Effects of Soil Ameliorants Produced from Recycled Glass on the Establishment of Table Grapes

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Sandy, gravelly or stony soils with low nutrient supply or plant available water are common in the table grape growing regions of South Africa. A field study was carried out to determine if an ameliorant recycled from waste glass could enhance the nutrient and water supply during the establishing phase of table grapes. Two grades of ameliorant, *i.e.* fine and coarse, were incorporated into the soil before the grapevines were planted. No ameliorants were applied to the control. After planting, the grapevines were irrigated by using 2.1 L/h drippers. To establish whether the ameliorants could compensate if less water is applied, the same treatments were applied under 1.2 L/h drippers. In general, the grapevines responded positively to the higher irrigation volumes, irrespective of ameliorant application. Where higher irrigation volumes were applied, the ameliorants did not have any positive effect on soil chemical or grapevine nutrient status compared to the control. This showed that the ameliorants were chemically inert under the given conditions. The ameliorants also did not improve grapevine water status, vegetative growth, yield or juice characteristics. Likewise, the ameliorants could not compensate for any measured aspect of grapevine performance where less irrigation was applied. In general, the ameliorants did not meet the expectations. Considering the additional costs of the ameliorant application, and the lack of positive grapevine responses, this practice cannot be justified under the given, or comparable conditions.

INTRODUCTION

Table grapes need adequate water and nutrients to sustain vegetative growth, yield and fruit quality. In addition to fertilizers, application of ameliorants such as lime to adjust soil acidity, or gypsum to reduce the level of salinity/sodicity, is common practice in vineyards soils (Conradie *et al.*, 2020). Some soils in the table grape regions may have low cation exchange capacity (CEC) that will require precise nutrition management. However, in practice no ameliorants are applied to enhance the CEC of vineyard soils.

Water resources are generally limited in South Africa. Due to inconsistent rainfall that can cause periodic droughts, adequate irrigation is a challenge in most table grape growing regions. This scenario may worsen if future climate change reduces rainfall and increases air temperature. Furthermore, grapevines in soils with low water holding capacity, *e.g.* sandy, gravelly or stony soils, will require more frequent irrigation compared to heavier soils. It was previously reported that stone contents in soils along the Hex River could be in excess of 50% (Eustice, 2008). A high irrigation frequency will increase evaporation losses from the soil, thereby reducing the yield water use efficiency (WUE_{yield}). A lower WUE_{yield} means less grapes produced per unit of irrigation water. Likewise, the blue water footprint (WF_{blue}) primarily due to irrigation (Hoekstra *et al.*, 2011) will increase, *i.e.* more water will be required produce a unit of grapes.

Ameliorants that improve CEC and/or water holding capacity could ensure more sustainable table grape production. The addition of unprocessed organic matter to enhance soil water holding capacity is widely promoted (Barzegar *et al.*, 2002; Leu *et al.*, 2010; Azlan *et al.*, 2012; Bhada *et al.*, 2017; Van Beek *et al.*, 2018; Herawati *et al.*, 2021). Nevertheless, the increased water holding capacity by means of organic matter application appears to be relatively small (Minasny & McBratney, 2018).

Processed organic matter, or biochar, can also increase water holding capacity in soils (Basso *et al.*, 2013; Yu *et al.*, 2013, Mao *et al.*, 2019; Hien *et al.*, 2021; Li *et al.*, 2021). However, biochars produced from different biomass sources seem to vary in their ability to improve soil water holding capacity (Brantley *et al.*, 2015; Mao *et al.*, 2019). According to Mao *et al.* (2019), biochar increased the water holding capacity in soils containing low levels of organic matter, but had no effect in soils containing high levels of organic matter, *i.e.* Phaeozems (IUSS Working Group WRB, 2015).

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Super absorbent polymers such as cross-linked polyacrylamide, or commonly referred to as hydrogels, can also enhance soil water holding capacity in soils (Abedi-Koupai *et al.*, 2008; Agaba *et al.*, 2010; Abdallah, 2019; Miller & Naeth, 2019). As a result, hydrogels could reduce the risk of water and nutrient losses caused by deep percolation, allow longer intervals between irrigations and serve as a buffer against water constraints in crops during periods of drought (Abdallah, 2019 and references therein). However, it seems that the positive effect of hydrogel can deteriorate over time (Miller & Naeth, 2019). Ameliorants produced from waste glass also holds promise for enhanced nutrient and water supply to crops. Furthermore, it would be an environmentally friendly practice if any ameliorant could be recycled from non-biodegradable waste materials. The objective of the study was to determine to what extent an ameliorant recycled from waste glass could improve the performance of table grapes during its establishing phase.

MATERIALS AND METHODS

Experiment layout

The field trial was carried out from August 2019 until July 2022 near Worcester in the Breede River Valley (-33.61676, 19.50294). The alluvial soil deposited by the Hex River consisted of 40 cm deep, stone-rich topsoil on heavy clay. The ameliorants were incorporated into the soil in August 2019 under the supervision of the suppliers. Plant hole dimensions were *ca.* 500 mm wide, 800 mm long and 400 mm deep. After excavating the soil, the ameliorants were mixed with soil as it was filled back into the holes. Two grades of the ameliorant were applied, *i.e.* particle size ≤ 3 mm and 3 mm to 10 mm in diameter. No other soil preparation was carried out. In September 2019, Thompson Seedless grapevines grafted onto Ramsey rootstock were planted in the center of the soil volume where ameliorants were applied. The plant spacing was 3 m x 2 m, and the grapevines were trained onto a slanting trellis (Ferreira, 2019).

