Soil Management in the Breede River Valley Wine Grape Region, South Africa. 4. Organic Matter and Macro-nutrient Content of a Medium-textured Soil

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Submitted for publication: September 2011
Accepted for publication: January 2012

Key words: cover crops, soil management, grapevines, soil nitrogen, soil organic matter, soil macro-nutrients

Eight cover crop treatments were applied for 12 consecutive years on a medium-textured soil (18% clay) in a vineyard near Robertson (33°50'S, 19°54'E). Full surface mulching combined with full surface chemical control from bud break to harvest (BB), i.e. T3, and no cover crop combined with BB (T2) were also applied. The control (T1) consisted of mechanical control in the work row and chemical control in the vine row from bud break to harvest. After 10 years, the %C in the 0 to 600 mm soil layer of the minimum cultivated treatments increased, except in the 0 to 300 mm soil layer, in which *Festuca arundinacae* was established (T11), and the 150 to 300 mm soil layer, in which *Vicia dasycarpa* (grazing vetch) was controlled in the vine row from bud break and in the work row from berry set (end of November) (T7). The %C in the 0 to 150 mm soil layer of the cover crop treatments also exceeded the 0.9% level above which the application of N is deemed unnecessary on these soils. During the first three years the total inorganic N in the 0 to 600 mm soil layer of the treatments in which an N-fixing cover crop was sown was higher (mostly significant) than that of T1, T2, T3 and T11 during full bloom, véraison and post-harvest. Over the medium term, grazing vetch controlled chemically on the full surface from bud break (T6) caused the total inorganic N in the 0 to 600 mm soil layer during full bloom to exceed the level at which the grapevines need additional N. During véraison, this was achieved with T7. Over the long term this was achieved during full bloom with T6 and T7. During véraison, T7 gave a similar result. T3 or the use of annuals as winter-growing cover crops may supply the fertiliser needs of the grapevines post-harvest. Although differences in the P concentration and exchangeable Ca and Mg concentrations occurred between some treatments, no significant trends were observed. The level of K in all the treatments was between two and six times higher than the optimal level for the clay loam soils in the Breede River Valley.

INTRODUCTION

The maintenance and improvement of soil quality is critical if agricultural productivity is to be sustained (Reeves, 1997). The effect of surface management on the organic matter content of the soil appears to manifest mainly in the 0 to 300 mm soil layer (Sicher *et al*., 1995; Fourie *et al*., 2007a, 2007b). Fourie *et al*. (2007a), however, observed that, by using grazing vetch as a cover crop on a sandy soil, the organic matter content could be increased in the 300 to 600 mm soil layer after a period of ten years. Intensive clean cultivation reduced the organic matter content of the topsoil over the long term (Laker, 1990; Merwin & Stiles, 1994). 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. The organic matter content of a medium-textured and a sandy vineyard soil, however, could be maintained over a period of ten years by restricting mechanical clean cultivation for weed control to the necessary minimum (Fourie *et al*., 2007a, 2007b). Fourie *et al*. (2007a, 2007b) also observed that the organic matter content of a sandy and medium-textured vineyard soil could be maintained over a period of ten years by allowing the weeds to grow during winter and applying post-emergence control during the grapevine growing season. It became clear, however, that the soil from no-tillage treatments (including cover crop management) could contain as much as 86% more organic matter than the mechanically cultivated treatment in the 0 to 150 mm soil layer after a period of five to six years (Gallaher & Ferrer, 1987; Fourie *et al*., 2007a). Continuous winter cropping with cereals and legume annuals as part of a minimum soil cultivation strategy resulted in increases in soil organic carbon of up to 163% in the topsoil compared to a minimum cultivation treatment in which no cover crop

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Acknowledgements: The author thanks the ARC and Winetech for financial support, as well as the staff of the Soil and Water Science Programme of ARC Infruitec-Nietvoorbij, for technical support.

was sown (Kuo *et al*., 1997; Fourie *et al*., 2007a, 2007b). 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 it was allowed to complete its life cycle (Sanderson, 1998). 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). Straw mulch (150 mm thick) resulted in a 17% increase in organic matter in the 0 to 200 mm soil layer (Merwin & Stiles, 1994). 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 %C exceeded 0.9%.

Dou *et al*. (1994) observed that total N availability was affected by the tillage method applied. More N was mineralised from legume tops than from the straw of cereals and grasses (Van Huyssteen *et al*., 1984; Amato *et al*., 1987; Fourie *et al*., 2007a, 2007b). 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). 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 and a sandy soil situated in the Olifants River Valley wine grape region of South Africa (Fourie *et al*., 2007a, 2007b). However, the effect of these management practices on the organic matter content and nutrient status of medium-textured soils in the warmer grape-growing regions of South Africa is not known.

The reviewed literature indicates that soil cultivation practices have a significant impact on the organic matter content and nutrient status of medium-textured soils. Cover crop growth and the N contributed by them depend on species, length of growing season, climate and soil conditions (Shennan, 1992). This study was therefore conducted to determine the effect of different soil cultivation practices on the organic matter and macro-nutrient content of a medium-textured soil in the Breede River Valley wine grape region of South Africa.

