21
Avena strigosa L. v. Saia (‘Saia’ oats), BB.	21.6	9.01	3.18
Avena strigosa L. v. Saia (‘Saia’ oats), AB.	22.1	8.92	3.21
N-fixing broadleaf species:			
Vicia dasycarpa Ten. (grazing vetch),BB.	21.6	8.97	3.22
Vicia dasycarpa Ten. (grazing vetch), AB.	22.8	8.67	3.22
Vicia faba L. v. Fiord (faba bean), BB.	22.1	8.83	3.23
Vicia faba L. v. Fiord (faba bean), AB.	22.4	8.71	3.24
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), BB.	22.1	9.14	3.22
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), AB.	22.2	8.65	3.24
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), BB.	22.1	8.91	3.24
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), AB.	22.2	8.76	3.22
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), BB.	21.1	9.15	3.20
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), AB.	21.8	8.79	3.41
Weeds, MC[3] (control).	22.1	8.81	3.21
Weeds, BB (weedchem).	22.1	8.97	3.18
LSD ($p \leq 0.05$)	NS[4]	0.35	NS

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]Data do not differ significantly on the 5% level.

tration was significantly higher in the AB treatment than in the BB treatment during the 2000/01 season (Table 5). This, as well as the NO_3-N concentration in the petioles of the AB treatment (Table 3), indicated that the species may be left to grow until mid-October without impacting negatively on the N status of the grapevines. The abnormally high N concentrations in the juice of 'Paraggio' medic (BB) and 'Woogenellup' subterranean clover (BB) indicated that these treatments over-supplied the grapevines with N throughout the 2001/02 growing season. As a high content in residual N in the must may encourage microbial instability (Jiranek *et al*., 1995) and ethyl carbamate accumulation in wine (Ough, 1991; Henschke & Jiranek, 1993), these treatments should be applied with caution over the long-term in full bearing vineyards established on medium textured soils in the Coastal grapevine region.

No significant differences in the concentration of P, Ca, Mg or Ca could be detected in the juice (data not shown).

Wine quality

Wine quality was not influenced by the different soil cultivation treatments (data not shown).

CONCLUSIONS

The effect of the different soil management practices started manifesting as early as the first season in which the treatments were applied. The annual sowing of a cover crop, preferably 'Paraggio medic', in combination with post-emergence chemical control from just before bud break to harvest (BB), proved to be the soil management practice that should be applied in young vineyards to enhance the development of the permanent structure of trellised vines. Even when the grapevines reached full production in the fourth growing season (third year that the treatments were applied) the vegetative growth and yield of the grapevines of most BB treatments were superior to that of the grapevines in which no cover crops were sown and the weeds were controlled mechanically or chemically in the work row. It was also beneficial to grapevine performance to control a cover crop chemically before bud break rather than allowing it to complete its life cycle. The last-mentioned management practice, as well as mechanical cultivation from bud break had a significantly negative effect on grapevine

Table 5. Effect of two cover crop management practices applied to three cereals and five legumes, on the N concentration in the juice of Chardonnay/99 Richter vines established on a medium textured soil near Stellenbosch.

Treatment	N (mg/L)		
	Mean values 1995/96 to 1998/99	2000/01	2001/02
Grain species:			
Secale cereale L. v. Henog (rye), BB[1].	460	494	570
Secale cereale L. v. Henog (rye) AB[2].	466	436	536
Avena sativa L. v. Overberg (‘Overberg’ oats), BB.	545	445	650
Avena sativa L. v. Overberg (‘Overberg’ oats), AB.	460	381	629
Avena strigosa L. v. Saia (‘Saia’ oats), BB.	558	413	561
Avena strigosa L. v. Saia (‘Saia’ oats), AB.	511	391	503
N-fixing broadleaf species:			
Vicia dasycarpa Ten. (grazing vetch),BB.	503	550	650
Vicia dasycarpa Ten. (grazing vetch), AB.	467	573	711
Vicia faba L. v. Fiord (faba bean), BB.	558	540	722
Vicia faba L. v. Fiord (faba bean), AB.	517	656	805
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), BB.	565	484	1121
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), AB.	511	490	642
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), BB.	601	644	691
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), AB.	554	553	625
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), BB.	507	459	1025
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), AB.	454	470	721
Weeds, MC[3] (control).	464	418	589
Weeds, BB (weedchem).	482	426	567
LSD ($p \leq 0.05$)	109	111	154

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002).
[3]MC = chemical control in vine row, mechanical control in working row. [4]Data do not differ significantly on the 5% level.

performance during the first four seasons and should, therefore, not be applied in young vineyards.

Although the legume cover crops were beneficial to grapevine performance initially, the supply of additional N from these species to the grapevines during the growing season may lead to excessive vegetative growth over the medium to long term. Care should, therefore, be taken to rotate these species on relatively fertile medium textured soils with a cereal after approximately four years to prevent this from happening. The performance of fully grown grapevines was not affected negatively, if the cover crops were controlled chemically during mid-October. This management practice could, therefore, be considered in the Coastal grapevine region during seasons when the rainfall in September and October is excessive, or even during dryer seasons if additional irrigation can be applied when necessary.

Although the different soil management practices affected grape yield significantly over the 10 year period, they did not affect berry volume and had no significant effect on wine quality.

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CHAPTER 8

Cover crop management in a Chardonnay/99 Richter vineyard in the Coastal region, South Africa. 3. Effect of different cover crops and cover crop management practices on organic matter and inorganic N content of a medium textured soil.

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ABSTRACT

The trial was conducted over a period of 10 years (1993/94 to 2002/03) on a medium textured soil in a Chardonnay/99 Richter vineyard near Stellenbosch (33°55'S, 18°52'E), situated in the Coastal wine grape region of the Western Cape. Sixteen treatments, consisting of three cereals and five legumes, managed according to two cover crop management practices, were included. In the one cover crop management practice cover crops were sown annually. Full surface post-emergence chemical control was applied before bud break and again when the berries reached pea size (BB). In the second management practice, cover crops were sown biennially. Post-emergence chemical control was applied to the vine row before bud break and full surface when the berries reached pea size (AB). From 1999/2000 to 2002/03 the cover crops were sown annually, while the full surface post-emergence chemical control applied end of November was advanced to mid-October. These treatments were compared to a control, in which no cover crop was sown and the weeds were controlled mechanically in the work row and chemically in the vine row from bud break to harvest (approximately the first week of February). A treatment in which no cover crop was sown and full surface post-emergence chemical weed control was applied from before bud break to harvest (weedchem), was also included. After five seasons the soil organic matter (SOM) content in the 0-300 mm soil layer increased in all the cover crop management treatments. In weedchem and the control SOM remained unchanged and decreased by 16%, respectively. The SOM content in the 0-150 mm soil layer of the cover crop treatments was, with the exception of grazing vetch, significantly higher than that of the mechanically cultivated control after a period of 10 years. The SOM content in the 0-300 mm soil layer of *Secale cereale* L. v. Henog and the treatments in which the N-fixing cover crops were sown (with the exception of *Vicia dasycarpa* Ten.) was significantly higher than that of weedchem. The total inorganic N concentration of the 0-150 mm soil layer in the BB treatments of the two *Medicago* species and *Trifolium subterraneum* L. v. Woogenellup, as measured for the 1996/97 season during full bloom of the grapevines, was significantly higher than that of the control, weedchem, and the AB treatments. The total inorganic N concentration of the 0-600 mm soil layer in the AB treatment of a species, as measured after the grapes were harvested during the 2002/03 season, tended to be higher than that of the BB treatment of that species. The applied treatments had no significant effect on the exchangeable K, Ca and Mg of the 0-600 mm soil layer.

