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 Macro-nutrient Content of a Medium-textured Soil

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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), which is situated in the Coastal wine grape region of the Western Cape, South Africa. 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, 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 (BB) (weedchem) was also included. After five seasons, the soil organic matter (SOM) content in the 0 to 300 mm soil layer increased in all the cover crop management treatments. In weedchem and in the control, SOM remained unchanged and decreased by 16% respectively. The SOM content in the 0 to 150 mm soil layer of the cover crop treatments was, with the exception of *Vicia dasycarpa* Ten. (grazing vetch), significantly higher than that of the mechanically-cultivated control after a period of 10 years. The SOM content in the 0 to 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 grazing vetch) was significantly higher than that of weedchem. The total inorganic N (TIN) concentration of the 0 to 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 treatments in which full-surface chemical control was applied after bud break (AB). The TIN concentration of the 0 to 600 mm soil layer in the AB treatment of a species, measured after harvest in 2002/03, 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.

INTRODUCTION

The maintenance and improvement of soil quality are critical for sustained agricultural productivity (Reeves, 1997). The effect of vineyard floor management practices on organic matter content was largely confined to the 0 to 200 mm soil layer (Sicher *et al.*, 1995). According to Laker (1990) and Merwin and Stiles (1994), intensive clean cultivation reduced the organic matter content of the topsoil over the long term. The organic matter content of chemically cleaned, cultivated soils showed a decrease of 5.7% (from 5.3 g/kg to 5.0 g/kg) over a period of six years (Merwin and 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 to 150 mm soil layer (Gallaher and Ferrer, 1987). The organic matter content in grassed soil-management treatments was significantly higher than that in 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 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% (Merwin and Stiles, 1994). Continuous winter cropping with *Secale cereale* L. v. Tetra Petkus ('Tetra Petkus' rye) resulted in a small increase in soil organic carbon (5 to 10 mg/kg), compared to the control treatment in which no cover crop was

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sown (Kuo *et al*., 1997). The organic matter content in the 0 to 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 fertiliser 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 levelling-off phase that 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 mineralised 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 and Baldock, 2001). Dry matter production, therefore, determines the N benefits for subsequent crops. Between 10% and 29% of the fixed N of temperate legumes is retained by the roots (Oke, 1967; Whiteman, 1971; Musa and Burhan, 1974; Jenkinson, 1981), indicating that legume roots could make a significant contribution towards the supply of N for 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 and Edwards, 1988; Imsande, 1989; Imsande and Touraine, 1994). The amount of mineralisable N, therefore, depends on the growth stage at which the cover crop is 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 and 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 macronutrient content of a medium-textured soil in the Coastal wine grape region of South Africa.

MATERIALS AND METHODS

Experimental vineyard and layout

The detailed experimental procedures and layout were previously described in Fourie *et al*. (2006a). 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°55'S, 18°52'E). Irrigation was scheduled according to the guidelines 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 cereals. 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 (superphospate) 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).

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 control 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 had 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 per plot 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 comparisons between treatment means. The Shapiro-Wilk test was performed to test for non-normality (Shapiro and 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 com-

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 to 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 in mid-October (1999 to 2002). [5]MC = chemical control in vine row, mechanical control in working row. [6]Cover crop left to re-establish.

posite 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, according to Conradie (1994)) measured before the treatments commenced (March 1993) did not differ significantly between plots in the 0 to 300 mm soil layer (Table 1). After five seasons (March 1998), no significant differences between treatments were detected in the SOM content of the 0 to 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% over this five-year period. This did not support the results of Merwin and Stiles (1994), who reported a 5.7% decline in the organic matter content of chemically-cleaned 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 cereals, was more than 20%. This supported the results of Gallaher and 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 were 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 to 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 to 300 mm soil layer was monitored in the present study (Table 1), as opposed to the 0 to 100 mm soil layer monitored by Sanderson (1998), also contributes to the lower values reported in the present study, as the effect of floor management practices seems to be restricted mainly to the 0 to 200 mm soil layer (Sicher *et al*., 1995). No significant differences or tendencies between treatments could be detected in the SOM of the 300 to 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 to 150 mm, 150 to 300 mm and 300 and 600 mm soil layers to determine whether the impact of the treatments was greater in the top 150 mm of the soil. The SOM content in the 0 to 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 to 300 mm soil layer was also significantly higher than that of weedchem. The percentage SOM in the 0 to 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 may not be necessary to apply fertiliser N to vineyards established on soils with a clay content of 6% or more. This indicates that these species could have a significantly positive impact on the organic matter content of the 0 to 300 mm soil layer of medium-textured soils in the Coastal region. Although grazing vetch performed extremely poorly 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 to 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 to 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 and 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, which explains the above-mentioned results. The total inorganic N concentration in the 150 to 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 topsoil corresponded to 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 abovementioned four BB treatments (Table 3) also induced luxurious vegetative growth 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 cereals in the 0 to 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 to 600 soil layer. These results indicate 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 to 150 mm and 150 to 300 mm soil layers of a medium-textured soil near Stellenbosch during March 2003 (tenth season of applying the treatments).

Treatment	SOM[1] (%)	
	0 to 150 mm soil layer	150 to 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 in mid-October (1999 to 2002). [4]MC = chemical control in vine row, mechanical control in working row.

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 to 150 mm, 150 to 300 mm and 300 to 600 mm soil layers of a medium-textured soil near Stellenbosch at full bloom (early November) during the fourth season of applying the treatments (1996/97).

Treatment	Total inorganic N (mg/kg)		
	0 to 150 mm soil layer	150 to 300 mm soil layer	300 to 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 in 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 to 150 mm, 150 to 300 mm and 300 to 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 in 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 to 150 mm, 150 to 300 mm and 300 to 600 mm soil layers of a medium-textured soil near Stellenbosch at 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 in 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 to 150 mm, 150 to 300 mm and 300 to 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	8.20
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 in mid-October (1999 to 2002). [3]MC = chemical control in vine row, mechanical control in working row.

The total inorganic N concentration in the 0 to 600 mm soil layer of 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 to 300 mm and 300 to 600 mm soil layers of the 'Woogenellup' subterranean clover (AB) treatment and the 300 to 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 to high levels of N in the juice of the grapevines (Fourie *et al*., 2006b). The total inorganic N concentration of the 0 to 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 differences between the two management practices for this species did not differ significantly in the deeper soil layers, the trend was the same as that observed for the 0 to 150 mm soil layer. This trend 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 and 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 and 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 therefore could have realised mainly from early October to late December, while that of the AB treatments could have realised from late December to early March.

The total inorganic N concentration in the BB treatments of 'Kelson' medic (0 to 150 mm soil layer) and faba bean (150 to 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 in mid-October in the AB treatments during 2002/03, the total inorganic N concentrations in the 0 to 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 in the 0 to 600 mm soil layer of 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 resemble those of the 1996/97 season. The fact that the inorganic N levels measured in the 0 to 600 mm soil layer of the cover crop treatments after harvest in 2002/03 (Table 6) are much higher than those 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 trends observed indicate 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 in the 0 to 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 those of the control and weedchem. This was true for the two rye treatments in the 150 to 300 mm soil layer. In the case of the AB treatments of the legume cover crops and faba bean (BB), this significant difference was observed in the 0 to 600 mm soil layer. This illustrates that cover crops controlled chemically by mid-October, especially legume cover crops, make a significant contribution to 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 trends 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 to 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 to 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 to 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 percentage of SOM in the 0 to 300 mm soil layer to more than 1.5%, the level above which the total withdrawal of fertiliser 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 concentrations in the 0 to 600 mm soil layer.

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