MATERIALS AND METHODS

Experiment vineyard and layout

The detailed experimental procedures and layout were previously described in Fourie (2010). The trial was carried out in a Chardonnay/99 Richter vineyard trained on a seven-strand double lengthened Perold trellis system (Booysen *et al*., 1992) and established on a sandy clay loam soil (27% clay) at the ARC Infruitec-Nietvoorbij research farm near Robertson during November 1992. Robertson (33°50'S, 19°54'E) is situated in the Breede River Valley region of the Western Cape. Mean annual rainfall amounts to 278 mm, of which approximately 178 mm precipitates from March to August. The grapevines were spaced at 1.5 m in the row and with 2.75 m between rows. The cover crops were sown annually during mid-April (seeding dates varying between 4 and 15 April) at seeding densities suggested by Fourie *et al*. (2001), with the exception of 1993, when infrastructural work delayed sowing until 24 May. Seedbed preparation was done to a depth of about 150 mm with a disc harrow approximately six weeks before the seeding date (two pass-overs in opposite directions). After sowing by hand, the seeds were covered using a disc harrow. The vineyard was irrigated by means of 25.7 L/h micro-sprinklers, which had a 360° wetting pattern. The micro-sprinklers were installed on the irrigation line in the upright position at 1.5 m intervals. Irrigation was scheduled as described by Fourie (2010) from the day the cover crops were established until the end of August. During summer, the soil water content was determined weekly with a neutron moisture probe (Hydroprobe 305DR, CPN, California) that was calibrated against gravimetric soil water content. Readily available water (RAW) was defined as the water retained between field water capacity and -0.1 MPa, and the grapevines were irrigated to field water capacity when approximately 60% RAW was depleted (P.A. Myburgh, 1993 – personal communication). The grapevines received 14 kg/ha of N during seedbed preparation (first week of March), as well as 14 kg/ha of N at the two- to four-leaf development phases of the grass cover crops. In the case of the N-fixing broadleaf cover crops, the N was applied to the grapevine row only, while in the other treatments it was broadcast. Post-emergence weed control was applied with glyphosate at a rate of 1.44 kg/ha (active ingredient) by means of a tractor sprayer. *Triticale* v. Usgen 18 (triticale), *Secale cereale* L. v. Henog (rye) and *Vicia faba* L v. Fiord (faba bean) were flattened with a roller approximately three weeks after being controlled chemically to create a mulched soil surface.

Eleven treatments were applied, as shown in Table 1. Six of these treatments consisted of full surface post-emergence chemical weed control from just before grapevine bud break (end of August) to harvest (BB) being applied to winter growing weeds (T2), triticale (T4), *Vicia dasycarpa* Ten. (grazing vetch) (T6), a mixture of rye and faba bean (T8), an annual rotation of triticale and vetch (T9), as well as a biennial rotation of triticale and vetch (T10). Two treatments consisted of triticale (T5) and vetch (T7) being sown annually as cover crops, with post-emergence chemical weed control being applied to a 1 m wide strip in the vine row just before grapevine bud break (end of August), followed by full surface post-emergence chemical control

TABLE 1
Treatments applied from April 1993 to March 2005.

Treatment	Treatment code
No cover crop, post-emergence chemical control of a 1 m wide strip in the vine row from just before grapevine bud break (end of August) to just before harvest (end of January) (VR) and mechanical cultivation in the work row during the same period.	T1 (Control)
No cover crop, full surface post-emergence chemical control from the end of August to the end of January (BB)	T2
Eight t/ha straw mulch packed out full surface just after grapevine bud break (third week of September), BB	T3
Triticale v. Usgen 18 (triticale) sown annually (100 kg/ha), BB.	T4
Triticale sown annually (100 kg/ha). Post-emergence chemical control of a 1 m wide strip in the vine row (end of August) and full surface post-emergence chemical control from when the berries reached pea size (end of November) to the end of January (AB)	T5
Vicia dasycarpa Ten. (vetch) sown annually (50 kg/ha), BB	T6
Vetch sown annually (50 kg/ha), AB	T7
A *Secale cereale* L. v. Henog (rye) and *Vicia faba* L. v. Fiord (Faba bean) mixture sown annually (50 kg/ha and 60 kg/ha respectively), BB.	T8
Triticale (100 kg/ha) and vetch (50 kg/ha) rotated annually, BB	T9
Triticale (100 kg/ha) and vetch (50 kg/ha) rotated biennially, BB	T10
Festuca arundinacae L. v. Cochise (dwarf fescue) established during 1993 (15 kg/ha) and 1998 (15 kg/ha). VR and slashing in the work row throughout the season	T11

from the stage when the grapevine berries reach pea size (end of November) to just before harvest (end of January) (AB). A full surface straw mulch packed out at a density of approximately eight tons per hectare during grapevine bud break combined with BB was also included in the trial (T3). Another treatment consisted of *Festuca arundinacae* L. v. Cochise (dwarf Fescue) being slashed in the work row throughout the season, with post-emergence chemical weed control being applied to a 1 m wide strip in the vine row from just before grapevine bud break to harvest (T11). These treatments were compared to a control, in which no cover crop was sown and post-emergence chemical weed control was applied to a 1 m wide strip in the vine row from just before grapevine bud break to harvest (T1).

Measurements

Soil samples were taken from the 0 to 150 mm, 150 to 300 mm and 300 to 600 mm soil layers. Soil was sampled from two positions for each layer 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).