INTRODUCTION

Maintenance and improvement of soil quality is critical for sustained agricultural productivity (Reeves, 1997). The effect of vineyard floor management practices on organic matter content was largely confined to the 0-200 mm soil layer (Sicher *et al*., 1995). According to Laker (1990) and Merwin & Stiles (1994), intensive clean cultivation reduced the organic matter content of the top soil over the long term. The organic matter content of chemically clean cultivated soils showed a decrease of 5.7% over a period of six years (Merwin & Stiles, 1994). After six years of applying no tillage treatments and mechanical soil cultivation on a Hernando loamy fine sand, the soil from the no-tillage treatments averaged 27% more organic matter than the mechanically cultivated treatment in the 0-150 mm soil layer (Gallaher & Ferrer, 1987). The organic matter content in grassed soil management treatments was significantly higher than that of the full surface chemical control and mechanically cultivated treatments (Sicher *et al*., 1995). Approximately 5 to 6 t/ha of plant residue is necessary to maintain the organic C level in soil (Larson et al., 1972; Rasmussen *et al*., 1980). Over a period of six years, a 150 mm thick straw mulch resulted in a 17% increase in organic matter in the 0-200 mm soil layer of a Hudson silty-clay loam with textural proportions of 7% sand, 71% silt and 22% clay and an initial organic matter content of 0.53%, (Merwin & Stiles, 1994). Continuous winter cropping with *Secale cereale* L. v. Tetra Petkus ('Tetra Petkus' rye) resulted in a small increase of soil organic carbon (5 to 10 mg/kg) compared to the control treatment in which no cover crop was sown (Kuo *et al*., 1997). The organic matter content in the 0-100 mm soil layer of a sandy loam soil was increased from 0.54% to 0.95% over a period of four years with *Medicago truncatula* Gaertn. v. Paraggio ('Paraggio' medic), if allowed to complete its life cycle and producing on average 4.2 t/ha/yr of dry matter (Sanderson, 1998). Conradie (1994) indicated that it may not be necessary to apply fertilizer N to vineyards established on soils with a clay content of 6% or more, if the organic matter content exceeded 1.5%.

Dou *et al*. (1994) observed that total N availability was strongly affected by the tillage method applied. Under no-till, a gradual increase, which lasted for approximately eight weeks after the legumes were controlled, was followed by a leveling off phase which persisted until the end of the season. The growth and N contribution of cover crops depend on the species, length of growing season, climate and soil conditions (Shennan, 1992). Amato *et al*. (1987) observed that more N was mineralized from legume tops than from wheat straw. Van Huyssteen *et al*. (1984) found that the fibre of *Vicia sativa* L. (broadleaf purple vetch) had 5.86% N available for recycling compared to the 2.05% N of *Lolium multiflorum* lam. (Wimmera ryegrass). The amount of N fixed by annual medics is closely associated with the total amount of dry matter produced (Holford, 1989; Peoples & Baldock, 2001). Dry matter production, therefore, determines the N benefits to subsequent crops. Between 10% and 29% of the fixed N of temperate legumes is retained by the roots (Oke, 1967; Whiteman, 1971; Musa & Burhan, 1974; Jenkinson, 1981), indicating that legume roots could make a significant contribution towards the supply of N to subsequent crops. The N concentration of a cover crop varies with the stage of growth (Kuo *et al*., 1996). In legumes, N fixation peaks at the flowering stage or during pod fill (Imsande & Edwards, 1988; Imsande, 1989; Imsande & Touraine, 1994). The amount of mineralizable N, therefore, depended on the growth stage at which the cover crop was incorporated into the soil (Kuo *et al*, 1996). Raised soil nitrate levels were detected three weeks after the incorporation of 'Paraggio' medic into the soil and were at their highest five to 11 weeks before returning to low levels at 14 weeks (Sanderson & Fitzgerald, 1999). Chemical control of the cover crop also caused an increase in soil nitrate. Although the nitrate levels were not as high in the early breakdown and release phase, nitrate was still detectable in mid-December up to a depth of 500 mm, while it was absent in the cultivated plots.

This study was conducted to determine the effect of two cover crop management practices applied to three grain species and five N-fixing broadleaf species on the organic matter and macro-nutrient content of a medium textured soil in the Coastal winegrape region of South Africa.

MATERIALS AND METHODS

Experiment vineyard and layout

The detailed experiment procedures and layout were previously described in Fourie *et al*. (2006). The trial was conducted in a Chardonnay/99 Richter vineyard trained on a hedge trellis system (Booysen *et al*., 1992) and established on a medium textured soil (18% clay) at the Nietvoorbij research farm near Stellenbosch (33^{o}55'S, 18^{o}52'E). Irrigation was scheduled according to the guideline supplied by Fourie *et al.* (2001) for the first ten weeks (April to mid-June) after the cover crops were sown. No irrigation was applied from mid-June to mid-September. During summer the irrigation was applied as described by Fourie *et al*. (2006b). The grapevines received 14 kg N/ha during seedbed preparation (first week of March) and 14 kg N/ha at the two to four leaf stage of the grass cover crops. The N in the treatments in which the cereals were sown was broadcasted, while the application of N to the treatments in which the legumes were sown was restricted to the vine row. From the 1998/99 season onwards, 19.5 kg P/ha was applied at the end of February. During the 2000/01 season, 2.5 t/ha of calcitic lime was applied at the end of February. The vines were spur pruned according to vigour and suckered a few weeks after bud break. Shoot positioning was done and the vines tipped and topped as soon as the canes grew more than 100 mm past the highest line of the trellis system (approximately 1,1 m above the cordon of the vine).

Eighteen treatments were applied (Table 1). Two cover crop management practices were applied to eight cover crop species. One cover crop management practice consisted of the cover crops being sown annually and full surface post-emergence chemical control being applied before bud break (first week of September) and when the berries reached pea size (end of November) (BB). The second management practice consisted of the cover crops being sown biennially and post-emergence chemical control being applied to the vine row before bud break and full surface when the berries reached pea size (AB). From 1999/2000 to 2002/03 the cover crops in the AB treatments were sown annually and the full surface post-emergence chemical control scheduled for the end of November was advanced to mid-October, since the species have proved unable to re-establish successfully in previous seasons (Fourie *et al*., 2006a). The cover crop treatments were compared to a control, in which no cover crop was sown and weeds were controlled mechanically in the work row and chemically in the vine row just before bud break and at the end of November. A treatment in which no cover crop was sown and full surface post-emergence chemical control was applied just before bud break and at the end of November (weedchem), was also included in the trial.