Six treatments were applied (Table 1). Drip irrigation was applied either at 2.1 L/h (hi- flow; T1 to T3), which is the flow rate preferred by the grower, or 1.2 L/h (lo-flow; T4 to T6). Since the irrigation was controlled by means of a single valve, the lo-flow drippers supplied 43% less water to the grapevines and could be considered continuous deficit irrigation compared to the hi-flow drip irrigation. The objective of the latter was to ascertain whether the ameliorant could compensate for lower irrigation volumes.

For each dripper flow rate, two grades of ameliorant were applied and compared to irrigation without ameliorant (T1 & T4). Each of the six treatments was replicated three times in a complete randomized experiment layout. Experiment plots consisted of four grapevines. Since only a limited amount of ameliorant could be imported, and treatment application was localized per grapevine, there were no border grapevines. Furthermore, the limited wetting pattern of the drip irrigation system, wide plant spacing and levelness of the land reduced the risk of overlapping treatment effects. The irrigation volumes were measured by means of three sets of water meters per flow level. The irrigation volumes were recorded at approximately 14-day intervals until harvest. During the post-harvest and dormant period, irrigation volumes were recorded every three to four weeks. Irrigation was terminated after significant winter rainfall occurred, *i.e.* in July. The grapevines were irrigated according to the grower's schedule, *i.e.* approximately three times a week. Fertilizers were applied by hand according to the grower's program.

Soil properties

In May 2021, soil samples were taken in all experiment plots on the grapevine row in the 400 mm deep layer approximately 150 mm from a grapevine, *i.e.* in the soil volume where the ameliorants were added. The soil analyses were carried out at a commercial laboratory (Labserve, Stellenbosch). Soil (pH_{KCl}), electrical conductivity (EC_e), phosphorus-Ambic 1 (P) and potassium (K), as well as extractable sodium (Na_{ex}), potassium (K_{ex}), calcium (Ca_{ex}) and magnesium (Mg_{ex}) levels were determined. The copper (Cu), zinc (Zn), manganese (Mn), boron (B), iron (Fe) and organic carbon (C) contents were also determined. Soil texture and water holding capacity were determined on a composite sample collected at three representative positions in the field trial.

Grapevine responses

Grapevine chemical status: Leaf samples were collected on 24 December 2020. Twenty-five mature, unscathed leaves opposite a bunch were picked on each plot. Leaf nitrogen (N), P, K, Ca, Mg, Na, Mn, Fe, Cu, Zn, B, chloride (Cl), sulphur (S) and molybdenum (Mo) contents were determined at the same laboratory as the soil.

Grapevine water status: Grapevine water potential was measured by means of a pressure chamber (Scholander *et al.*, 1965). Midday stem water potential (Ψ_S) in the newly

TABLE 1
Treatments applied to Thompson seedless/Ramsey table grapes in a field trial near Worcester.

Treatment no	Ameliorant particle diameter & application per grapevine	Dripper flow rate (L/h)
T1	None	2.1
T2	≤ 3 mm Ø, 10 L/grapevine	2.1
T3	3 to 10 mm Ø, 20 L/grapevine	2.1
T4	None	1.2
T5	≤ 3 mm Ø, 10 L/grapevine	1.2
T6	3 to 10 mm Ø, 20 L/grapevine	1.2

planted grapevines was measured on 28 November 2019 and 12 February 2020 in all experiment plots. Midday Ψ_S was measured on 11 November and 30 December in the 2020/21 season, as well as on 28 October and 20 January in the 2021/22 season. To determine if the ameliorants could reduce the development of possible water constraints, irrigation was stopped two days before midday Ψ_S was measured.

Vegetative growth: Since the newly planted grapevines were trained as a single stem onto the trellis system, the elongation rate of the stem, or trunk, was measured. Trunk length measurements were carried out on 26 November 2019 and repeated on 9 December 2019. The mean daily growth rate over the 13-day period was obtained by dividing the difference in height by the number of days between measurements. Grapevine trunk diameter was measured before pruning on 6 July 2020. The trunk diameter was measured in line with the work row, as well as across the work row at a height of 50 cm above the ground on each experiment grapevine using an electronic Vernier caliper. To obtain an indication of the accumulative growth over the season, cane mass was measured at pruning on 23 July 2020, 9 July 2021 and 30 June 2022.

Yield components: Grapes were harvested on 3 February in the 2020/21 and the 2021/22 seasons. Fresh berry mass was determined in all the plots at harvest. Fifty-berry samples were obtained by picking ten berries along the longitudinal axis from each of five bunches per plot. Berries were removed by cutting through the pedicel as close as possible to the berry using a small pair of scissors. All bunches in each plot were picked, counted and weighed to obtain the total mass per plot. Mean yield per grapevine was calculated and converted to ton per hectare. Bunch mass was determined by dividing the total grape mass per plot by the number of bunches per plot. The WUE_{yield} was calculated as grapes (kg) produced per unit of irrigation water (m^3), whereas the WF_{blue} is irrigation water (m^3) applied to produce a unit of grapes (t) (Hoekstra *et al.*, 2011). The WUE_{yield} and WF_{blue} were only calculated for the full-bearing grapevines in the 2021/22 season.

Juice characteristics: Total soluble solids (TSS), pH and total titratable acidity (TTA) in the juice of the fifty-berry samples were determined according to the standard procedures of the wine laboratory at ARC Infruitec-Nietvoorbij.

