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 the Organic Matter and Macro-Nutrient Contents of a Sandy Soil

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Submitted for publication: March 2007
Accepted for publication: July 2007
Key words: Cover crops, soil management, grapevines, soil inorganic nitrogen, soil organic material, soil macro-nutrients.

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. Full surface post-emergence chemical control was applied before bud break and again when the berries reached pea size (BB). The second management practice consisted of cover crops which were sown biennially. Post-emergence chemical control was applied to the vine row before bud break and full surface control was applied 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 at 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 measured 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 cereal treatments in the 0-300 mm and 0-150 mm soil layers, respectively. The TIN in the 0-150 mm soil layer of the legumes was, with the exception of pink Seradella (BB), significantly higher than that of the control, weedchem and the BB treatments of the cereals 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.

Maintenance and improvement of soil quality is critical for sustaining agricultural productivity (Reeves, 1997). The effect of surface management on the organic matter content of the soil appears to be restricted to the 0-300 mm soil layer (Sicher *et al.*, 1995; *Fourie et al.*, 2007a). Intensive clean cultivation reduced the organic matter content of the top soil over the long term (Laker, 1990; Merwin & Stiles, 1994). Fourie *et al.* (2007a) observed that the organic matter content of a medium textured soil could be maintained over a period of five years in a vineyard soil by allowing the weeds to grow during winter and applying post-emergence control during the grapevine growing season. The organic matter content of chemically clean cultivated soils decreased by between 5.7% and 16% over a period of five to six years (Merwin & Stiles, 1994; Fourie *et al.*, 2007a). According to Gallaher &

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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.

Ferrer (1987), the soil from no-tillage treatments averaged 27% more organic matter than the mechanically cultivated treatment in the 0-150 mm soil layer after a period of six years. 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). Larson *et al*. (1972) and Rasmussen *et al*. (1980) indicated that approximately five to six t/ha of plant residue are necessary to maintain the organic C level in soils. Straw mulch (150 mm thick) resulted in a 17% increase in organic matter in the 0-200 mm soil layer (Merwin & Stiles, 1994). Continuous winter cropping with *Secale cereale* L. resulted in a small increase in soil organic carbon (five 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 tons of dry matter per hectare per year (Sanderson, 1998). Fourie *et al*. (2007a) reported increases in the soil organic matter contents of the 0-300 mm soil layer, after a period of five years, where cereals and legume annuals were employed as cover crops. 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%.

The growth and N contribution of cover crops depend on species, length of the growing season, climate and soil conditions (Shennan, 1992). Dou *et al*. (1994) observed 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 which lasted until the end of the season. Amato *et al*. (1987) noted 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, 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, were at their highest after five to 11 weeks, and returned to low levels after 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 to a depth of 500 mm, but 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 grapevine growing season (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 grapegrowing 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 grain species and four N-fixing broadleaf species on the organic matter and macro-nutrient content of a sandy soil in the semi-arid Olifants River Valley.

MATERIALS AND METHODS

Experiment vineyard and layout

The detailed experimental 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 irrigation was scheduled as described by Fourie *et al.* (2007b). The grapevines received 30 kg P/ha (Superphosphate) at the end of February (just before seedbed preparation), 30 kg K/ha (Potassium chloride) and 14 kg N/ha (Limestone Ammonium Nitrate) 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 were 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 are reported on with respect to soil reaction (Table 1). The remaining five were 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. the end of November (BB). In the other cover crop management practice, the cover crops were sown biennially and 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 in the AB treatments were sown annually and the full surface post-emergence chemical control applied at the end of November was advanced to mid-October, the species having 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 eight cover crops and two management practices, plus 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 by 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 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

Soil was sampled from two positions in approximately the middle of the work row. 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 for organic carbon by 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 experimental plots 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 made by Fourie *et al*. (2007a) in a trial on a medium textured soil in the Coastal region. The SOM in the minimum cultivated cover crop treatments increased by between 23% and 94% in the 0-300 mm soil layer, depending

TABLE 1

Effect of three cover crop management practices applied selectively to three grain species and four N-fixing broadleaf species 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[1] (%)			
	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

on species and management practice applied (Table 1). These increases 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 were 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. These 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 an increase of only 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 oxidative 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 had been applied for five seasons (data not shown).