Statistical procedures

The experiment was a complete randomised design with eleven treatments replicated four times. The experiment was repeated for 12 consecutive seasons (years). The size of each replication (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% significance level to facilitate comparison between treatment means. The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965).

RESULTS AND DISCUSSION

Soil organic matter (%C)

During March 1994, one season after the different treatments were initiated, the %C in the 0 to 150 mm soil layer of T11 was higher than that of T7 and T10 (Table 2). After three seasons (March 1996), the % C in the 0 to 150 mm soil layer of T3 and T11 was higher than that of T1 and T2. With the exception of T8, the %C in the 0 to 150 mm soil layer of all the treatments in which an annual cover crop was sown (T4 to T10) was higher than that of T1. The abovementioned trends were not observed in the 150 to 600 mm soil layer during both March 1994 and March 1996. During the tenth year of the trial, the %C in the 0 to 150 mm soil layer of the treatments in which triticale and grazing vetch were rotated as cover crops (T9 and T10) was higher than that of the other treatments, with the exception of T8. The %C in the 0 to 150 mm soil layer of T8 was higher than that of T1. These results indicate that the combination of a grain species and an N-fixing species, either in a mixture or as part of a crop rotation system, promoted the build-up of organic C in the topsoil over the long term. The %C in the 150 to 600 mm soil layer of T5 was higher than that of T1 and T11 after a period of ten years. The %C in the 300 to 600 mm soil layer of T5 was also higher than that of treatments T3 and T4. This is an indication that the practice to allow a grain species to complete its life cycle also promotes the build-up of carbon in the deeper soil layers. Between 1994 and 1996, an increase in %C was observed in the 0 to 150 mm soil layer of T3, T4, T6, T7 and T10. This is an indication that, although difficult, it is possible to increase the %C in this soil over the short term by mulching the soil surface or by using grazing vetch and triticale as cover crops. This supports the observation

TABLE 2
Effect of different soil cultivation practices on the soil organic carbon (C) content in the 0 to 600 mm soil layer of a medium-textured soil near Robertson, during March 1994 (one season after the different treatments were initiated), March 1996 (third season of applying treatments) and March 2003 (tenth season of applying treatments).

Treatment	%C								
	0–150 mm soil layer			150–300 mm soil layer			300–600 mm soil layer		
	March 1994	March 1996	March 2003	March 1994	March 1996	March 2003	March 1994	March 1996	March 2003
T1. No cover crop, MC[1] (Control)	0.66	0.60	0.83	0.51	0.47	0.67	0.32	0.33	0.48
T2. No cover crop, BB[2]	0.64	0.70	0.85	0.39	0.43	0.72	0.23	0.33	0.55
T3. Full surface straw mulch, BB	0.60	0.88	0.99	0.44	0.49	0.84	0.22	0.25	0.54
T4. *Triticale* v. Usgen 18 (triticale), BB	0.67	0.85	0.97	0.48	0.52	0.87	0.27	0.43	0.57
T5. Triticale, AB[3]	0.68	0.79	0.96	0.52	0.56	0.93	0.34	0.36	0.80
T6. *Vicia dasycarpa* Ten. (vetch), BB	0.67	0.85	0.94	0.55	0.55	0.85	0.32	0.35	0.57
T7. Vetch, AB	0.58	0.81	0.98	0.54	0.54	0.74	0.22	0.31	0.59
T8. *Secale cereale* L. v. Henog (rye)/*Vicia faba* L. v. Fiord (faba bean) mixture, BB	0.64	0.73	1.01	0.43	0.44	0.81	0.31	0.45	0.66
T9. Triticale/vetch rotated annually, BB	0.70	0.83	1.17	0.49	0.50	0.76	0.32	0.33	0.65
T10. Triticale/vetch rotated biennially, BB	0.58	0.83	1.21	0.50	0.54	0.74	0.32	0.36	0.74
T11. *Festuca arundinacae* L. v. Cochise (dwarf Fescue), SL[4]	0.76	0.88	0.91	0.54	0.64	0.69	0.27	0.37	0.57
LSD ($p \leq 0.10$)		0.16			0.21			0.21	

[1]Post-emergence chemical control in vine row and mechanical control in working row from the end of August. [2]Full surface post-emergence chemical control from the end of August. [3]Post-emergence chemical control in vine row at the end of August, full surface post-emergence chemical control from when the grape berries reached pea size (end of November). [4]Chemical control in vine row from end of August, work row slashed throughout the season.

by Sicher *et al*. (1995) that the effect of floor management practices seems to be restricted mainly to the 0 to 200 mm soil layer. However, after the treatments were implemented for ten years, the %C in the 0 to 600 mm soil layer of all the minimum cultivated treatments increased, with the exception of the 0 to 300 mm soil layer of T11 and the 150 to 300 mm soil layer of T7 (Table 2). This again contradicts the observation by Sicher *et al*. (1995) and supports the results of Gallaher and Ferrer (1987), Sanderson (1998) and Fourie *et al*. (2007a, 2007b). The increase observed in the 0 to 600 mm soil layer of T2 did not support the results of Merwin and Stiles (1994), who reported a 5.7% decline in the organic matter content of chemically-clean cultivated soils over a period of six years. Fourie *et al*. (2007a, 2007b) observed that the soil organic matter content could be maintained over a period of five years by controlling the winter growing weeds chemically just before grapevine bud break and again during the grapevine berry set stage (end of November) on both a sandy (98.6% sand) and medium-textured (18% clay) soil respectively. The %C in the mechanically cultivated control (T1) tended to be lower in the 0 to 300 mm soil layer during 1996 than the level observed during 1994 (Table 2). Similar results were reported by Fourie *et al*. (2007b) for a medium-textured soil (18% clay) in the coastal grapevine region of South Africa.