Statistical analyses: Data was subjected to analysis of variance (Anova) using GLM (General Linear Models) Procedure of SAS software (Version 9.4; SAS Institute Inc, Cary, USA). Shapiro-Wilk test was performed on the standardized residuals from the model to test for deviation from normality (Shapiro, 1965). Fisher's least significant difference was calculated at the 5% level to compare treatment means (Ott, 1998). A probability level of 5% was considered significant for all significance tests.

RESULTS AND DISCUSSION

Soil texture and water holding capacity

The topsoil contained 4% clay and 12% silt, as well as 41%, 27% and 16% coarse, medium and fine sand, respectively. According to the particle size distribution, the soil had a loamy sand texture. The water holding capacity amounted to 72 mm/m, *i.e.* only 29 mm in the 400 mm deep topsoil.

Irrigation volumes

The grower steadily increased the irrigation volumes as the grapevines developed (Fig. 1). In the second and third seasons, irrigation volumes applied *via* the hi-flow drippers (T1, T2 & T3) were appreciably more than the *ca.* 260 mm applied to drip irrigated Dan-ben-Hannah table grapes near Paarl in the cooler Berg River Valley region where the rainfall is higher compared to the Breede River valley (Myburgh & Howell, 2012). However, it was less than the *ca.* 700 mm required by drip irrigated Thompson Seedless table grapes under warm, arid conditions in the Lower Orange River Valley region where table grapes require irrigation throughout the year (Myburgh, 2012). In the third season, the 275 mm applied *via* the 1.2 L/h drippers was comparable to that of the full-bearing table grapes near Paarl.

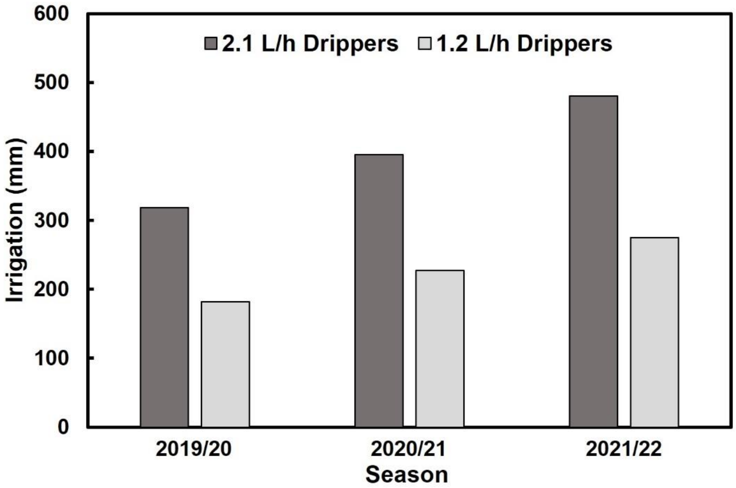

FIGURE 1

Irrigation volumes applied by means of drippers with different flow rates to young Thompson Seedless/Ramsey grapevines from September until July in the 2019/20, 2020/21 and 2021/22 seasons near Worcester.

Soil chemical status

The soil pH_{KCl} was generally higher than the upper norm of 6.5 for table grapes (Conradie *et al.*, 2020). Although the ameliorants did not have any effect on the pH_{KCl}, it tended to be higher where the lower irrigation volumes were applied (Table 2). Furthermore, EC_e was higher where less irrigation was applied, except for the coarse ameliorant (T6). Neither irrigation volume, nor ameliorant had any effect on the organic C, P or K (Table 2). Considering the extractable cations, higher irrigation volumes tended to reduce K_{ex} (Table 2). In some treatments, the higher irrigation volumes reduced Na_{ex}, Ca_{ex} and Mg_{ex} levels in the soil compared to less irrigation. The foregoing suggested that the higher irrigation volumes tended to leach more salts from the root zone compared to less irrigation. Irrigation volume and/or ameliorant did not affect trace element concentrations in the soil, except B (Table 2). Similar to the extractable cations, the higher irrigation volumes tended reduce the level of B in the root zone compared to les irrigation. The Mn, Cu, Zn and B contents were well above the minimum requirements of 2 mg/kg, 0.5 mg/kg, 0.5 mg/kg and 0.3 mg/kg, respectively, as proposed by Conradie *et al.* (2020) for vineyard soils (Table 2).

Grapevine responses

Grapevine chemical status: Al the macro- and micronutrients were within the norms for table grape leaf blades at véraison (Conradie, *et al.*, 2020), except for Fe and Mo (Table 3). Iron levels of around 500 mg/kg in leaves of Concord grapevine did not seem to have any negative effects (Pradubsuk & Davenport, 2011). Molybdenum levels were well above the lower limit of 0.01 mg/kg to 0.09 mg/kg where deficiencies are expected (Williams *et al.*, 2004). In fact, Mo levels were within the range of 0.2 mg/kg to 0.4 mg/kg reported for grapevine petioles (Gąstoł & Domagała-Świątkiewicz, 2014). Although some elements differed between treatments, the differences could not be explained in relation to the level of irrigation or the ameliorants. Since the element levels were within the norms for table grapes, these differences were unlikely to have caused any negative effect on grapevine growth and yield. Furthermore, it must be noted that the tendency towards leaching of elements by the higher irrigation volumes did not reflect in the nutrient status of the grapevines.

