Fertigation of *Vitis vinifera* L. cv. Bukettraube/110 Richter on a Sandy Soil

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Fertigation and conventional fertilisation were compared for a Bukettraube vineyard on sandy soil in the arid Olifants River region of South Africa. During the first stage (four years) of the experiment, all treatments received 120 kg N.ha^{-1}.yr^{-1} and 80 kg K.ha^{-1}.yr^{-1}. The first treatment (C120) entailed conventional (broadcast) fertiliser applications at three-week intervals the second (F120) was fertigated at three-week invervals, while the third (I120) was fertigated twice per week. Yield and shoot growths were not affected significantly, indicating that conventional fertilisation was just as effective as fertigation (C120 vs F120). Furthermore, the fact that the application of N in regular, small increments (I120) held no advantage over larger applications at longer intervals (F120) suggested that leaching of nutrients did not occur, probably as a result of well-managed irrigation practices. During the second stage of the experiment (three years) I120 was discontinued, while C120 and F120 were compared with a third treatment (F80), fertigated at 80 kg N.ha^{-1}.yr^{-1} and 60 kg K.ha^{-1}.yr^{-1}. Irrigation for these three treatments was scheduled by means of tensionmeters and soil was replenished to field water capacity twice per week. In a fourth treatment (D120), fertigated at 120 kg N.ha^{-1}.yr^{-1} and 80 kg K.ha^{-1}.yr^{-1}, deficit irrigation was practised, with monthly water application being approximately 30 mm less in comparison to the other treatments. In general, no differences were observed between F120 and C120, while cane mass and yield for both these treatments were higher than those of F80 and D120. This indicated that 80 kg N.ha^{-1}.yr^{-1} was insufficient and that suboptimal irrigation can have a marked negative effect on vines growing in a low-potential soil. The results suggested that K was still adequately supplied in the case of F80, and that reduced performance could be ascribed to N deficiency only. Annual application of 80 kg K.ha^{-1}.yr^{-1} by means of fertigation (F120 and D120) was needlessly excessive and impaired Mg uptake. Fertigation showed no positive or negative effects on wine quality overall.

Application of nutrients through irrigation water, generally referred to as fertigation, allows flexible fertiliser programmes and is widely practised in South African viticulture. Properly managed fertigation may reduce ground water pollution (Willis & Davies, 1991) and labour costs (Colapietra, 1987). Because the correct amount of fertilizer can be applied at the right time and rapidly to the root zone, efficiency may also be improved relative to conventional broadcasting. Consequently, the quantity of N required to produce maximum yield can sometimes be halved (Smith, Kenworthy & Bedford, 1979). The technique is thought to be particularly suitable for sandy soil, in which it facilitates the maintenance of N nutrition levels whilst minimising leaching losses (Haynes, 1986).

None of the above aspects has been investigated for grapevines in South Africa. Our objective was to determine the efficiency of fertigation, in comparison to conventional broadcast fertilisation, for grapevines under intensive irrigation on a sandy soil in an arid region.

MATERIALS AND METHODS

Experimental vineyard: The investigation was carried out at the Lutzville Experiment Station in the Olifants River region. This is a class V climatic region (Winkler, 1962) at 31°36' latitude. Annual precipitation is less than 200 mm. Soil was of the Garies form (Soil Classification Working Group, 1991), *i.e.* duripan at approximately 600 mm to 900 mm, overlaid with aeolian deposited sand (<3% silt and clay). The soils was ripped to a depth of 900 mm. During soil preparation, superphosphate (8.3%P) was mixed with the soil in order to increase P level to 25 mg.kg^{-1}. In September 1979 *Vitis vinifera* L. *cv.* Bukettraube, grafted onto 110 Richter, was planted at a spacing of 2.75 m x 1.25 m. Vines were trained on a slanting trellis with four permanent cordons (H-development), as described by Zeeman (1981).