The increase in the %C observed over the long term in the two treatments in which no cover crop was established during winter, namely T1 and T2, was attributed to the weed spectrum in these treatments being dominated by *Bromus diandrus* Roth (ripgut brome), providing significant amounts of dry matter to the soil (Fourie, 2010).

The %C in the 0 to 150 mm soil layer of the cover crop treatments (T4 to T11) and the treatment in which full surface mulching was applied (T3) exceeded the 0.9% 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.

Total inorganic N

Before the grapevines reached the full bearing stage

Full bloom

The total inorganic N (NH_4-N + NO_3-N) concentrations in the 0 to 600 mm soil layer at full bloom during the second (1994/95) and third (1995/96) season of the trial are presented in Table 3. The total inorganic N in the 0 to 150 mm soil layer of treatments in which an annual cover crop was sown (T4 to T10) was higher than that of the other treatments (T1 to 3 and T11) during the second season of the trial. The same trend was observed during the third season of the trial, albeit only significantly for T7. The total inorganic N in the 150 to 300 mm soil layer of the treatments in which an annual cover crop was sown was higher than that of the other treatments (T1 to T3 and T11), with the exception of T4, during both the second and third seasons of the trial. This trend was similar to that observed for the 0 to 150 mm soil layer. In the 300 to 600 mm soil layer, the total inorganic N of the treatments in which an N-fixing cover crop was sown (T6 to T9) was higher than that of the other treatments during the second season of the trial, with the exception of T5 and T10 (biennial rotation of triticale and grazing vetch). The same trend was observed in the third season, when the treatments in which an N-fixing cover crop was sown (T6 to T8 and T10) was higher than that of the other treatments, with the exception of T5 and T9 (annual rotation of triticale and grazing vetch).

TABLE 3

Effect of different soil cultivation practices on 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 Robertson at full bloom, during the second season (November 1994) and third season (November 1995) of the trial.

Treatment	Total inorganic N (mg/kg)					
	November 1994			November 1995		
	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer
T1. No cover crop, MC[1] (Control)	8.57	4.00	4.07	8.89	6.76	4.81
T2. No cover crop, BB[2]	8.47	5.48	4.16	9.79	5.62	4.73
T3. Full surface straw mulch, BB	8.80	5.52	4.72	9.73	5.85	5.11
T4. *Triticale* v. Usgen 18 (triticale), BB	13.86	7.68	4.52	13.65	6.73	5.02
T5. Triticale, AB[3]	14.57	9.82	7.54	12.36	12.36	7.19
T6. *Vicia dasycarpa* Ten. (vetch), BB	25.13	12.98	7.89	15.57	12.06	8.86
T7. Vetch, AB	16.41	12.93	9.33	25.49	15.98	12.89
T8. *Secale cereale* L. v. Henog (rye)/*Vicia faba* L. v. Fiord (faba bean) mixture, BB	13.36	9.61	7.58	12.98	9.78	8.55
T9. Triticale/vetch rotated annually, BB	22.96	9.92	7.26	15.70[t]	10.25[t]	9.09[t]
T10. Triticale/vetch rotated biennially, BB	13.36[t]	8.01[t]	6.94[t]	13.22	18.08	14.40
T11. *Festuca arundinacae* L. v. Cochise (dwarf Fescue), SL[4]	6.96	3.47	2.68	6.98	4.25	3.05
LSD ($p \leq 0.10$)	4.07	2.37	2.42	6.78	3.95	6.51

[1]Post-emergence chemical control in vine row and mechanical control in working row from the end of August. [2]Full surface post-emergence chemical control from the end of August. [3]Post-emergence chemical control in vine row at the end of August, full surface post-emergence chemical control from when the grape berries reached pea size (end of November). [4]Chemical control in vine row from end of August, work row slashed throughout the season. [t]Year in which triticale was sown.

The abovementioned results support the observations of Van Huyssteen *et al*. (1984), Amato *et al*. (1987) and Fourie *et al*. (2007a, 2007b). In the case of T6 and T10, these higher levels of N in the soil (Table 3) resulted in the levels of N in the grapevines during the early growing season being slightly elevated (Fourie, 2011).

The total inorganic N in the treatment in which a permanent cover crop was sown (T11) was the lowest in the 0 to 600 mm soil layer during both the second and third season of the trial (Table 3). These low amounts of N available in the soil (Table 3), as well as the growing cover crop and summer growing weeds (Fourie, 2010) competing with the young grapevines for the available N, contributed to the N deficiency experienced by the grapevines, which impacted negatively on shoot growth and grape yield (Fourie, 2011). The relatively low levels of available N in T1 and T2, especially during the second season of the trial (Table 3), as well as the competition from summer growing weeds (Fourie, 2010) for the available N, resulted in the young grapevines in these two treatments experiencing N deficiencies early in the grapevine growing season (Fourie, 2011). Despite the fact that the total inorganic N in the 0 to 600 mm layer of the soil covered with a straw mulch throughout the year (T3) was similar to that of T1 and T2 (Table 3), the young grapevines did not experience any N deficiencies early in the grapevine growing season (Fourie, 2011). This was attributed, inter alia, to seasonal soil temperatures at a depth of 200 mm under full surface mulch being more favourable for grapevine roots than mechanical cultivation or a clean soil surface (Fourie & Freitag, 2010).