Grapevine water status: Early in the 2019/20 season, grapevines receiving the higher irrigation volumes (T1, T2 & T3) experienced low water constraints, *i.e.* midday Ψ_S was approximately -0.6 MPa (Fig. 2A). In contrast, lower irrigation volumes induced moderate water constraints, *i.e.* midday Ψ_S was less than -0.8 MPa. Both ameliorants did not affect grapevine water status where the higher irrigation volumes were applied. However, the ameliorants tended to induce more water constraints in the grapevines that received less irrigation (T5 & T6) compared to no ameliorants (T4). In fact, the combination of less irrigation and ameliorants (T5 & T6) induced more water constraints in grapevines with ameliorants compared to grapevines that received more irrigation (T1, T2 & T3). In February 2020, when the atmosphere was warmer and drier, the lack of irrigation caused midday Ψ_S in the grapevines to vary between -1 MPa and -1.2 MPa (Fig. 2B). This indicated that the grapevines experienced moderate to high water constraints.

TABLE 2
Effect of irrigation volume and soil ameliorants on soil pH, EC_e, C, P and K, as well as extractable cations and trace element concentrations as determined in May 2021 near Worcester. Refer to Table 1 for the treatment description.

Element	Treatment					
	T1	T2	T3	T4	T5	T6
pH_{KCl}	6.88 a*	6.52 a	6.93 a	7.01 a	7.70 a	7.27 a
EC_e (dS/m)	0.04 b	0.04 b	0.04 b	0.14 a	0.11 a	0.09 ab
C (%)	0.40 a	0.39 a	0.42 a	0.46 a	0.49 a	0.42 a
P (mg/kg)	100.3 a	89.2 a	83.5 a	81.6 a	94.6 a	93.2 a
K (mg/kg)	77 a	60 a	52 a	80 a	73 a	93 a
Na_{ex} (cmol/kg)	0.31 c	0.30 c	0.32 c	0.69 ab	0.88 a	0.43 bc
K_{ex} (cmol/kg)	0.20 a	0.15 a	0.13 a	0.21 a	0.26 a	0.24 a
Ca_{ex} (cmol/kg)	7.11 bc	5.58 c	7.41 bc	10.85 ab	13.71 a	12.72 a
Mg_{ex} (cmol/kg)	0.58 bc	0.53 c	0.80 ab	0.89 a	0.81 ab	0.79 ab
Cu (mg/kg)	2.10 a	1.62 a	1.93 a	1.79 a	1.84 a	1.90 a
Zn (mg/kg)	5.25 a	2.02 a	4.00 a	3.11 a	3.28 a	5.25 a
Mn (mg/kg)	10.39 a	6.90 a	8.34 a	10.40 a	11.49 a	10.73 a
B (mg/kg)	0. 74 bc	0.42 c	0.58 bc	1.27 ab	1.89 a	1.16 abc
Fe (mg/kg)	210.8 a	210.6 a	182.4 a	222.2 a	205.8 a	210.0 a

* Values followed by the same letter within a row do not differ significantly ($p \leq 0.05$).

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TABLE 3
Effect of irrigation volume and soil ameliorants on element concentration in Thompson Seedless leaves determined in December 2020 near Worcester, as well as leaf element norms for grapevine leaf blades at véraison (Conradie *et al.*, 2020). Refer to Table 1 for the treatment description.

Element	**Treatment**						**Norms**
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	
N (%)	2.28 a*	2.34 a	2.14 a	2.28 a	2.21 a	2.24 a	2.8-3.4
P (%)	0.34 ab	0.27 b	0.27 b	0.28 b	0.25 b	0.40 a	0.26-0.45
K (%)	1.22 ab	1.05 b	1.07 b	0.97 b	1.02 b	1.38 a	0.60-1.05
Ca (%)	2.05 a	2.14 a	2.21 a	1.96 a	1.96 a	2.21 a	1.5-2.4
Mg (%)	0.23 a	0.24 a	0.26 a	0.25 a	0.26 a	0.27 a	0.2-0.6
Na (mg/kg)	432 ab	425 ab	454 ab	408 b	424 ab	511 a	< 2500
Mn (mg/kg)	140 a	149 a	193 a	174 a	203 a	149 a	20-300
Fe (mg/kg)	437 a	433 a	507 a	426 a	453 a	485 a	60-200
Cu (mg/kg)	124 a	115 a	106 a	93 a	102 a	126 a	3-6
Zn (mg/kg)	42 a	38 a	43 a	40 a	42 a	46 a	15-30
B (mg/kg)	56 a	57 a	58 a	56 a	53 a	61 a	25-100
S (%)	0.28 ab	0.27 b	0.28 ab	0.28 ab	0.27 b	0.31 a	**
Mo (mg/kg)	0.38 a	0.32 a	0.49 a	0.24 a	0.30 a	0.39 a	< 0.09

* Values followed by the same letter within a row do not differ significantly ($p \leq 0.05$).
** No S norms available for grapevine leaves.

The generally low midday Ψ_S confirmed that frequent drip irrigation is essential in this sandy soil with a high stone content. Furthermore, the ameliorants could not reduce water constraints compared to grapevines where no ameliorants were applied (Fig. 2B). Similar to earlier in the season, the combination of less irrigation and ameliorants (T5 & T6) induced more water constraints in grapevines compared to grapevines that received more irrigation (T1, T2 & T3).