The irrigation system, with an application efficiency of 65%, comprised 50L h^{-1} micro-sprinklers, spaced 1.25 m apart. Soil water matric potential was measured by means of five sets of mercury manometer tensiometers, installed on the vine row at depths of 300 mm, 600 mm and 900 mm. Soil water retention curves were determined *in situ* by measuring gravimetric soil water content and matric potential. Drainage curves were obtained by monitoring soil water content and matric potential after saturation. These soil water retention curves were used to convert matric potential to soil water content. Field capacity was estimated at the point where the drainage rate began to decrease. Tensiometer readings, taken twice per week before irrigation,

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were used to calculate the amount of water needed to restore the soil to field water capacity. From budbreak to harvest (middle September to middle February), the required amount of water was applied twice per week (Tuesdays and Fridays) to all treatments, except one (described later). From harvest to leaf fall vines were irrigated once per week, and once per month during the dormant period (middle June to end August).

Experiment layout:

The experiment layout consisted of a randomised block design with five replications. Each experiment plot consisted of four rows of 17 vines each. For experimental measurements five vines from the two middle rows were selected, based on uniformity of shoot mass. Vines were spur-pruned during the course of the investigation, i.e. two-node spurs spaced approximately 150 mm apart. Depending on the vigour, approximately eighteen spurs were allocated per vine. The investigation was carried out in two stages.

First stage: During this stage (1998/89 to 1991/92 seasons) different fertiliser application methods were investigated. Annual application times, amounts and increments of N and K fertilisers are presented in Table 1. Venturi-type pumps were used to inject the required volumes of liquid fertiliser into the irrigation lines. In order to prevent undue leaching, fertilisers were added during the last quarter of an irrigation cycle.

Second stage: During the second stage (1992/93 to 1994/95), C120 and F120 were kept unchanged. A third and a fourth treatment were added in a part of the vineyard previously treated identically to F120. Plot size and experiment layout were similar to the other treatments. Fertiliser application details of these treatments are presented in Table 2. The fourth treatment (D120) was fertilised identically to F120, but deficit irrigation was practised, *i.e.* water applications were about 4 mm less per irrigation than the amount needed to restore the soil to field capacity. On average this treatment received 928 mm between budbreak and harvest, in comparison to 1087 mm for the non-deficit treatments.

Soil analyses: Soil was sampled at the start of the experiment (1987) and in 1994. All samples were analysed for pH (1.0 M KCl), P (Bray No. 2), K, Ca, Na and Mg (extracted with 1.0 M ammonium acetate) and organic C (The Non-Affiliated Soil Analysis Work Committee, 1990). Samples from 1994 were also extracted with 1.0 M KCl and analysed for NH_4-N and NO_3-N, using a colorimetric method (The Non-Affiliated Soil Analysis Work Committee, 1990).

Viticultural parameters: Cane mass and grape yield were determined annually. Juice, sampled at harvest, and leaves, sampled at fruit-set, were analysed for N, P, K, Ca, Mg and Na according to standard Institute procedures. During the second stage of the experiment (1992/93 to 1994/95) experimental wines

TABLE 1
Treatments applied during the first stage (*i.e.* from 1989/90 to 1991/92) of a fertilisation trial on a sandy soil in the Olifants River region.

Treatment	Pre-harvest (*i.e.* middle September to end December)				Post-harvest (*i.e.* beginning March to middle April)			
	Nutrient (kg.ha^{-1})		Fertiliser	Number of applications	Nutrient (kg.ha^{-1})		Fertiliser	Number of applications
	N	K			N	K		
C120(1)	80	80	1:0:1(37)-granular	6	40	0	LAN(28)-granular	3
F120(2)	80	80	1:0:1(14)-liquid	6	40	0	AN(19)-liguid	3
I120(2)	80	80	1:0:1(14)-liquid	30	40	0	AN(19)-liquid	12

(1) Fertiliser applied conventionally (broadcast).
(2) Fertiliser applied through irrigation water.