Véraison

Total inorganic N concentrations in the 0 to 600 mm soil layer at véraison during the second (1994/95) and third (1995/96) season of the trial are presented in Table 4. Total inorganic N in the 0 to 150 mm soil layer of treatments in which an N-fixing cover crop was sown (T6 to T9) was higher than that of T1, T2 and T11 during the second season. A similar trend was observed during the third season. Although this trend could also be observed in the 150 to 300 mm soil layer during the second season, it was not significant, with the exception of T7. Total inorganic N in the 150 to 300 mm layer of T5, T6, T8 and T10 was higher than that of T1, T2 and T11 during the third season. Although no differences occurred in the 300 to 600 mm soil layer during the second season, total inorganic N of the treatments in which N-fixing cover crops were sown during the second and third seasons (T6 to T10) was higher than that of the other treatments (T1 to T5 and T11) during the third season. This had a positive impact on the grape yield of the young grapevines in T10 (Fourie, 2011).

A permanent cover crop (T11) resulted in the lowest total inorganic N in the 0 to 600 mm soil layer during both seasons (Table 3). These low amounts of N available in the soil during the latter part of the season (Table 3), as well as the growing cover crop and summer growing weeds (Fourie, 2010) competing with the young grapevines for available N, contributed to the low N concentration in the juice of the young grapevines observed by Fourie (2011).

Post-harvest

The total inorganic N concentrations in the 0 to 600 mm soil layer after harvest during the second (1994/95) and third

(1995/96) season of the trial are presented in Table 5. Total inorganic N in the 0 to 600 mm soil layer of the treatments in which an N-fixing cover crop was sown (T6 to T9) was higher than that of T1, T2, T3 and T11 during the second season. The same trend was observed during the third season (N-fixing cover crops were sown in T6, T7, T8 and T10). Total inorganic N in the 0 to 600 mm soil layer of T5 was also higher than that of T1, T2, T3 and T11 during both

TABLE 4
Effect of different soil cultivation practices on 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 Robertson at véraison, during the second season (January 1995) and the third season (January 1996) of the trial.

Treatment	Total inorganic N (mg/kg)					
	January 1995			January 1996		
	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer
T1. No cover crop, MC[1] (Control)	6.26	4.68	3.55	12.98	10.57	5.33
T2. No cover crop, BB[2]	6.18	5.36	3.92	14.08	11.82	6.93
T3. Full surface straw mulch, BB	8.75	5.62	4.34	16.47	11.91	7.01
T4. *Triticale* v. Usgen 18 (triticale), BB	11.21	5.20	4.41	24.29	16.01	7.07
T5. Triticale, AB[3]	11.95	6.07	5.23	22.73	17.69	7.81
T6. *Vicia dasycarpa* Ten. (vetch), BB	12.43	6.20	5.21	28.98	21.66	15.45
T7. Vetch, AB	16.25	9.07	7.51	25.17	16.81	12.90
T8. *Secale cereale* L. v. Henog (rye)/*Vicia faba* L. v. Fiord (faba bean) mixture, BB	13.66	5.53	4.77	27.53	19.23	12.62
T9. Triticale/vetch rotated annually, BB	19.19	7.10	5.24	26.25[t]	15.53[t]	16.60[t]
T10. Triticale/vetch rotated biennially, BB	9.16[t]	5.62[t]	4.69[t]	25.24	23.92	26.32
T11. *Festuca arundinacae* L. v. Cochise (dwarf Fescue), SL[4]	5.84	4.85	3.36	4.82	5.08	2.89
LSD ($p \leq 0.10$)	5.56	2.17	NS[5]	4.56	5.07	4.58

[1]Post-emergence chemical control in vine row and mechanical control in working row from the end of August. [2]Full surface post-emergence chemical control from the end of August. [3]Post-emergence chemical control in vine row at the end of August, full surface post-emergence chemical control from when the grape berries reached pea size (end of November). [4]Chemical control in vine row from end of August, work row slashed throughout the season. [5]Data do not differ significantly at the 10% level. [t]Year in which triticale was sown.

TABLE 5
Effect of different soil cultivation practices on 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 Robertson after harvest, during the second season (March 1995) and the third season (March 1996) of the trial.