Statistical procedures

Eighteen treatments were randomly allocated within each of three blocks. The treatment design was an (8x2)+2 factorial. Factors were eight cover crops, two management practices, plus two other practices. The experiment was repeated over 10 consecutive seasons (years). The size of each unit (plot) was 165 m^2. Ten experimental grapevines were used for measurements. Individual plots were separated by two border grapevine rows and five border grapevines within rows. Analyses of variance were performed for each season separately, using SAS (SAS, 1990). Student's *t* least significant difference

(LSD) was calculated at the 5% and 10% significance level to facilitate comparison between treatment means. The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965).

Measurements

Soil was sampled annually from two positions in approximately the middle of the work row. Samples were drawn when the grapevines reached full bloom (early November) and after harvest, just before seedbed preparation was done (early March). The composite samples were analysed for pH (1.0 M KCl), P and K (Bray II), exchangeable K, Ca, Mg and Na (extracted with 0.2 M ammonium acetate) and organic carbon by means of the Walkley-Black method (The Non-affiliated Soil Analysis Work Committee, 1990). The NH_4-N and NO_3-N (extracted with 1.0 M KCl) were determined by means of the colorimetric method described by The Non-affiliated Soil Analysis Work Committee (1990).

RESULTS AND DISCUSSION

Soil organic matter (SOM)

The SOM (%C x 1.717) measured before the treatments commenced (March 1993), did not differ significantly between treatments in the 0-300 mm soil layer (Table 1). After five seasons (March 1998), no significant differences were detected in the SOM content of the 0-300 mm soil layer. All the cover crop treatments, however, showed an increase in SOM, while that of the weedchem treatment did not change. The SOM in the mechanically cultivated control showed a decrease of 16% in this five year period. No decline in the SOM was observed for the weedchem treatment (Table 1). This did not support the results of Merwin & Stiles (1994), who reported a 5.7% decline in the organic matter content of chemically clean cultivated soils over a period of six years. Although not significant, the increase in SOM measured in all the cover crop BB treatments, with the exception of *Vicia dasycarpa* Ten. (grazing vetch), as well as that of the AB treatments of the grain species was more than 20%. This supported the results of Gallaher & Ferrer (1987). Negligible increases in SOM were detected in the grazing vetch treatments and the AB treatment of *Medicago scutellata* (L.) Mill. v. Kelson (‘Kelson’ medic), and small increases observed in the AB treatments of *Vicia faba* L. v. Fiord (faba bean), ‘Paraggio’ medic and *Trifolium subterraneum* L. v. Woogenellup

(‘Woogenellup’ subterranean clover). This was attributed to the poor performance of the cover crops in these treatments during 1995 and 1997 (Fourie *et al*., 2006a). The organic matter content in the 0-100 mm soil layer of a sandy loam soil was increased from 0.54% to 0.95% over a period of four years with ‘Paraggio’ medic (if allowed to complete its life cycle) producing on average 4.2 t/ha/yr dry matter (Sanderson, 1998). This 75% increase in SOM is much higher than the 33% and 10% increase reported for the BB and AB treatments of ‘Paraggio’ medic, respectively, in the present study (Table 1). The differences in SOM increase was attributed to the differences in average dry matter production (DMP) which was 2.96 t/ha/yr and 1.69 t/ha/yr for the BB and AB treatments of ‘Paraggio’ medic (Fourie *et al*., 2006a), respectively, which were much lower than the DMP reported by Sanderson (1998). The fact that the 0-300 mm soil layer was monitored in the present study (Table 1), as opposed to the 0-100 mm soil layer monitored by Sanderson (1998) also contributed to the lower values reported in the present study, as the effect of floor management practices seems to be restricted mainly to the 0-200 mm soil layer (Sicher *et al*., 1995). No significant differences or tendencies between treatments could be detected in the SOM of the 300-600 mm soil layer before the treatments commenced or after the treatments were applied for five seasons (data not shown).

During March 2003, the SOM was determined for the 0-150 mm, 150-300 mm and 300-600 mm soil layers, to determine whether the impact of the treatments were not greater in the top 150 mm of the soil. The SOM content in the 0-150 mm soil layer of the cover crop treatments was, with the exception of grazing vetch, significantly higher than that of the mechanically cultivated control (Table 2). The SOM content in the faba bean, ‘Paraggio’ medic, ‘Kelson’ medic, ‘Woogenellup’ subterranean clover and *Secale cereale* L. v. Henog (rye) treatments was significantly higher than that of weedchem, irrespective of whether full surface chemical control was applied before bud break or in mid-October. A similar result was achieved with the BB treatment of *Avena strigosa* L. Saia (‘Saia’ oats). In the case of the rye treatments, faba bean (AB) and ‘Kelson’ medic (AB), the SOM content in the 150-300 mm soil layer was also significantly higher than that of weedchem. The % SOM in the 0-300 mm soil layer of these four cover crop treatments also exceeded the 1.5% level regarded by Conradie (1994) as the level above which it

Table 1. Effect of two cover crop management practices applied to three cereals and five legumes, on the soil organic matter (SOM) content in the 0-300 mm soil layer of a medium textured soil near Stellenbosch, during March 1993 (before the treatments commenced) and March 1998 (fifth season of applying treatments).

Treatment	SOM[1,2] (%)	
	March 1993	March 1998
Grain species:		
Secale cereale L. v. Henog (rye), BB[3].	0.94	1.22
Secale cereale L. v. Henog (rye) AB[4].	0.91	1.15[6]
Avena sativa L. v. Overberg (‘Overberg’ oats), BB.	0.91	1.12
Avena sativa L. v. Overberg (‘Overberg’ oats), AB.	0.86	1.05[6]
Avena strigosa L. v. Saia (‘Saia’ oats), BB.	0.94	1.25
Avena strigosa L. v. Saia (‘Saia’ oats), AB.	0.94	1.29[6]
N-fixing broadleaf species:		
Vicia dasycarpa Ten. (grazing vetch),BB.	0.93	0.98
Vicia dasycarpa Ten. (grazing vetch), AB.	0.93	0.94[6]
Vicia faba L. v. Fiord (faba bean), BB.	0.74	1.06
Vicia faba L. v. Fiord (faba bean), AB.	0.88	1.03[6]
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), BB.	0.88	1.17
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), AB.	0.89	0.98[6]
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), BB.	0.74	0.96
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), AB.	0.93	0.98[6]
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), BB.	0.81	0.96
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), AB.	0.93	1.06[6]
Weeds, MC[5] (control).	1.00	0.84
Weeds, BB (weedchem).	0.94	0.94

[1]Data do not differ significantly at the 10% level. [2]SOM = 1.717 x %C. [3]BB = full surface chemical control before bud break. [4]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [5]MC = chemical control in vine row, mechanical control in working row. [6]Cover crop left to re-establish.

may not be necessary to apply fertiliser N to vineyards established on soils with a clay content of 6% or more. This indicated that these species could make a significant positive impact on the organic matter content of the 0-300 mm soil layer of medium textured soils in the Coastal region. Although grazing vetch performed extremely poor during 1999, 2001 and 2002 (Fourie *et al*., 2006a), the SOM content still compared favourably with that of weedchem and the mechanically cultivated control (Table 2).