TABLE 2
Treatments applied during the second stage (*i.e.* from 1992/93 to 1994/95) of a fertilisation trial on a sandy soil in the Olifants River region.

Treatment	Pre-harvest (*i.e.* middle September to end December)				Post-harvest (*i.e.* beginning March to middle April)			
	Nutrient (kg.ha^{-1})		Fertiliser	Number of applications	Nutrient (kg.ha^{-1})		Fertiliser	Number of applications
	N	K			N	K		
C120(1)	80	80	1:0:1(37)-granular	6	40	0	LAN(28)-granular	3
F120(2)	80	80	1:0:1(14)-liquid	6	40	0	AN(19)-liquid	3
F80(2)	60	60	1:0:1(14)-liquid	6	20	0	AN(19)-liquid	3
D120(3)	80	80	1:0:1(14)-liquid	6	40	0	AN(19)-liquid	3

(1) Fertiliser applied conventionally (broadcast).
(2) Fertiliser applied through irrigation water.
(3) Fertiliser applied through irrigation water and deficit irrigation practised, *i.e.* 4 mm per irrigation less than for the other treatments.

were made in the Institute's Experimental Cellar and evaluated organoleptically on a nine-point score card (Tromp & Conradie, 1979).

Statistical analyses: A Genstat software package was used to calculate Tukey's least significant difference values ($p \leq 0.10$), for comparison between treatment means.

RESULTS AND DISCUSSION

First stage:

Soil water content: The soil water retention curve, as measured *in situ* at 600 mm depth, is presented in Fig. 1. Curves determined at 300 mm and 900 mm were almost identical (data not shown). Field capacity was estimated as the point where either rate of drainage or the slope of the curve for matric potential vs time declined markedly. For this particular soil it was at a volumetric water content of ca 10% or a matric potential of approximately -3.5 kPa (Fig. 2). Hence, most of the readily available water, which amounted to 36 mm, was retained at matric potentials between -3.5 kPa and -15 kPa. Irrigation was applied to avoid soil water matric potentials exceeding ca -6.5 kPa. Similarly, low water retention capacities were found for a sandy soil in the Hex River Valley (Myburgh, 1996). This depletion level was maintained throughout the season (Fig. 3A).

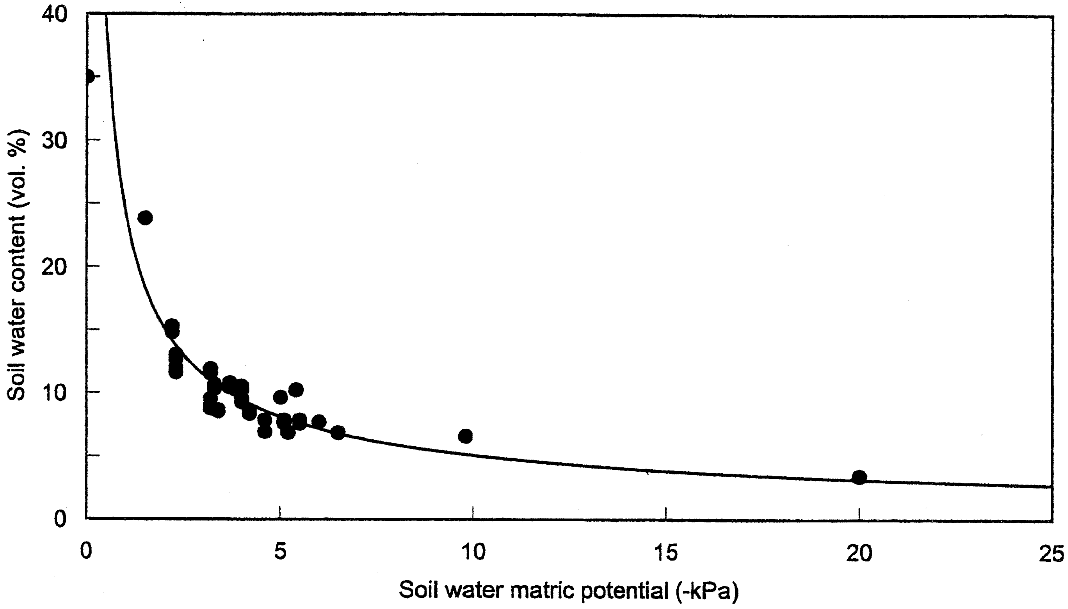

FIGURE 1

Soil water retention curve at 600 mm depth as determined *in situ* on a sandy soil in the Olifants River region.