Treatment	Total inorganic N (mg/kg)					
	March 1995			March 1996		
	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer
T1. No cover crop, MC[1] (Control)	8.41	6.18	5.59	6.68	8.61	5.92
T2. No cover crop, BB[2]	8.11	6.68	4.80	12.41	15.42	6.58
T3. Full surface straw mulch, BB	8.39	6.93	4.88	17.42	18.11	8.55
T4. *Triticale* v. Usgen 18 (triticale), BB	13.25	12.76	6.20	14.65	20.32	10.58
T5. Triticale, AB[3]	18.38	12.88	9.04	25.26	24.16	18.92
T6. *Vicia dasycarpa* Ten. (vetch), BB	19.25	14.32	11.76	29.41	32.60	20.78
T7. Vetch, AB	19.79	16.53	11.20	25.75	29.07	26.98
T8. *Secale cereale* L. v. Henog (rye)/*Vicia faba* L. v. Fiord (faba bean) mixture, BB	16.15	11.68	9.17	25.80	23.73	16.22
T9. Triticale/vetch rotated annually, BB	23.82	12.75	9.48	28.32[t]	29.47[t]	23.75[t]
T10. Triticale/vetch rotated biennially, BB	12.54[t]	10.24[t]	7.65[t]	20.26	25.57	15.05
T11. *Festuca arundinacae* L. v. Cochise (dwarf Fescue), SL[4]	7.56	5.31	3.34	7.33	5.89	5.34
LSD ($p \leq 0.10$)	5.08	3.61	3.24	6.99	6.01	5.98

[1]Post-emergence chemical control in vine row and mechanical control in working row from the end of August. [2]Full surface post-emergence chemical control from the end of August. [3]Post-emergence chemical control in vine row at the end of August, full surface post-emergence chemical control from when the grape berries reached pea size (end of November). [4]Chemical control in vine row from end of August, work row slashed throughout the season. [t]Year in which triticale was sown.

seasons. This is an indication that N in the fibre of the roots and mulch of triticale was released at a slightly later stage if left to die back naturally. Similar trends were observed with other cover crop species (Fourie *et al*., 2007a, 2007b).

Full bearing stage

Full bloom

Total inorganic N in the 0 to 600 mm soil layer at full bloom during the sixth (1998/99) and tenth (2002/03) season of the trial are presented in Table 6. Total inorganic N in the 0 to 150 mm soil layer of T3 and T6 was higher than that of T1 and T11, as well as that of the two treatments in which triticale was sown annually as cover crop (T4 and T5) during the sixth season. This trend, however, did not occur in the deeper soil layers. Total inorganic N in the 150 to 300 mm soil layer of T6 and T9 was higher than that of T11. The average level of total inorganic N in the 0 to 600 mm soil layer of T6 and T9 (Table 6) was also above the level at which no N fertiliser needs to be applied in a vineyard under South African conditions (Conradie, 1994). This is a strong indication that grazing vetch has the ability to supply sufficient amounts of N to grapevines during the early growing season (Table 6), when the above-ground growth exceeds one ton of dry matter per hectare (Fourie, 2010) and chemical control is applied from the end of August (just before bud break). In the long term, the total inorganic N of T6 and T7 was higher than that of T1 and T11 in the 0 to 150 mm and 0 to 600 mm soil layers respectively (Table 6). Total inorganic N observed in the 150 to 600 mm soil layer of T2 was also lower than that measured in T7. Total inorganic N in the 0 to 600 mm soil layer of T6 and T7 (Table 6) was above the level at which no N fertiliser needs to be applied in a vineyard under South African conditions (Conradie, 1994). This indicates that grazing vetch has the ability to supply sufficient amounts of N to the grapevine during the early growing season over the long term (Table 6), when the above-ground growth exceeds one ton of dry matter per hectare (Fourie, 2010), even when chemical control is postponed until the end of November (when the grapevine berries reach pea size).

The total inorganic N observed in T11 was the lowest in the 0 to 600 mm soil layer during both the sixth and tenth seasons. These low amounts of N available in the soil (Table 6), as well as the growing cover crop and summer growing weeds (Fourie, 2010) competing with the young grapevines for the available N, contributed to the N deficiency experienced by the grapevines over the long term (Fourie, 2011). The continuous low total inorganic N in the 0 to 600 mm soil layer observed in T2 (Table 6) might have contributed to the slight early season N deficiency experienced by the grapevines during the seventh (1999/2000) season of the trial (Fourie, 2011).

Véraison

Total inorganic N concentrations in the 0 to 600 mm soil layer at véraison during the sixth (1998/99) and tenth (2002/03) season of the trial are presented in Table 7. The total inorganic N in T3 and T6 was significantly higher than that of T11 during the sixth season. This supports the trend observed during full bloom. No significant differences occurred in the 150 to 600 mm soil layer.

During the tenth season, total inorganic N in the 0 to 600 mm soil layer of T7 was higher than that of the other treatments, except for the 300 to 600 mm soil layer of T9. Total inorganic N in the 300 to 600 mm soil layer of T9 was also higher than that of T11. However, only in T7 was the average total inorganic N of the 0 to 600 mm soil layer

TABLE 6

Effect of different soil cultivation practices on 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 Robertson at full bloom, during the sixth season (November 1998) and tenth season (November 2002) of the trial.