During March 2003, the SOM contents in the 0-150, 150-300 and 300-600 mm soil layers 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 over the ten year period (1993 to 2003) was 52%. 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) from 1993 to 2003 was 64% and 71%, respectively. The increases 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), were greater than 60%. These results indicate 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 of South Africa over the long term. After a period of

TABLE 2

Effect of three cover crop management practices applied selectively to three grain species and four N-fixing broadleaf species 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[1] (%)**			
	0-150 mm soil layer	**150-300 mm soil layer**	**300-600 mm soil layer**	**Average 0-300 mm soil layer**
Grain species:				
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 = not applicable

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 in 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 result once again indicated that the mechanical incorporation of grazing vetch and 'Saia' oats into the soil led to accelerated breakdown of its fibre. It is, however, strongly dependant on the age of the plant material, its degree of lignification and the formation of particulate organic matter.

Total inorganic N

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, is 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 more than 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 applied inorganic N. 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 more 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 Se-

TABLE 3

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

radella (AB). These results imply that these two species supply 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 results of Amato *et al*. (1987) who showed 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%. 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 concentrations in the 0-150 mm soil layer of the grazing vetch and pink Seradella treatments were significantly higher than in the control, weedchem and cereal treatments, as measured during the full bloom stage of the grapevines (Table 3). The total inorganic N concentrations in the 150-300 mm soil layer of grazing vetch treatments were also significantly higher than in the control, weedchem and cereal species, with the exception of the AB treatments of rye and *Avena sativa* L. v. Overberg ('Overberg' oats). These results indicated that grazing vetch and pink Seradella had the ability 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 which is normally applied to the sandy vineyard soils of the Olifants River Valley. No significant differences or tendencies between treatments were 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 concentrations 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), were significantly higher than that of the control, weedchem and cereal 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 imply that these two species should be controlled during berry set, to improve the supply of inorganic N to the grapevines in the post 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 grape juice (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

TABLE 4

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

species always exceeded that of the BB treatment of the species, with the exception of 'Paraggio' and 'Parabinga' medic (Table 4). This supported the observations of Fourie *et al*. (2007a) in a trial executed 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 inorganic N data for the 0-300 mm soil layer accumulated during the 2002/03 season (Table 5). Although the cover crops were controlled in mid-October in the AB treatments during the 2002/03 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 in the BB treatment of that species during full bloom, with the 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 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 higher than that of the control, weedchem and the treatments in which the cereals 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 grain treatments. The N-fixing broadleaf species, 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, as well as the AB treatment of grazing vetch, the elevated levels of inorganic N in the soil corresponded with abnormally high total N concentrations in the grape juice (Fourie *et al*., 2007b).

TABLE 5

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

Exchangeable K, Ca and Mg

Although significant differences in the P concentration and exchangeable Ca and Mg concentrations did occur between some treatments, no significant tendencies were detected in the years during which they were measured, namely 1997, 2000 and 2003 (data not shown). The K concentration in the 0-600 mm soil layer of the different treatments during 1997 is shown in Table 6. 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). The K concentration in the 150-300 mm soil layer of grazing vetch (AB) and pink Seradella (BB) was also significantly higher than that of the last-mentioned three treatments. No significant differences occurred 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 uptake by the grapevines after harvest. Similar trends occurred during the 2000 and 2003 seasons although they did not manifest as strongly (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 compared to 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 or grazing vetch were 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). 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 post harvest period. The application of BB 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 concentrations 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 positive impact on the K concentration in the top soil layer post harvest. Pink Seradella increased the K concentration in the top soil irrespective of the management practice applied. These cover crops could, therefore, be used to retain K in sandy soils.

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