Early in the 2020/21 season, grapevines experienced low water constraints, *i.e.* midday Ψ_S was less negative than -0.6 MPa, irrespective of irrigation volume or ameliorant (Fig. 3A). Although, the coarse ameliorant (T3 & T6) caused more water constraints in the grapevines compared to T1, the low levels of water constraints are not expected to have negative effects on grapevine functioning. Later in the season, *i.e.* on 30 December 2020, grapevines experienced moderate to high water constraints, irrespective of irrigation volume or ameliorant (Fig. 3B). Although irrigation volume or ameliorant had no effect on midday Ψ_S in the grapevines, the fine grade ameliorant tended to increase water constraints where less irrigation was applied (T5).

Similar to the first two seasons, grapevine water constraints were generally low early in the 2021/22 season (Fig. 4A). Furthermore, irrigation volume or ameliorant did not affect midday Ψ_S in the grapevines. On 20 January, the grapevines experienced moderate to high water constraints, except for T1 where Ψ_S was approximately -0.8 MPa (Fig. 4B). The combination of less irrigation and ameliorants (T5 & T6) induced more water constraints compared to more irrigation volume without ameliorants (T1). In fact, the T5 and T6 grapevines experienced high water constraints, *i.e.* Ψ_S was more negative than -1.2 MPa.

Trunk elongation in the first season: Where more irrigation was applied, the growth rate of the newly planted grapevines tended to be lower where the coarse ameliorant was applied (T3) compared to the T1 (no ameliorant) and T2 (fine ameliorant) grapevines (Fig. 5). A similar trend occurred where less irrigation was applied. Furthermore, the combination of less irrigation and coarse ameliorant (T6) reduced the grapevine growth rate by *ca.* 50% compared to the T1 and T2 grapevines. This was probably due to more water constraints in the T5 and T6 grapevines as discussed above (Fig. 2).

Trunk diameter: At the end of the 2019/20 season, grapevine trunks were thinner where less irrigation was applied compared to the higher irrigation volume where no ameliorants were applied (Table 4). This trend also occurred in the second and third seasons. This showed that less irrigation had a consistent, negative effect on grapevine vigour where no ameliorants were applied. After the first year, the newly planted grapevines had thinner trunks where the ameliorants were applied (T2, T3, T5 & T6) compared to the higher irrigation without ameliorants (T1). In the 2020/21 season, the combination of coarse ameliorant and less irrigation (T5) reduced trunk diameter compared to high irrigation and no ameliorants (T1) (Table 4). By the end of the third season, grapevine trunk diameter was smaller where the ameliorants were applied compared to T1, *i.e.* irrespective of irrigation volume. This showed that the ameliorants had a negative effect on the vegetative growth over the first three years after

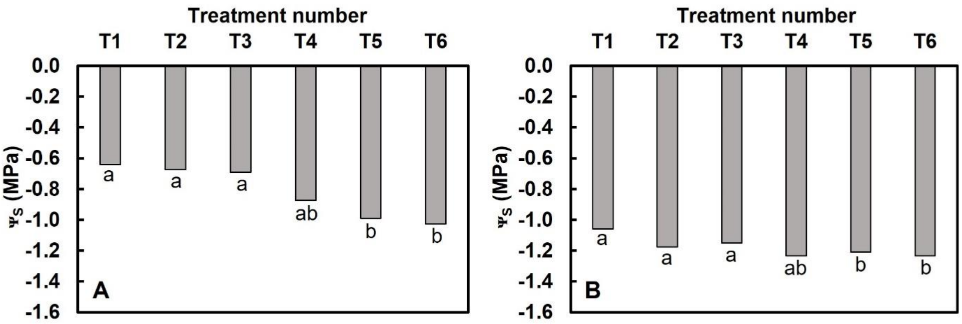

FIGURE 2
Effect of irrigation volume and soil ameliorants on midday stem water potential (Ψ_S) in newly-planted Thompson seedless/ Ramsey grapevines measured on (A) 28 November 2019 and (B) 12 February 2020 near Worcester. Refer to Table 1 for an explanation of the treatments. Columns designated by the same letter do not differ significantly ($p \leq 0.05$).

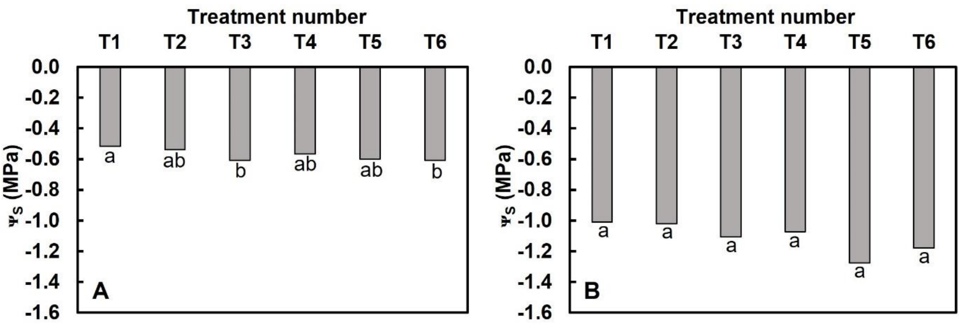

FIGURE 3
Effect of irrigation volume and soil ameliorants on midday stem water potential (Ψ_S) in Thompson seedless/Ramsey grapevines measured on (A) 11 November 2020 and (B) 30 January 2021 near Worcester. Refer to Table 1 for an explanation of the treatments. Columns designated by the same letter do not differ significantly ($p \leq 0.05$).