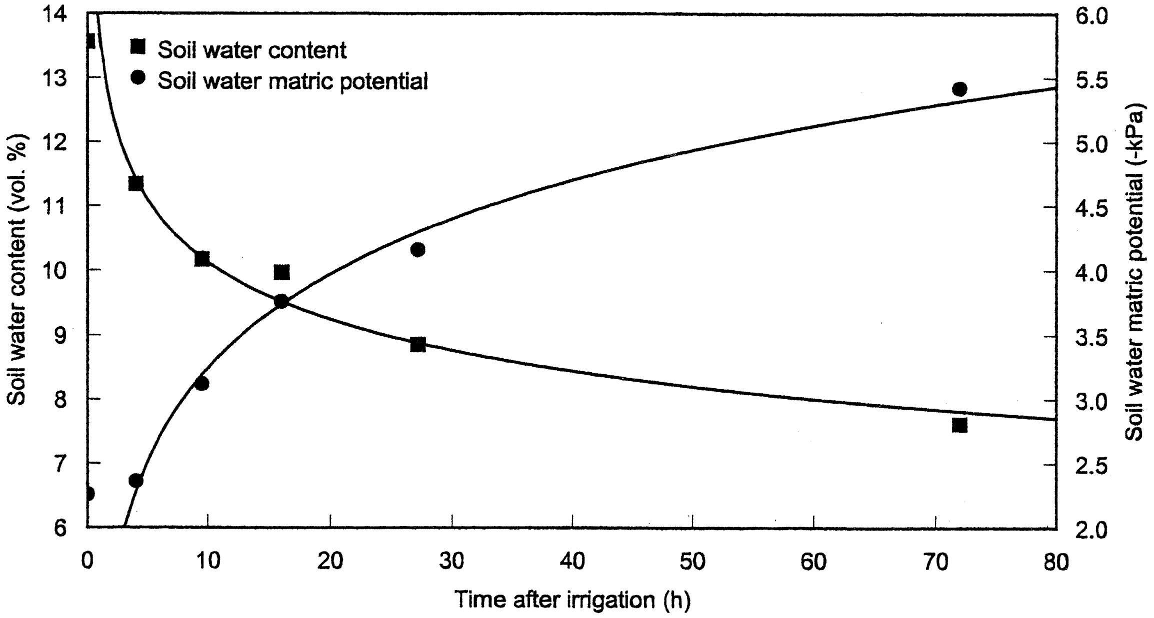

FIGURE 2

Drainage curve of a sandy soil in the Olifants River region determined at 300 mm soil depth by monitoring soil water content and soil water matric potential after saturation.