Total inorganic N

The trends between treatments differed significantly between years during both phases of the trial (1993/94 to 1998/99 and 1999/2000 to 2002/03). The total inorganic N (NH_4-N + NO_3-N) concentrations in the 0-600 mm soil layer during full bloom and after harvest, for selected years (to illustrate the impact of the cover crops and cover crop management over time) are presented in Tables 3 to 6.

The total inorganic N concentration of the 0-150 mm soil layer in the BB treatments of the two *Medicago* species and 'Woogenellup' subterranean clover, as measured for the 1996/97 season during full bloom of the grapevines, was significantly higher than that of the control, weedchem, and the AB treatments (Table 3). Dou *et al*. (1994) and Sanderson & Fitzgerald (1999) reported maximum levels of NO_3-N in the 0-450 mm and 0-500 mm soil layers, respectively, between seven and eight weeks after chemical control of legume cover crops, which explains the above-mentioned results. The total inorganic N concentration of the 150-300 mm soil layer of faba bean BB was significantly higher than that of all the other treatments. In 'Kelson' medic (BB), the elevated level of N in the top soil corresponded with a high concentration of NO_3-N in the leaf petioles of the grapevines (Fourie *et al*., 2006b). The elevated levels of total inorganic N in the top 300 mm soil layer of the above-mentioned four BB treatments (Table 3) also induced luxurious vegetative growth in these treatments over the medium term (Fourie *et al*., 2006b). The total inorganic N concentration in the AB treatments was similar to that of the BB treatments of the grain species in the 0-300 mm soil layer and, with the exception of *A. sativa* L. v. Overberg ('Overberg' oats) and grazing vetch, tended to be higher than that of the control and weedchem in the 0-600 soil layer. These results indicated that the cover crops that were sown biennially and left to grow until the berry set stage of the grapevines did not have a significantly negative impact on the N status of the soil early in the grapevine growing season.

Table 2. Effect of two cover crop management practices applied to three cereals and five legumes, on the soil organic matter (SOM) content in the 0-150 mm and 150-300 mm soil layers of a medium textured soil near Stellenbosch during March 2003 (tenth season of applying the treatments).

Treatment	SOM[1] (%)	
	0-150 mm soil layer	150-300 mm soil layer
Grain species:		
Secale cereale L. v. Henog (rye), BB[2].	2.30	1.92
Secale cereale L. v. Henog (rye) AB[3].	1.85	1.48
Avena sativa L. v. Overberg (‘Overberg’ oats), BB.	1.85	1.17
Avena sativa L. v. Overberg (‘Overberg’ oats), AB.	1.77	1.08
Avena strigosa L. v. Saia (‘Saia’ oats), BB.	1. 92	1.18
Avena strigosa L. v. Saia (‘Saia’ oats), AB.	1.75	1.30
N-fixing broadleaf species:		
Vicia dasycarpa Ten. (grazing vetch),BB.	1.70	1.17
Vicia dasycarpa Ten. (grazing vetch), AB.	1.63	1.13
Vicia faba L. v. Fiord (faba bean), BB.	2.40	1.22
Vicia faba L. v. Fiord (faba bean), AB.	2.33	1.49
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), BB.	1.96	1.18
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), AB.	1.94	1.13
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), BB.	1.92	1.32
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), AB.	2.16	1.79
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), BB.	1.96	1.17
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), AB.	2.13	1.06
Weeds, MC[4] (control).	1.32	0.81
Weeds, BB (weedchem).	1.48	0.89
LSD ($p \leq 0.05$)	0.41	0.54

[1]SOM = 1.717 x %C. [2]BB = full surface chemical control before bud break. [3]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [4]MC = chemical control in vine row, mechanical control in working row.

The total inorganic N concentration of the 0-600 mm soil layer in faba bean (BB) and 'Kelson' medic (AB), as measured after the grapevines were harvested during the 1996/97 season, was significantly higher than that of the control and weedchem (Table 4). This was also observed for the 150-300 mm and 300-600 mm soil layers of the 'Woogenellup' subterranean clover (AB) treatment and the 300-600 mm soil layer of the 'Kelson' medic (BB) treatment. The relatively high N levels in the soil of these treatments did not, however, correspond with high levels of N in the juice of the grapevines (Fourie *et al*., 2006b). The total inorganic N concentration of the 0-150 mm soil layer in the AB treatment of 'Kelson' medic was significantly higher than that of the BB treatment of the species (Table 4). Although the difference between the two management practices for this species did not differ significantly in the deeper soil layers, the tendency was the same as that observed for the 0-150 mm soil layer. This tendency between the two management practices within a species, namely for AB to be higher than BB, was also apparent in the cereals, 'Paraggio' medic and 'Woogenellup' subterranean clover. Dou *et al*. (1994) and Sanderson & Fitzgerald (1999) reported maximum levels of NO_3-N in the 0 to 450 mm and 0 to 500 mm soil layers, respectively, between seven and eight weeks after chemical control of legume cover crops. Sanderson & Fitzgerald (1999) observed slightly elevated levels of NO_3-N in the 500 mm soil layer up to 14 weeks after 'Paraggio' medic was controlled chemically and left on the soil surface. The release of N from the fibre of the cover crops in the BB treatments of the present study could, therefore, have realised mainly from early October to late December, while that of the AB treatments could have realized from late December to early March.

The total inorganic N concentration in the BB treatments of 'Kelson' medic (0-150 mm soil layer) and faba bean (150-300 mm soil layer) during full bloom of the grapevines, as measured for the 2002/03 season, was significantly higher than that in the mechanically cultivated control (Table 5). Although the cover crops were controlled mid-October in the AB treatments during 2002/03, the total inorganic N concentrations in the 0-600 mm soil layer of the AB treatment of a species still tended to be lower than that of the BB treatment of that species during full bloom. The total inorganic N concentration of the 0-600 mm soil layer in the AB treatment of a species, as measured after the grapes were harvested during the 2002/03 season, tended to be higher than that of the BB treatment of that species (Table 6). With the exception of the two *Vicia* species, these results

Table 3. Effect of two cover crop management practices applied to three cereals and five legumes, on the total inorganic N (NH_4-N + NO_3-N) concentration in the 0-150 mm, 150-300 mm and 300-600 mm soil layers of a medium textured soil near Stellenbosch during full bloom (early November) during the fourth season of applying the treatments (1996/97).