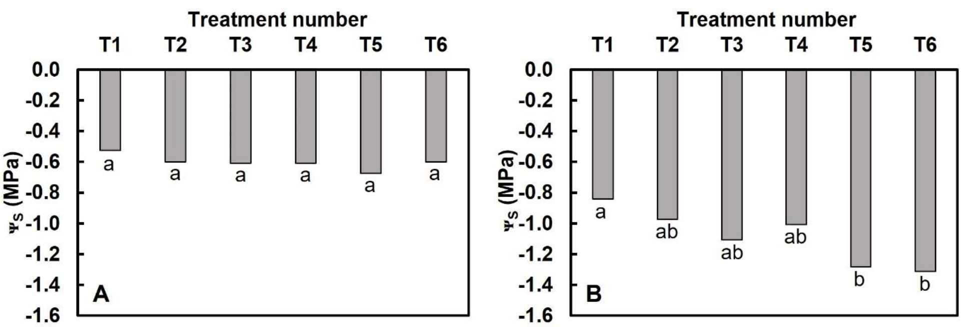

FIGURE 4
Effect of irrigation volume and soil ameliorants on midday stem water potential (Ψ_S) in Thompson seedless/Ramsey grapevines measured on (A) 28 October 2021 and (B) 20 January 2022 near Worcester. Refer to Table 1 for an explanation of the treatments. Columns designated by the same letter do not differ significantly ($p \leq 0.05$).

the grapevines were planted.

Cane mass: In the first two seasons, less irrigation (T4) reduced cane mass at pruning compared to the higher irrigation volume (T1) where no ameliorants were applied (Table 5). This negative response of vegetative growth of table grapes to reduced irrigation volumes is in agreement with earlier findings (Myburgh, 1996; Myburgh, 2003; Zúñiga-Espinoza *et al.*, 2015). In the third season, *i.e.* 2021/22, cane mass obtained with the higher irrigation volume without ameliorants was comparable to the ca. 5 to 6 t/ha previously reported for full-bearing Thompson seedless table grapes that received daily drip irrigation around noon in the lower Orange River region (Myburgh, 2012). However, less irrigation (T4 to T6) only tended to reduce vegetative growth in the third season compared to T1. In the first two seasons, the coarse ameliorant (T3)

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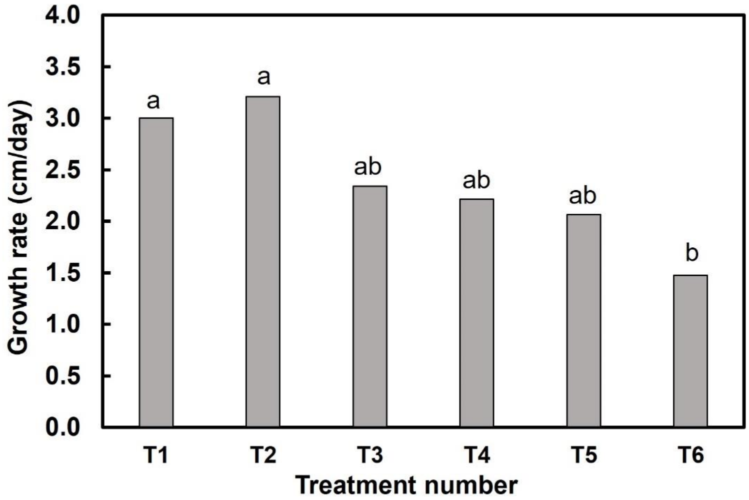

FIGURE 5
Effect of irrigation volume and soil ameliorants on the mean daily trunk elongation of newly-planted Thompson seedless/Ramsey grapevines near Worcester in the 2019/20 season. Refer to Table 1 for an explanation of the treatments. Columns designated by the same letter do not differ significantly ($p \leq 0.05$).

TABLE 4
Effect of irrigation volume and soil ameliorants on trunk diameter of Thompson seedless/Ramsey grapevines in 2019/20, 2020/21 and 2021/22 near Worcester.

Treatment	Irrigation	Ameliorant	Trunk diameter (mm)		
			2019/20	2020/21	2021/22
T1	Hi-flow	None	11.1 a*	28.0 a	42.4 a
T2	Hi-flow	Fine grade	9.6 b	25.0 ab	34.5 b
T3	Hi-flow	Coarse grade	9.1 b	25.9 ab	35.6 b
T4	Lo-flow	None	8.6 b	22.9 b	35.9 b
T5	Lo-flow	Fine grade	9.0 b	22.8 b	34.9 b
T6	Lo-flow	Coarse grade	8.7 b	24.8 ab	36.1 b

* Values within a column designated by the same letter do not differ significantly ($p \leq 0.05$).

reduced cane mass, whereas the fine ameliorant (T2) only tended to reduce the vigour compared to T1 where the higher irrigation volumes were applied (Table 5). In the 2021/22 season, both ameliorants (T2 & T3) caused lower cane mass compared to high irrigation and no ameliorants (T1). Where less irrigation was applied, the ameliorants (T5 & T6) only tended to suppress grapevine vigour compared to T1. The foregoing confirmed that the ameliorants could not improve the vegetative growth of the grapevines nor compensate for the reduction in vegetative growth where less irrigation was applied.

Yield components: Due to the differences in vegetative growth in 2019/20, the number of bunches per grapevine was limited where less irrigation or ameliorants were applied compared to T1, except for the combination of high irrigation volume and fine ameliorant (Fig. 6). However, given the stronger vegetative growth in the 2021/22 season, the grower allowed approximately 28 bunches to all grapevines. Consequently, there were no differences in crop load between treatments.