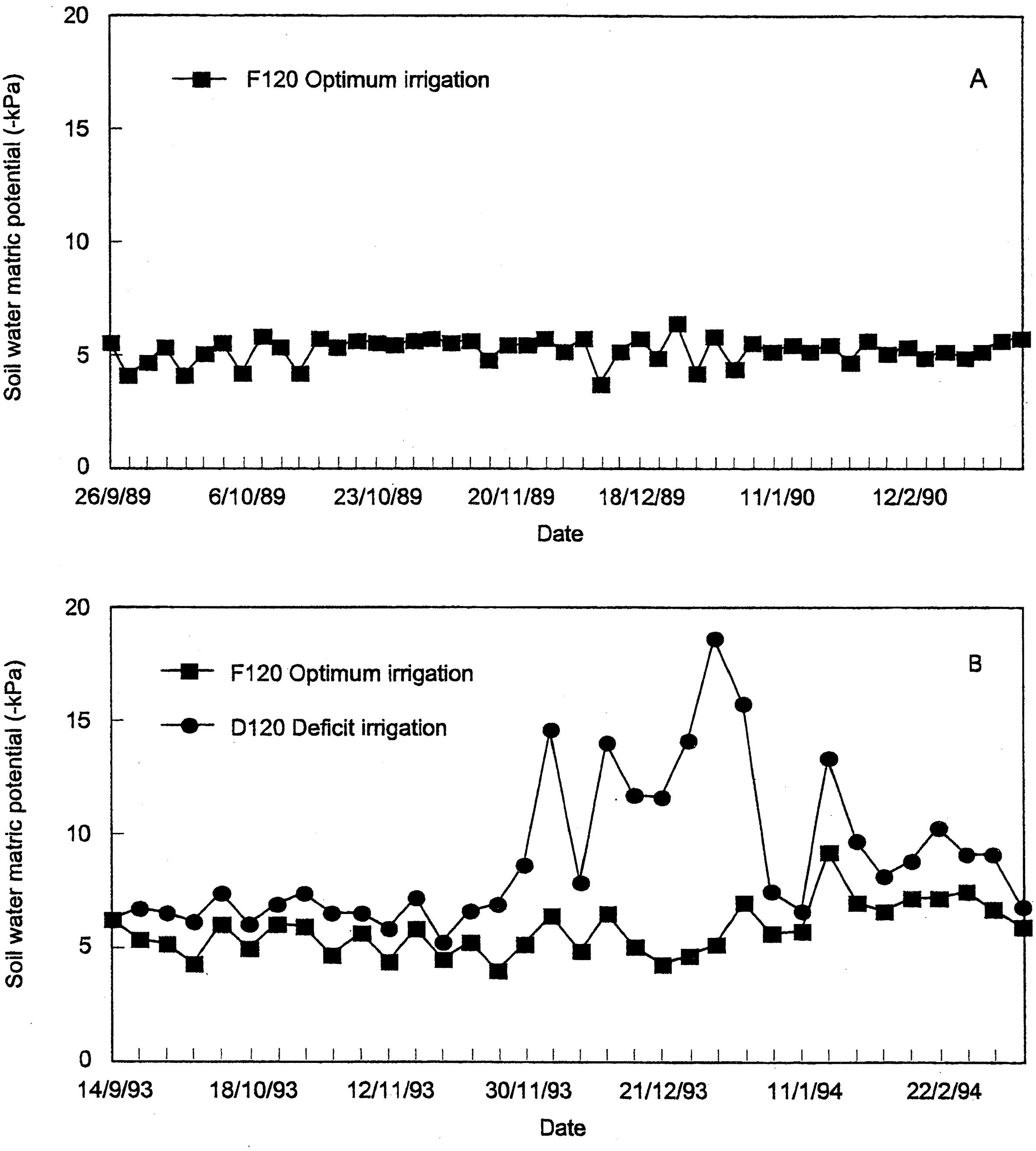

FIGURE 3
Mean soil water matric potential in the root zone (A) as measured during the 1989/90 season and (B) during the 1993/94 season when a deficit irrigaiton treatment was also applied.

Grapevine response: No significant differences in plant response could be detected between fertiliser application methods. Data for the fourth year only are shown in Table 3. Relatively high yields and low cane masses resulted in a high yield: cane mass ratio of approximately 20. Leaf analyses indicated a satisfactory nutritional status and did not differ between treatments. Mediocre shoot growth thus pointed towards 110 Richter not being the ideal rootstock for the large trellising system used in this trial. The more moderate vigour of this rootstock should have been accommodated on a smaller trellis. On sandy soils more luxurious shoot growth and higher yields can be expected with Ramsey as rootstock (Loubser & Uys, 1997).