Treatment	Total inorganic N (mg/kg)		
	0-150 mm soil layer	150-300 mm soil layer	300-600 mm soil layer
Grain species:			
Secale cereale L. v. Henog (rye), BB[1].	4.56	2.57	4.29
Secale cereale L. v. Henog (rye) AB[2].	4.53	2.44	2.72
Avena sativa L. v. Overberg (‘Overberg’ oats), BB.	5.53	2.61	3.53
Avena sativa L. v. Overberg (‘Overberg’ oats), AB.	3.91	2.13	2.01
Avena strigosa L. v. Saia (‘Saia’ oats), BB.	5.85	3.66	3.13
Avena strigosa L. v. Saia (‘Saia’ oats), AB.	5.36	2.85	2.75
N-fixing broadleaf species:			
Vicia dasycarpa Ten. (grazing vetch),BB.	7.26	3.17	2.71
Vicia dasycarpa Ten. (grazing vetch), AB.	4.47	1.80	1.90
Vicia faba L. v. Fiord (faba bean), BB.	8.54	8.26	6.57
Vicia faba L. v. Fiord (faba bean), AB.	5.11	3.22	2.58
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), BB.	10.65	4.29	2.92
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), AB.	4.52	3.68	2.37
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), BB.	10.46	4.03	3.54
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), AB.	5.47	2.28	2.30
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), BB.	10.69	5.80	3.29
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), AB.	4.15	2.93	2.97
Weeds, MC[3] (control).	2.96	1.18	1.59
Weeds, BB (weedchem).	3.74	2.24	2.29
LSD ($p \leq 0.05$)	4.94	3.58	NS[4]

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row. [4]Data do not differ significantly on the 10% level.

Table 4. Effect of two cover crop management practices applied to three cereals and five legumes, on the total inorganic N (NH_4-N + NO_3-N) concentration in the 0-150 mm, 150-300 mm and 300-600 mm soil layers of a medium textured soil near Stellenbosch after harvest (March) during the fourth season of applying the treatments (1996/97).

Treatment	Total inorganic N (mg/kg)		
	0-150 mm soil layer	150-300 mm soil layer	300-600 mm soil layer
Grain species:			
Secale cereale L. v. Henog (rye), BB[1].	7.33	3.55	2.23
Secale cereale L. v. Henog (rye) AB[2].	8.03	4.73	2.96
Avena sativa L. v. Overberg ('Overberg' oats), BB.	5.37	2.48	2.61
Avena sativa L. v. Overberg ('Overberg' oats), AB.	5.49	2.98	2.06
Avena strigosa L. v. Saia ('Saia' oats), BB.	5.81	3.79	2.45
Avena strigosa L. v. Saia ('Saia' oats), AB.	6.93	5.54	2.97
N-fixing broadleaf species:			
Vicia dasycarpa Ten. (grazing vetch),BB.	5.90	3.01	2.46
Vicia dasycarpa Ten. (grazing vetch), AB.	3.80	2.57	1.78
Vicia faba L. v. Fiord (faba bean), BB.	13.70	8.96	6.49
Vicia faba L. v. Fiord (faba bean), AB.	11.75	4.26	2.83
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	5.86	3.13	2.73
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	6.35	4.22	2.53
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), BB.	8.22	5.70	4.46
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), AB.	16.36	7.54	6.02
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), BB.	8.26	6.08	5.92
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), AB.	11.15	7.79	6.93
Weeds, MC[3] (control).	4.52	1.67	1.24
Weeds, BB (weedchem).	6.69	2.29	1.63
LSD ($p \leq 0.05$)	5.57	4.21	2.06

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row.

Table 5. Effect of two cover crop management practices applied to three cereals and five legumes, on the total inorganic N (NH_4-N + NO_3-N) concentration in the 0-150 mm, 150-300 mm and 300-600 mm soil layers of a medium textured soil near Stellenbosch during full bloom (early November) during the tenth season of applying the treatments (2002/03).

Treatment	Total inorganic N (mg/kg)		
	0-150 mm soil layer	150-300 mm soil layer	300-600 mm soil layer
Grain species:			
Secale cereale L. v. Henog (rye), BB[1].	11.96	6.02	7.32
Secale cereale L. v. Henog (rye) AB[2].	6.89	6.19	6.24
Avena sativa L. v. Overberg (‘Overberg’ oats), BB.	12.18	8.25	6.75
Avena sativa L. v. Overberg (‘Overberg’ oats), AB.	7.01	5.70	7.22
Avena strigosa L. v. Saia (‘Saia’ oats), BB.	12.84	7.33	7.36
Avena strigosa L. v. Saia (‘Saia’ oats), AB.	6.41	6.08	4.78
N-fixing broadleaf species:			
Vicia dasycarpa Ten. (grazing vetch),BB.	12.21	7.39	6.27
Vicia dasycarpa Ten. (grazing vetch), AB.	8.72	6.64	7.99
Vicia faba L. v. Fiord (faba bean), BB.	12.31	9.60	8.96
Vicia faba L. v. Fiord (faba bean), AB.	9.34	7.11	6.70
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), BB.	10.27	8.37	8.53
Medicago truncatula Gaertn v. Paraggio (‘Paraggio’ medic), AB.	5.32	5.28	5.36
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), BB.	14.23	9.97	6.78
Medicago scutellata (L.) Mill. v. Kelson (‘Kelson’ medic), AB.	12.54	7.55	6.32
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), BB.	11.77	7.17	7.29
Trifolium subterraneum L. v. Woogenellup (‘Woogenellup’ subterranean clover), AB.	9.95	6.57	7.07
Weeds, MC[3] (control).	8.91	5.26	6.48
Weeds, BB (weedchem).	9.59	7.11	6.21
LSD ($p \leq 0.05$)	4.81	3.23	NS[4]

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002).
[3]MC = chemical control in vine row, mechanical control in working row. [4]Data do not differ significantly on the 10% level.

Table 6. Effect of two cover crop management practices applied to three cereals and five legumes, on the total inorganic N (NH_4-N + NO_3-N) concentration in the 0-150 mm, 150-300 mm and 300-600 mm soil layers of a medium textured soil near Stellenbosch after harvest (March) during the tenth season of applying the treatments (2002/03).

Treatment	Total inorganic N (mg/kg)		
	0-150 mm soil layer	150-300 mm soil layer	300-600 mm soil layer
Grain species:			
Secale cereale L. v. Henog (rye), BB[1].	18.51	11.27	6.34
Secale cereale L. v. Henog (rye) AB[2].	19.17	13.31	5.82
Avena sativa L. v. Overberg ('Overberg' oats), BB.	17.86	8.99	3.66
Avena sativa L. v. Overberg ('Overberg' oats), AB.	20.31	8.82	8.64
Avena strigosa L. v. Saia ('Saia' oats), BB.	24.00	8.40	5.96
Avena strigosa L. v. Saia ('Saia' oats), AB.	26.26	8.51	8.2
N-fixing broadleaf species:			
Vicia dasycarpa Ten. (grazing vetch),BB.	25.07	9.36	7.78
Vicia dasycarpa Ten. (grazing vetch), AB.	31.82	18.18	10.46
Vicia faba L. v. Fiord (faba bean), BB.	40.61	12.84	10.47
Vicia faba L. v. Fiord (faba bean), AB.	41.93	14.38	11.77
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), BB.	20.33	6.19	6.56
Medicago truncatula Gaertn v. Paraggio ('Paraggio' medic), AB.	21.28	6.29	6.97
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), BB.	35.52	6.99	6.28
Medicago scutellata (L.) Mill. v. Kelson ('Kelson' medic), AB.	41.55	15.72	13.62
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), BB.	26.35	6.80	5.16
Trifolium subterraneum L. v. Woogenellup ('Woogenellup' subterranean clover), AB.	39.54	14.90	11.44
Weeds, MC[3] (control).	8.71	3.83	4.07
Weeds, BB (weedchem).	8.48	2.69	3.47
LSD ($p \leq 0.05$)	11.41	6.21	4.81