Treatment	Total inorganic N (mg/kg)					
	November 1998			November 2002		
	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer
T1. No cover crop, MC[1] (Control)	10.63	10.22	10.55	11.65	9.97	9.48
T2. No cover crop, BB[2]	13.41	10.41	7.29	15.15	9.37	9.41
T3. Full surface straw mulch, BB	19.36	10.36	8.92	15.25	14.85	11.00
T4. *Triticale* v. Usgen 18 (triticale), BB	11.03	10.01	8.83	15.01	13.05	11.25
T5. Triticale, AB[3]	12.00	10.05	10.64	14.90	14.73	10.51
T6. *Vicia dasycarpa* Ten. (vetch), BB	19.94	12.93	12.59	20.46	13.00	11.91
T7. Vetch, AB	13.14	11.66	10.93	19.36	25.13	19.61
T8. *Secale cereale* L. v. Henog (rye)/*Vicia faba* L. v. Fiord (faba bean) mixture, BB	12.66	10.31	9.41	14.91	10.72	9.72
T9. Triticale/vetch rotated annually, BB	15.44	13.73	18.19	18.57	11.20	10.06
T10. Triticale/vetch rotated biennially, BB	15.53[t]	11.51[t]	9.51[t]	14.58[t]	16.49[t]	11.41[t]
T11. *Festuca arundinacae* L. v. Cochise (dwarf Fescue), SL[4]	9.26	7.22	5.38	10.25	9.09	7.01
LSD ($p \leq 0.05$)	7.03	4.67	8.52	7.35	7.71	6.10

[1]Post-emergence chemical control in vine row and mechanical control in working row from the end of August. [2]Full surface post-emergence chemical control from the end of August. [3]Post-emergence chemical control in vine row at the end of August, full surface post-emergence chemical control from when the grape berries reached pea size (end of November). [4]Chemical control in vine row from end of August, work row slashed throughout the season. [t]Year in which triticale was sown.

(Table 7) above the level at which no N fertiliser needs to be applied in a vineyard under South African conditions (Conradie, 1994). This supports the trends observed during full bloom.

Post-harvest

Total inorganic N concentrations in the 0 to 600 mm soil layer after harvest during the sixth (1998/99) and tenth (2002/03) season of the trial are presented in Table 8. Total inorganic N in the 0 to 150 mm soil layer of T3, T6 and T7 was higher than that of T2 and T11 during the sixth and tenth season of the trial. Average total inorganic N in the 0 to 600 mm soil layer of T3 and all treatments in which an annual cover crop was established, with the exception of T5, was above the level at which no N fertiliser needs to be applied in a vineyard under South African conditions (Conradie, 1994). This is an indication that, over the long term, full surface straw mulch or annuals as a winter growing cover crop may supply in the N needs of grapevines established on these medium-textured soils in the Breede River Valley.

Phosphorous, potassium and exchangeable K, Ca and Mg

Although differences in the P concentration and exchangeable Ca and Mg concentrations did occur between some treatments, no significant trends were observed in the years during which they were measured, namely 2000 and 2003 (data not shown). The K concentration in the 0 to 600 mm soil layer of the different treatments during 2003 is shown in Table 9. The level of K in all the treatments was between two and six times higher than the optimal level for the clay loam soils in the Breede River Valley (Conradie, 1994), resulting in K being on average 5.6% of the total exchangeable cation capacity in the 0 to 600 mm soil layer (data not shown). This, however, did not cause the levels of K in the must to exceed the maximum norm of 2 000 mg/L (W.J. Conradie, 2011 – personal communication), as indicated by Fourie (2011). The absence of grapevine reaction to the luxurious supply of K was attributed to the grapevines only being irrigated to field water capacity when approximately 60% RAW was depleted (P.A. Myburgh, 1993 – personal communication), as well as the vegetative growth and production of the vines being in balance (Fourie, 2011). The K concentration in the 0 to 150 mm soil layer of T1, T3, T4 and T11 was higher than that of T5 and T7 to T10. The K concentration of T6 and T11 was higher than that of T7 and T9 in the 150 to 600 mm soil layer and higher than that of T5 and T8 in the 150 to 300 mm soil layer (Table 9). These results indicate that the annual winter growing cover crops must have incorporated some of the K into their fibre, resulting in the K being fixed in the increased amount of organic matter present in the 0 to 600 mm soil layer (Table 2).

CONCLUSIONS

Cover crop management resulted in an increase in soil organic matter to a depth of 600 mm. This could also be achieved with full surface chemical control and mechanical control in the work row if the winter growing weed spectrum is dominated by ripgut brome. With cover crop management it was possible to raise the soil organic matter content to a level at which the annual application of N fertiliser becomes unnecessary.

During the first three years after a vineyard is established on these sandy clay loam soils, an annual winter growing N-fixing cover crop improved the N supply to the vineyard

TABLE 7

Effect of different soil cultivation practices on 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 Robertson at véraison, during the sixth season (January 1999) and the tenth season (January 2003) of the trial.

Treatment	Total inorganic N (mg/kg)					
	January 1999			January 2003		
	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer
T1. No cover crop, MC[1] (Control)	10.34	5.49	7.30	8.45	8.40	7.02
T2. No cover crop, BB[2]	10.82	5.34	5.30	6.83	8.14	6.98
T3. Full surface straw mulch, BB	16.74	8.60	6.71	9.12	8.93	6.60
T4. *Triticale* v. Usgen 18 (triticale), BB	13.50	5.65	5.03	12.05	6.85	6.52
T5. Triticale, AB[3]	13.20	9.40	8.11	13.35	9.11	8.42
T6. *Vicia dasycarpa* Ten. (vetch), BB	15.58	9.86	10.58	11.77	6.72	7.06
T7. Vetch, AB	13.28	10.96	10.23	22.38	23.27	16.72
T8. *Secale cereale* L. v. Henog (rye)/*Vicia faba* L. v. Fiord (faba bean) mixture, BB	13.80	8.91	8.29	11.65	11.24	9.21
T9. Triticale/vetch rotated annually, BB	13.75	11.20	14.10	14.70	7.29	11.18
T10. Triticale/vetch rotated biennially, BB	12.93[t]	8.48[t]	7.42[t]	12.33[t]	7.59[t]	5.64[t]
T11. *Festuca arundinacae* L. v. Cochise (dwarf Fescue), SL[4]	7.79	6.25	5.09	8.47	6.68	5.38
LSD ($p \leq 0.05$)	6.74	NS[5]	NS	8.42	6.89	5.74