Since the grapes were only produced for the local market in the 2020/21 season, they did not receive the full hormone treatment to obtain bigger berries. Consequently, the berries were generally small, *i.e.* less than 4 g per berry (Table 6). Where less irrigation was applied, the coarse ameliorant (T6) reduced berry mass compared to most of the other treatments. Neither irrigation nor ameliorant had any effect on bunch mass. Where higher irrigation volumes were applied, the coarse ameliorant (T3) only tended to reduce yield compared to T1 and T2 (Table 6). However, where less irrigation was applied, the coarse ameliorant (T6) reduced the yield substantially compared to T1 and T2. In 2021/22, *i.e.* the first full bearing season, the crop load was thinned to *ca.* 28 bunches per grapevine for all treatments. Berry mass was generally higher compared to the 2020/21 season (Table 6). Although the combination of less water and the coarse ameliorant (T6) reduced berry mass, it did not reflect in the yield. However, the yield tended to be higher where the higher irrigation volume was applied without ameliorant (T1).

Yield water use efficiency and blue water footprint: The WUE_{yield} was appreciably higher where the lower irrigation volumes were applied (T4, T5 & T6) compared to the grapevines that received more irrigation (Table 7). However, the WUE_{yield} of hi-flow grapevines was still slightly higher compared to *ca.* 5.1 kg/m^3 reported for drip irrigated table grapes in the nearby Hex River Valley (Kangueehi, 2018). The latter is the mean for two vineyards over two years. In contrast, the mean WUE_{yield} was considerably higher than 1.35 kg/m^3 for micro-sprinkler irrigated table grapes having a relatively short growth period of only 90 days (Teixeira *et al.*, 2007). The WF_{blue} was appreciably smaller where the lower irrigation volumes were applied compared to more irrigation (Table 7). Furthermore, the WF_{blue} was smaller compared to 211 m^3/t of drip irrigated table grapes in the Hex River Valley (Kangueehi, 2018). It must be noted that the WF_{blue} was substantially lower compared to the general value of 454 m^3/t reported for table grapes in the Hex River Valley (Jarmain *et al.*, 2020). Under the prevailing conditions, the ameliorants did not have any positive effect on the WUE_{yield} or WF_{blue} of the drip irrigated table grapes (Table 7).

Juice characteristics: In 2020/21, the ameliorants tended to favour juice TSS at harvest, particularly where less irrigation was applied (Table 8). However, the juice TSS content was strongly related to the crop load, *i.e.* the rate of sugar accumulation was higher where the grapevines bore less fruit and *vice versa* (Fig. 7). Similar trends were previously reported for grapevines (Čuš, 2004; Somkuwar & Ramteke, 2006; McDonnell, 2011; Akin *et al.*, 2012; Gamero *et al.*, 2015; Senthilkumar *et al.*, 2015 and references therein). This suggested that the combined effect of irrigation volume and ameliorant indirectly, *i.e.* through their effect on the allocation of crop loads according to vegetative growth, caused the differences in TSS between treatments (Table 8). Where more irrigation was applied, the coarse ameliorant (T3) increased the rate of juice TTA breakdown compared to T1 and T2. In contrast, the fine ameliorant (T5) had a similar effect compared to T4 where less water was applied. The higher irrigation volume reduced the juice pH compared to less irrigation, except where the coarse ameliorant was applied (Table 8). The ameliorants did not affect juice pH, irrespective of the irrigation volume. In 2021/22, neither irrigation volume, nor ameliorant had any effect on juice TSS, TTA and pH (Table 8). Although there were no differences between treatments, TSS tended to decrease with a slight

TABLE 5
Effect of irrigation volume and soil ameliorants on cane mass at pruning of Thompson seedless/Ramsey grapevines in 2019/20, 2020/21 and 2021/22 near Worcester.

Treatment	Irrigation	Ameliorant	Cane mass (t/ha)		
			2019/20	2020/21	2021/22
T1	Hi-flow	None	0.17 a*	3.25 a	6.97 a
T2	Hi-flow	Fine grade	0.15 ab	2.03 ab	3.56 b
T3	Hi-flow	Coarse grade	0.11 b	1.96 b	3.92 b
T4	Lo-flow	None	0.09 b	1.40 b	4.44 ab
T5	Lo-flow	Fine grade	0.05 b	1.69 b	4.11 ab
T6	Lo-flow	Coarse grade	0.06 b	1.90 b	4.38 ab

* Values within a column designated by the same letter do not differ significantly ($p \leq 0.05$).

TABLE 6
Effect of irrigation volume and soil ameliorants on yield components of Thompson seedless/Ramsey grapevines in the 2020/21 and 2021/22 seasons near Worcester. Refer to Table 1 for an explanation of the treatments.

Treatment	Berry mass (g)		Bunch mass (g)		Yield (t/ha)	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
T1	3.9 a*	4.9 a	771 a	877 a	19.6 a	41.0 a
T2	3.5 ab	4.1 ab	783 a	778 a	18.6 a	37.0 a
T3	3.6 a	4.1 ab	879 a	815 a	12.7 ab	35.9 a
T4	3.6 a	4.2 ab	937 a	776 a	10.9 ab	36.1 a
T5	3.7 a	3.9 b	753 a	768 a	11.5 ab	34.9 a
T6	2.8 b	3.9 b	678 a	745 a	7.5 b	35.9 a

* Values within a column designated by the same letter do not differ significantly ($p \leq 0.05$).

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increase in yield (Fig. 7). However, the TSS decrease was less steep compared to 2020/21 when the crop loads were substantially lower, and the differences between treatments more pronounced.

