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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Submitted for publication: August 2006

Accepted for publication: September 2006

Key words: Cover crops, soil management, grapevines, grape yield, shoot growth, grape juice.

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 grain species 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 at the 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.

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 (Fourie *et al*., 2001; Van Huyssteen *et al*., 1984) and has the ability to suppress both winter- and summer-growing weeds (Fourie *et al*., 2005; Fourie *et al*., 2006).

Van Huyssteen and Weber (1980) found that grape production and pruning mass were significantly affected 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 (Lombard *et al*., 1988; Pool *et al*., 1990; Soyer *et al*., 1984; Van Huyssteen & Weber, 1980). 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*

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Acknowledgements: The authors thank the ARC and Winetech for financial support, as well as the staff of the Soil Science Section of ARC Infruitec-Nietvoorbij for technical support. This study is part of a PhD (Agric) dissertation at the University of Stellenbosch.

al., 2005), in which the weeds were disked in during early spring (Ingels *et al*., 2005; Pool *et al*., 1990; Van Huyssteen & Weber, 1980) and in which full surface chemical control was applied (Pinamonti *et al*., 1996; Sicher *et al*., 1995; Van Huyssteen & Weber, 1980). 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 (Lombard *et al*., 1988; Pinamonti *et al*., 1996; Sicher *et al*., 1995; Soyer *et al*., 1984; Van Huyssteen & Weber, 1980). 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 into 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 (Pinamonti *et al*., 1996; Tan & Crabtree, 1990;). 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 those of grapevines grown under full surface chemical weed control or mechanical soil cultivation (Sicher *et al*., 1995; Soyer *et al*., 1984). Grapevine petiole N was significantly higher when 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 indicates 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 the 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 experimental 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 stages 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 (see 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 to be 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. Grapes from all treatments were harvested on the same date.

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 that 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)

TABLE 1

Effect of two cover crop management practices applied to three grain species and five N-fixing broadleaf species 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.

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 kilograms 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. Sulphur 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), where-after 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) (see 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 N-fixing cover crop species 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, however, not, 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 (see 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 was, 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 emphasised 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 (see 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 grain 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 (see 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 in most treatments during 2000/01 and in all the treatments during 2002/03 (see 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

TABLE 2

Effect of two cover crop management practices applied to three grain species and five N-fixing broadleaf species 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, MC3 (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.

'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 (see 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) and the 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 presented to illustrate the impact that 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 (see 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 (see 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 (see 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 (see 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 (see Table 2). The NO_3-N concentration in the petioles of 'Paraggio' medic (BB) and 'Kelson' medic (AB) indicated a luxurious supply of N

TABLE 3

Effect of two cover crop management practices applied to three grain species and five N-fixing broadleaf species 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 grain species and five N-fixing broadleaf species 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.

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 (see 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 (see 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 that the cover crops and cover crop management practices had on grapevine nutrient status during harvest over the long term (see 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) tended to be lower than that of grazing vetch (AB) during the 2000/01 and 2001/02 seasons. This was attributed to the cover crop dry matter production being considerably higher in the

TABLE 5

Effect of two cover crop management practices applied to three grain species and five N-fixing broadleaf species 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.

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 concentration was significantly higher in the AB treatment than in the BB treatment during the 2000/01 season (see Table 5). This, as well as the NO_3-N concentration in the petioles of the AB treatment (see 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 chemically control a cover crop 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 N-fixing 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 grain species 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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