[1]Post-emergence chemical control in vine row and mechanical control in working row from the end of August. [2]Full surface post-emergence chemical control from the end of August. [3]Post-emergence chemical control in vine row at the end of August, full surface post-emergence chemical control from when the grape berries reached pea size (end of November). [4]Chemical control in vine row from end of August, work row slashed throughout the season. [5]Data do not differ significantly at the 10% level. [t]Year in which triticale was sown.

TABLE 8
Effect of different soil cultivation practices on 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 Robertson after harvest, during the sixth season (March 1999) and the tenth season (March 2003) of the trial.

Treatment	Total inorganic N (mg/kg)					
	March 1999			March 2003		
	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer
T1. No cover crop, MC[1] (Control)	10.76	9.13	4.17	15.70	10.22	10.17
T2. No cover crop, BB[2]	8.53	2.80	4.31	17.86	14.40	9.91
T3. Full surface straw mulch, BB	15.43	9.08	8.29	23.96	13.85	12.57
T4. *Triticale* v. Usgen 18 (triticale), BB	12.73	4.47	4.63	17.72	16.93	10.45
T5. Triticale, AB[3]	13.57	9.10	6.84	16.56	13.02	12.87
T6. *Vicia dasycarpa* Ten. (vetch), BB	16.09	10.11	9.58	21.83	18.57	13.98
T7. Vetch, AB	15.61	10.61	10.83	27.63	17.07	14.13
T8. *Secale cereale* L. v. Henog (rye)/*Vicia faba* L. v. Fiord (faba bean) mixture, BB	13.40	8.82	7.35	16.04	20.64	13.16
T9. Triticale/vetch rotated annually, BB	12.90	9.94	12.06	18.23	18.34	10.90
T10. Triticale/vetch rotated biennially, BB	11.63[t]	6.96[t]	6.38[t]	16.92[t]	16.73[t]	11.60[t]
T11. *Festuca arundinacae* L. v. Cochise (dwarf Fescue), SL[4]	7.05	5.76	4.94	13.09	10.71	7.30
LSD ($p \leq 0.10$)	6.60	NS[5]	NS	9.31	NS	NS

[1]Post-emergence chemical control in vine row and mechanical control in working row from the end of August. [2]Full surface post-emergence chemical control from the end of August. [3]Post-emergence chemical control in vine row at the end of August, full surface post-emergence chemical control from when the grape berries reached pea size (end of November). [4]Chemical control in vine row from end of August, work row slashed throughout the season. [5]Data do not differ significantly at the 10% level. [t]Year in which triticale was sown.

TABLE 9
Effect of different soil cultivation practices on the K concentration in the 0 to 150 mm, 150 to 300 mm and 300 to 600 mm soil layers of a medium-textured soil near Robertson after harvest, during the tenth season (March 2003) of the trial.

Treatment	K (mg/kg)		
	0–150 mm soil layer	150–300 mm soil layer	300–600 mm soil layer
T1. No cover crop, MC[1] (Control)	493	416	274
T2. No cover crop, BB[2]	472	449	298
T3. Full surface straw mulch, BB	557	424	308
T4. *Triticale* v. Usgen 18 (triticale), BB	526	424	238
T5. Triticale, AB[3]	384	333	270
T6. *Vicia dasycarpa* Ten. (vetch), BB	413	480	340
T7. Vetch, AB	364	327	193
T8. *Secale cereale* L. v. Henog (rye)/*Vicia faba* L. v. Fiord (faba bean) mixture, BB	395	343	270
T9. Triticale/vetch rotated annually, BB	371	349	178
T10. Triticale/vetch rotated biennially, BB	383	383	279
T11. *Festuca arundinacae* L. v. Cochise (dwarf Fescue), SL[4]	533	504	432
LSD ($p \leq 0.10$)	90	125	118

[1]Post-emergence chemical control in vine row and mechanical control in working row from the end of August. [2]Full surface post-emergence chemical control from the end of August. [3]Post-emergence chemical control in vine row at the end of August, full surface post-emergence chemical control from when the grape berries reached pea size (end of November). [4]Chemical control in vine row from end of August, work row slashed throughout the season. [5]Data do not differ significantly at the 10% level.

throughout the growing season of the vines.

Over the medium and long term, full surface chemical control of grazing vetch from bud break supplied sufficient amounts of N to the grapevines during full bloom. Over the long term, however, grazing vetch controlled chemically in the vine row from bud break and in the work row from berry set supplied the grapevines with sufficient amounts of N throughout the growing season of the vines. The use of a full surface straw mulch or the use of annuals as winter growing cover crops could supply in the fertilizer needs of the grapevines during the post-harvest period over the long term.

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