Fertiliser applications twice per week (I120) held no advantage over less frequent applications (F120). This observation is in contrast to the general belief that nutrients leach with ease on unbuffered, sandy soils and that fertilisers should therefore be applied in small increments, at short intervals, to such soils. The fact that no differences could be detected in this investigation was most likely on account of leaching being prevented by means of well-managed irrigation scheduling (Fig. 3A). For the same reason conventional fertilisation (C120) appeared to be as effective as fertigation (F120). However, the amount of N applied in this trial (120 kg.ha^{-1}) approached the upper limit for wine grapes in South Africa (Conradie, 1981; Saayman, 1981). It was

TABLE 3
Effect of fertiliser application method on cane mass and grape yield of Bukettraube/110 Richter (fourth year of the first stage of experiment)(1).

Application method	Cane mass ($ton.ha^{-1}$)	Yield ($ton.ha^{-1}$)
Conventional, broadcasted every three weeks	1.86 a(2)	37.7 a
Fertigated every three weeks	1.94 a	37.1 a
Fertigated twice per week	1.86 a	36.4 a

(1) Fertiliser applied: 120 kg $N.ha^{-1}yr^{-1}$ and 80 kg $K.ha^{-1}yr^{-1}$.
(2) Values within columns followed by the same letter do not differ significantly ($p \leq 0.10$).

TABLE 4
Analyses of soil at the end of the fertigation trial (average for all treatments).(1)

Parameter	Soil depth (mm)		
	0-150	150-300	300-600
pH	6.26	5.75	5.65
Resistance (ohm)	1462.0	2542.0	3138.0
P ($mg.kg^{-1}$)	34.8	34.5	31.5
Ca ($cmol(+).kg^{-1}$)	1.50	1.22	0.89
Mg ($cmol(+).kg^{-1}$)	0.85	0.77	0.61
Na ($cmol(+).kg^{-1}$)	0.23	0.20	0.20
C (%)	0.13	0.12	0.11
CEC ($cmol(+).kg^{-1}$)(2)	2.98	2.49	2.00

(1) No differences ($p=\leq 0.10$) occurred between treatments.
(2) S-value.

therefore argued that a smaller amount, applied by means of fertigation, could have been equally effective. For this reason I120 was replaced with F80 during the second stage of the experiment.

Second stage:

Soil water content: Deficit irrigation (D120) tended to induce slightly lower matric potentials compared to optimum irrigation (C120, F120 and F80) up to middle November. However, as the climate became warmer and the canopy increased, the difference between the two irrigation approaches became more pronounced. In fact, soil matric potentials were consistently lower than -6 kPa during December and January (Fig. 3B).

Soil analyses: Soil analysis indicated that pH, P, Ca, Mg, Na and C values were unaffected by the different treatments. Hence, only mean values for all treatments are shown in Table 4. Organic C was exceptionally low, implying a low capacity to supply N by mineralisation, thus necessitating addition of N fertiliser. According to local norms the P content was adequate (Conradie & Saayman, 1989a). The fact that P content was higher than the initial value of 25 $mg.kg^{-1}$ was due to annual P fertilisation before the start of the experiment (1979 to 1988). A low Na content in relation to Ca and Mg excluded sodicity as a potential problem.

No clear tendencies could be discerned for inorganic N in the soil (data not shown). For fertigated treatments No_3-N ranged from 11 $mg.kg^{-1}$ in the topsoil (0-150 mm) to 6 $mg.kg^{-1}$ in the subsoil (300-600 mm). In general, values illustrated the lack of a reliable relationship between N applied and N recovered in soil (Neyroud & Parisod, 1983).