[1]BB = full surface chemical control before bud break. [2]AB = full surface chemical control at the end of November (1993 to 1998) and mid-October (1999 to 2002).
[3]MC = chemical control in vine row, mechanical control in working row.

resemble those of the 1996/97 season. The inorganic N levels measured in the 0-600 mm soil layer of the cover crop treatments after harvest in 2002/03 (Table 6) being much higher than that measured after harvest in 1996/97 (Table 4) can be attributed partially to the fact that the samples was taken after and before seedbed preparation, respectively. The tendencies observed indicated that chemical control of all the species during mid-October should result in more N being available to the grapevines after harvest, while chemical control before bud break should result in more N being available during full bloom on the medium textured soils of the Coastal region. The total inorganic N concentrations of the 0-150 mm soil layer in the cover crop treatments were, with the exception of the two rye treatments and 'Overberg' oats (BB), significantly higher than that of the control and weedchem. This was true for the two rye treatments in the 150-300 mm soil layer. In the case of the AB treatments of the N-fixing cover crops and faba bean (BB) this significant difference was observed for the 0-600 mm soil layer. This illustrated that cover crops controlled chemically by mid-October, especially N-fixing cover crops, make a significant contribution towards the availability of N in the soil after harvest over the long term, if applied on medium textured soils in the vineyards of the Coastal region. This N should help to ensure that sufficient N is present in the grape juice during harvest (Fourie *et al*., 2006b) to prevent stuck fermentation.

Exchangeable K, Ca, Mg and P.

Although significant differences in exchangeable K, Ca and Mg did occur between some treatments, no significant or consistent tendencies were detected in the years during which these parameters were measured, namely 1997, 1999 and 2003 (data not shown). The effect of different cover crop management practices on the level of P in the 0-600 mm soil layer was discussed previously by Fourie *et al*. (2006a).

CONCLUSIONS

All the cover crops tested, irrespective of the management practice applied, improved the soil organic matter (SOM) content of the 0-300 mm soil layer over a period of five years. SOM increases in excess of 20% were achieved with the legumes, except grazing vetch, where these were sown annually and controlled chemically before bud break. Such increases were also achieved with the cereals, irrespective of the management practice applied. After 10 years, the use of faba bean, ‘Paraggio’ medic, ‘Kelson’ medic, ‘Woogenellup’ subterranean clover and rye as cover crops resulted in significantly higher SOM contents in the 0-300 mm soil layer compared to that in soils where no cover crops were sown and the weeds were controlled chemically or mechanically during the grapevine growing season. Faba bean, ‘Kelson’ medic and rye also showed the ability to increase the % SOM in the 0-300 mm soil layer to more than 1.5%, the level above which the total withdrawal of fertilizer N may be considered under South African conditions.

The cover crops that were sown biennially and left to grow until the berry set stage of the grapevines did not have a significantly negative impact on the N status of the soil early in the grapevine growing season. On the medium textured soils of the Coastal region, chemical control of the cover crop species during mid-October should result in more N being available to the grapevines after harvest, while chemical control before bud break should result in more N being available during full bloom.

The different cover crops and two cover crop management practices had no significant effect on the exchangeable K, Ca and Mg concentration of the 0-600 mm soil layer.

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CONCLUSIONS

A selection of species suitable for cover crop management in the different wine grape regions of the Western Cape is required to enable more producers to apply this environment friendly practice in a sustainable manner as part of an integrated production strategy. The correct management practice(s) to be applied to these species over both the short and long term, to maximize cover crop performance and grapevine performance, needed clarification.

The effect of seeding date on the dry matter production (DMP) and weed control efficacy of seven grasses and sixteen legumes, as well as varieties of three of these species, was determined during 1991 and 1992. The decomposition rate of the mulches was determined. This trial was executed in both Stellenbosch (33°55'S, 18°52'E), situated in the cooler Coastal wine grape region of the Western Cape, and Lutzville (31°35'S, 18°52'E), situated in the warmer semi-arid Olifants River Valley of the Western Cape.

A second trial was conducted over ten years (1993/94 to 2002/03) on a sandy soil in a Sauvignon blanc/Ramsey vineyard near Lutzville. Twenty four treatments were applied. Sixteen treatments, consisting of four cereals and four legumes, receiving the same amount of fertilizer and managed according to two cover crop management practices, were included. One management practice consisted of cover crops which were sown annually and full surface post-emergence chemical weed control which was applied before bud break and when the berries reached pea size (BB). The second management practice consisted of the cover crops which were sown biennially. Post-emergence chemical weed control was applied to the vine row before bud break and full surface when the berries reached pea size (AB). From 1999/2000 to 2002/03 the cover crops were sown annually, while the full surface post-emergence chemical weed control applied at the end of November was advanced to mid-October. Two treatments in which *Avena sativa* L. v. Saia (‘Saia’ oats) and *Vicia dasycarpa* Ten. (grazing vetch) were sown annually, controlled mechanically in the work row and chemically in the vine row from bud break to harvest (MC), were also applied. In addition to these eighteen treatments, two fertiliser application rates were applied to ‘Saia’ oats and grazing vetch. These treatments were compared to a control, in which no cover crop was sown and MC was applied. A treatment in which no cover crop was sown and BB was applied (weedchem), was also included.

A third trial was conducted over a period of 10 years (1993/94 to 2002/03) on a medium textured soil in a Chardonnay/99 Richter vineyard near Stellenbosch. Sixteen treatments, consisting of three cereals and five legumes managed according to two cover crop management practices (BB and AB), were included. These treatments were compared to a control (as above) and weedchem treatment managed the same as described for the trial in Lutzville.