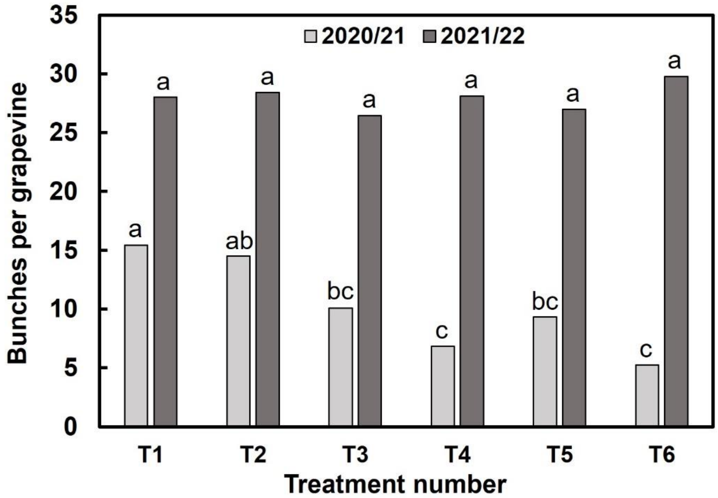

FIGURE 6
Effect of irrigation volume and soil ameliorants on crop load of Thompson seedless/Ramsey grapevines in the 2020/21 and 2021/22 seasons near Worcester. Refer to Table 1 for an explanation of the treatments. Columns designated by the same letter do not differ significantly ($p \leq 0.05$).

TABLE 7
Effect of irrigation volume and soil ameliorants on yield water use efficiency (WUE_{yield}) and blue water footprint (WF_{blue}) of Thompson seedless/Ramsey grapevines in the 2021/22 season near Worcester.

Treatment	Irrigation	Ameliorant	WUE_{yield} (kg/m^3)	WF_{blue} (m^3/t)
T1	Hi-flow	None	8.5 b*	118 a
T2	Hi-flow	Fine grade	7.7 b	132 a
T3	Hi-flow	Coarse grade	7.5 b	134 a
T4	Lo-flow	None	13.1 a	66 b
T5	Lo-flow	Fine grade	12.7 a	84 b
T6	Lo-flow	Coarse grade	13.1 a	77 b

* Values within a column designated by the same letter do not differ significantly ($p \leq 0.05$).

TABLE 8
Effect of irrigation volume and soil ameliorants on total soluble solids (TSS), total titratable acidity and pH in juice of Thompson seedless/Ramsey grapevines in the 2020/21 and 2021/22 seasons near Worcester. Refer to Table 1 for an explanation of the treatments.

Treatment	TSS (°Brix)		TTA (g/L)		pH	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
T1	18.4 c*	16.0 a	7.41 a	10.16 a	3.41 b	3.32 a
T2	18.6 c	16.5 a	7.47 a	9.74 a	3.41 b	3.26 a
T3	20.2 ab	16.7 a	7.11 bc	8.77 a	3.46 ab	3.30 a
T4	20.2 ab	16.7 a	7.14 b	8.83 a	3.49 a	3.24 a
T5	19.9 b	16.9 a	6.87 c	8.53 a	3.50 a	3.22 a
T6	21.1 a	16.6 a	6.90 bc	7.96 a	3.52 a	3.22 a

* Values within a column designated by the same letter do not differ significantly ($p \leq 0.05$).

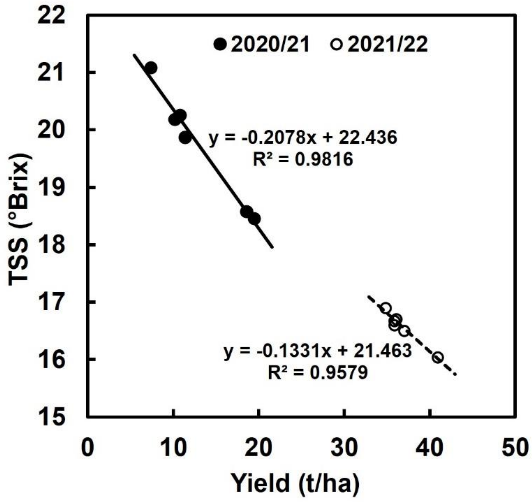

FIGURE 7

Relationship between total soluble solids (TSS) and yield of Thompson seedless/Ramsey grapevines in the 2020/21 and 2021/22 seasons near Worcester.

CONCLUSIONS

Since the ameliorants did not affect soil or grapevine chemical status, they appeared to be chemically neutral. Where no ameliorants were applied, lower irrigation volumes reduced grapevine growth and yield compared to more irrigation. Where grapevines received the higher irrigation volumes, the ameliorants did not have any positive effect on grapevine water status, vegetative growth, yield or juice characteristics compared to grapevines where no ameliorants were applied. Furthermore, the ameliorants could not improve grapevine water status, vegetative growth and yield of grapevines that received less irrigation. Given the lack of positive yield responses, the ameliorants could not improve the WUE_{yield} or WF_{blue}. The results strongly suggest that the ameliorants limited water availability to the grapevines. Water absorbed by the ameliorants was probably either released too slowly or not available at all. Although table grapes did not respond to the ameliorants, it does not rule out the possibility that they might have positive effects on other crops. It should be noted that it will be difficult, if not impossible, to remove any ameliorant once it has been applied to the soil. Considering the additional costs of the ameliorant application, and the lack of positive grapevine responses, the specific ameliorants tested in this study cannot be justified for table grape production under the prevailing, or comparable, conditions.

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