Taking both the ability of the grass species to suppress the winter growing weeds and produce the five tons of dry matter deemed necessary to control the summer growing weeds into account, 'Saia' oats, *Avena sativa* L. v. Overberg ('Overberg' oats), *Secale cereale* L. v. Henog (rye) and *Triticale* v. Usgen 18 (triticale) could be considered for cover crop management in the vineyards of both the Coastal region and the Olifants River Valley. In the cooler climate of Stellenbosch (Coastal region) these crops need at least 18 mm of irrigation or rainfall per week from March to May to match these criteria. Weekly irrigation or rainfall of 18 mm up to 10 weeks after seeding, followed by fortnightly irrigations of 18 mm enabled these species to produce the necessary dry matter in the warmer and arid Lutzville area (Olifants River Valley). None of the broadleaf species could produce more than the minimum norm of eight tons of dry matter suggested to be necessary for effective summer weed control by a broadleaf species. In Stellenbosch, rainfall in excess of 18 mm per week from mid-March to mid-May caused the weeds to outgrow the N-fixing broadleaf species, making it risky in the short-term to use these species as cover crops in this region. These species, except *Vicia faba* L. v. Fiord (fababean), seemed to be well adapted to the warmer climate of the Olifants River valley and sandy soil of the trial site. DMP response of different species and varieties to seeding date differed at both experimental sites, making it very risky to extrapolate these results to new species of the genera or even new varieties of the same species. Decomposition rate of the different mulches during summer showed a significant correlation with the initial amount of dry matter present on the soil surface.

In the second trial, executed on a sandy soil in the in the warmer and semi-arid Olifants River Valley, rye and *Ornithopus sativus* v. Emena (pink Seradella) were the least sensitive to water deficits and should, therefore, be the preferred species for cover crop management in the sandy soils of the semi-arid Olifants River Valley. *Medicago truncatula* Gaertn. v. Paraggio ('Paraggio' medic) and 'Saia' oats could also be considered for cover crop management in this region. Although grazing vetch did not perform on average as well as the above-mentioned species, it could also be considered for cover crop management during years in which the water quota for the region is not reduced. Indications are that both the total amount of water and the frequency of irrigations and/or rainfall, could affect the DMP of the cover crop species from April to August. The effect of different irrigation schedules on cover crop performance in this region should, therefore, be researched, to supply scientifically based guidelines for the optimal irrigation of cover crops on the sandy soils of the semi-arid Olifants River Valley. It seemed that P and K at levels of 10 mg/kg and 78 mg/kg, respectively, in the top 300 mm soil layer, supplied in the needs of grazing vetch. 'Saia' oats, however, performed poorly if 30 kg of P was not broadcast just before seedbed preparation, followed by an application of 30 kg of K and 28 kg of N just after the cover crops were sown and 14 kg of N were not applied at the two to four leaf development phases. Although it was luxurious to double the amount of fertiliser, the standard amount of fertiliser applied should be increased to maximize DMP. The specific amount should be determined by future research. The cover crops (not controlled chemically at the end of August) did not produce additional dry matter from September to November if they received sufficient amounts of water on a regular basis during winter. If sown late (first week in May) the two oats species, grazing vetch and to a lesser extent pink Seradella should produce additional fibre if not controlled chemically at the end of August. Grazing vetch would most likely produce additional fibre under these edaphic conditions, if not controlled chemically at the end of August. The preceding winter, therefore, determines the cover crop management practice that should be applied end of August. The cover crops did not produce enough seeds to re-establish themselves successfully over a period of five years. It may, however, be possible to cut back on the seeding density of the two *M. truncatula* varieties (20% after five seasons) and grazing vetch (40% after two seasons) if the species are allowed to ripen their seeds. The seedbed prepared by a disc harrow or rotary harrow (available to grape producers) is not as fine as that prepared by the implements of the cereal producers (planters etc.). During seedbed preparation some of the viable seeds might also have been buried deeper than the 0-100 mm soil layer from which they normally germinate. The effect of planters on the percentage seed germination and capacity of the legumes to re-establish in vineyards needs, therefore, to be researched. All the cover crops showed the ability to compete effectively with the winter growing weeds.

The effect of the different soil management practices on the performance of the Sauvignon blanc/ Ramsey grapevines established on the sandy soil in Lutzville started manifesting as early as the first season in which the treatments were applied. The annual sowing of a cover crop, preferably grazing vetch, in combination with post-emergence chemical control from just before bud break (BB), proved to be the soil management practice that should be applied in young vineyards on sandy soils in the warmer climatic regions. This will enhance the development of the permanent structure of trellised grapevines, while maximizing the harvest. When the grapevines reached full production (fourth growing season, third season of the trial), the yield of the BB treatments in which grazing vetch, pink Seradella and 'Paraggio' medic was established, were superior to that of the grapevines in which the cover crops or weeds were mechanically incorporated into the top soil during bud break, as well as those in which the weeds were controlled chemically from just before bud break. Allowing the cereal and Medicago species to complete its life cycle, had a negative effect on grapevine performance both in the short and medium term (treatments applied for six consecutive years). Mechanical control of weeds and a grain cover crop from bud break or chemical control of weeds from just before bud break also impacted negatively on grapevine performance. The performance of full bearing grapevines established on a sandy soil was not affected negatively, if the cover crops were controlled chemically during mid-October. It should be possible to reduce the inorganic N applied after bud break on sandy soils in the warmer climatic regions in the short term (approximately after three years) or even stop the application in the medium term (after approximately five years) when using pink Seradella or grazing vetch with BB as soil management practice. Indications are that it may also be possible to reduce the inorganic N applied after bud break over the medium to long term with the BB treatments of the two Medicago species, as well as that of grazing vetch and pink Seradella controlled chemically during berry set. The impact that the cover crops have on the N status of the grapevines will be dependant on the performance of the cover crop. Pink Seradella and grazing vetch had a positive effect on the N concentration in the juice of the grapevines, irrespective of the soil management practice applied. A similar result could probably be achieved with the two Medicago species if they were controlled chemically before bud break. Although the different soil management practices affected grape yield significantly over the 10 year period, they did not affect berry volume or wine quality.

Grazing vetch, pink Seradella, rye and ‘Saia’ oats have the ability to significantly increase the organic matter content of a sandy soil in the warmer and semi-arid Olifants River Valley over the long term. The SOM content of the 0-300 mm soil layer was improved to a greater extent if grazing vetch and ‘Saia oats were controlled chemically and the top growth left on the soil surface than when these species were incorporated mechanically into the top soil during bud break. The 42 kg/ha of inorganic N applied to the grapevines after bud break could be reduced by 50% after three seasons and omitted after six seasons where pink Seradella and grazing vetch was sown annually and controlled chemically before bud break (BB). The application of inorganic N to the grapevines after bud break could be reduced by 50% after six seasons where these two species were sown biennially and controlled chemically after bud break (AB). The application of these four practices did not affect the inorganic N concentration in the soil during the full bloom stage of the grapevines negatively over the long term. Pink Seradella and grazing vetch should be controlled chemically during berry set to improve the supply of inorganic N to the grapevines in the after harvest period. BB applied to ‘Paraggio’ and ‘Parabinga’ medic over the long term, increased the inorganic N concentration in the 0-300 mm soil layer to a level where a cut back in the application of inorganic N on these soils could be considered. The legumes showed the ability to supply significant amounts of inorganic N to the grapevines after harvest, especially if chemical control was applied during mid-October. The different cover crops and cover crop management practices had no significant effect on the P concentration or the exchangeable Ca and Mg of the 0-600 mm soil layer. Rye, ‘Paraggio’ medic and grazing vetch controlled chemically during the berry set stage of the grapevines had a significantly positive impact on the K concentration in the top soil layer after harvest. Pink Seradella increased the K concentration in the top soil irrespective of the management practice applied. These cover crops could, therefore, serve as catch crops for K on sandy soils.

In the third trial, executed on a medium textured soil in the cooler Coastal grapevine region, the cover crop species did not re-establish successfully. The cereals had the ability to produce significant amounts of dry matter over the long-term, despite the fact that they have been planted on the same soil for 10 consecutive years. The decline in DMP after four seasons, however, indicated that they should be rotated with other cover crop species. The cereals, with the exception of 'Saia' oats during one season, did not produce significantly more dry matter when left to complete its life cycle, if sown before mid April. It is, therefore, not worthwhile to allow these species to complete their life cycle if they were established before mid-April. The two oat species suppressed the winter growing weeds common to the Coastal grapevine region significantly, irrespective of the management practice applied. To achieve similar results with rye, however, post-emergence chemical control should be applied before bud break. To obtain effective suppression of the winter growing weeds in the region, the two oat species should be established annually and controlled chemically before bud break. The grain species controlled the summer growing weeds effectively if sown annually and controlled chemically before bud break. It seems, therefore, that this management practice should preferably be applied to the grain species on a well drained medium textured soil in this region. 'Woogenellup' subterranean clover should not be considered for cover crop management in this region. The other legumes also performed poorly over the long-term on this medium-textured soil. Faba bean, grazing vetch and the two *Medicago* species must not be established on the same soil for more than four consecutive years, since this would necessitate the use of additional chemicals as protection against pests and diseases. This defeats the purpose of reducing the use of chemicals in grapevine cultivation. The legumes produced more dry matter if allowed to complete their life cycle, irrespective of seeding date. To achieve effective weed control with these species, however, post-emergence chemical control must be applied before bud break. The preference for the use of legumes in a rotation system with a cereals on medium textured soils in this region should be 'Kelson' medic > faba bean > grazing vetch > 'Paraggio' medic.

The effect of the different soil management practices on the performance of the Chardonnay/99 Richter grapevines established on the medium textured soil in Stellenbosch started manifesting as early as the first season in which the treatments were applied. The annual sowing of a cover crop, preferably 'Paraggio medic', in combination with post-emergence chemical control from just before bud break to harvest (BB), proved to be the soil management practice that should be applied in young vineyards to enhance the development of the permanent structure of trellised vines. Even when the grapevines reached full production in the fourth growing season (third year that the treatments were applied) the vegetative growth and yield of the grapevines of most BB treatments were superior to that of the grapevines in which no cover crops were sown and the weeds were controlled mechanically or chemically in the work row. It was also beneficial to grapevine performance to control a cover crop chemically before bud break rather than allowing it to complete its life cycle. The last-mentioned management practice, as well as mechanical cultivation from bud break had a significantly negative effect on grapevine performance during the first four seasons and should, therefore, not be applied in young vineyards. Although the legumes were beneficial to grapevine performance initially, the supply of additional N from these species to the grapevines during the growing season may lead to excessive vegetative growth over the medium to long term. Care should, therefore, be taken to rotate these species on relatively fertile medium textured soils with a cereal after approximately four years to prevent this from happening. The performance of fully grown grapevines was not affected negatively, if the cover crops were controlled chemically during mid-October. This management practice could, therefore, be considered in the Coastal grapevine region during seasons when the rainfall in September and October is excessive, or even during dryer seasons if additional irrigation can be applied when necessary. Although the different soil management practices affected grape yield significantly over the 10 year period, they did not affect berry volume and had no significant effect on wine quality.

All the cover crops, irrespective of the management practice applied, improved the soil organic matter (SOM) content of the 0-300 mm soil layer of a medium textured soil in the cooler Coastal grapevine region over a period of five years. Increases in excess of 20% were achieved with the legumes, except grazing vetch, if they were sown annually and controlled chemically before bud break. This was also achieved with the cereals irrespective of the management practice applied. After 10 years, the use of faba bean, ‘Paraggio’ medic, ‘Kelson’ medic, ‘Woogenellup’ subterranean clover and rye as cover crops resulted in a significantly higher SOM content in the 0-300 mm soil layer compared to that of the soils where no cover crops were sown and the weeds were controlled chemically or mechanically during the growing season of the grapevines. These species also showed the ability to increase the %SOM in the 0-300 mm soil layer to more than

1.5%, the level above which the total withdrawal of fertilizer N may be considered under South African conditions. The cover crops that were sown biennially and left to grow until the berry set stage of the grapevines did not have a significantly negative impact on the N status of the soil early in the growing season of the grapevines. Chemical control of all the species during mid-October should result in more N being available to the grapevines after harvest, while chemical control before bud break should result in more N being available during full bloom on the medium textured soils of the Coastal region.

From this very comprehensive study it became clear that:

- The cover crops should preferably be sown early April in both regions, as autumn rain (Coastal grapevine region) and available irrigation water (Olifants River Valley) plays an important and vital role, respectively, in the succesfull cultivation of the cover crops.
- Rye and pink Seradella were the least sensitive to water deficits and should, therefore, be the preferred species for cover crop management in the sandy soils of the semi-arid Olifants River Valley. ‘Paraggio’ medic, ‘Saia’ oats and grazing vetch did not perform as well as the above-mentioned species, but could also be considered for cover crop management during years in which the water quota for the region is not reduced (very little water available for irrigation during winter).
- ‘Overberg’ oats, ‘Saia’ oats, rye were the cover crops most suitable for cover crop management on the medium textured soils of the cooler Coastal region. The performance of the legumes was inferior to that of the cereals over the long term. The cover crops should be rotated at least once every four years on these soils. The preference for the use of legumes in a rotation system with cereals is ‘Kelson’ medic > faba bean > grazing vetch > ‘Paraggio’ medic.
- On sandy soils the cereals should receive 30 kg of P just before seedbed preparation, 30 kg of K and 28 kg of N just after establishment and a further 14 kg of N at the two to four leaf development phases.
- The cover crops should be sown annually and controlled chemically before bud break in both regions, to enhance the development of the permanent structure of young grapevines. For this purpose the preferred species for the medium textured soils of the Coastal region is ‘Paraggio’ medic, while that for the sandy soils in the semi-arid Olifants River Valley is grazing vetch.

- Irrespective of soil type and climatic region, the performance of the fully grown grapevines was not affected negatively if the cover crops were controlled chemically during mid-October. If, however, allowed to complete its life cycle up to the berry set stage of the grapevines, the performance of both young and fully grown grapevines were negatively affected.
- It should be possible to reduce the inorganic N applied to sandy soils after bud break (42 kg/ha N) in the warmer climatic regions in the short term (approximately after three years) and even stop the application in the medium term (approximately after five years) with pink Seradella and grazing vetch sown annually and controlled chemically before bud break. The impact will depend on the performance of the cover crop.
- The cover crops, irrespective of the management practice applied, increased the SOM of the top soil over both the medium and long term in the medium textured soil of the cooler Coastal region, as well as in the sandy soil of the warmer semi-arid Olifants River Valley.