In contrast to NO_3-N, soil analyses, showed significantly lower K values for the F80 treatment (Table 5), thus reflecting K application levels. However, even for F80, K levels exceeded 50 $mg.kg^{-1}$, which can be regarded as a realistic norm for this sandy soil with a cation exchange capacity of less than 3.0 $cmol(+).kg^{-1}$ (Table 4). If K requirement is taken at 3 kg per ton of grapes produced (Conradie, 1981) and average production at 25 $ton.ha^{-1}$ (Tables 3 and 6), annual K removal must have been around 75 $kg.ha^{-1}$. At the start of the investigation the K level in the soil was 100 $mg.kg^{-1}$, suggesting that soil-K remained fairly constant for F80 (60 kg $K.ha^{-1}$), while increases occurred for the treatments that received 80 kg $K.ha^{-1}$. For the latter treatments (C120, F120, D120) the saturation level for K (% of CEC), exceeded 10%. If a K level of 80 $mg.kg^{-1}$ is accepted as the upper

TABLE 5

Potassium content of soil after being differently fertilised and irrigated for three years.

Treatment(1)	K (mg.kg^{-1})		
	0-150mm	150-300mm	300-600mm
C120	144 a(2)	144 a	129 a
F120	152 a	125 ab	117 ab
F80	109 ab	90 c	78 c
D120	136 a	113 bc	94 bc

(1) See Table 2 for details of treatments.

(2) Values within columns followed by the same letter do not significantly ($p \leq 0.10$).

limit for soils like these (Saayman, 1981), application of 80 kg K.ha^{-1} appeared to have been excessive. For this vineyard, with mediocre shoot growth, annual K removal was probably less than 3 kg per ton of grapes produced.

Grapevine response: Cane mass (Table 6) did not differ during the first season (1992/93), confirming that grapevines require more than one year to respond to changes in fertilisation programmes. During the second season (1993/94) F120 showed the highest cane mass ($p \leq 0.10$), pointing to fertigation as being superior to conventional fertilisation during this specific season. In the next season (1994/95), however, cane mass of the conventional treatment (C120) was again comparable to that of its fertigated counterpart (F120). This coincided with results obtained during the first stage of the experiment (Table 3), indicating that fertigation need not necessarily be superior to conventional fertilisation. In the third season (1994/95) cane masses of F80 and D120 were about 50% lower than those of C120 and F120. Application of only 80 kg N.ha^{-1} (F80) thus appeared to be suboptimal for this soil, while efforts to save irrigation water (D120) were also contra-productive, affecting shoot growth negatively.

Grape yield did not respond during the first (1992/93) and second (1993/94) seasons, in spite of differences in cane mass during the second season, indicating that yield takes longer than shoot growth to respond to changes in fertilisation practices. In the third season (1994/95) yield correlated with cane mass, confirming the benefits of an adequate fertilisation programme, irrespective of application method, and the negative effect of suboptimal irrigation practices.

During 1992/93 and 1993/94 grapes from F120, with the highest cane mass, tended to have the highest sugar content (Table 6). This phenomenon is expected for grapevines with suboptimal growth, while nitrogen fertilisation will normally retard maturation in vigorous vineyards. Titratable acidity and pH were not affected by any of the treatments throughout the duration of the trial.

Juice from C120, F120 and D120 showed the highest N concentrations (Table 7), in spite of higher yields for C120 and F120. Uptake of N was therefore enhanced by higher N levels, irrespective of application method. The N concentration in juice from F120 was 56 mg/L higher than that from F80. On more clayey soil an increase of only 27 mg/L was found when N fertilisation was increased from 56 kg.ha^{-1} to 96 kg.ha^{-1} (Conradie & Saayman, 1989b), confirming that vines on sandy soil, with low organic material, are more responsive to fertilisation. The K concentration of juice showed a lower value for F80, thus correlating with soil analysis (Table 5).

Nitrogen content of leaf blades (Table 8) did not differ during the final year of the experiment (1994/95) and appeared to be adequately supplied (Conradie, 1986). Petiole N was lower for C120, suggesting improved N uptake in fertigated treatments up to fruit-set. However, the fact that vines from C120 performed

TABLE 6

Effect of fertilisation and irrigation on performance and grape quality of Bukettraube/110 Richter.

Treatment (1)	Cane mass (ton.ha^{-1})			Yield (ton.ha^{-1})			Sugar content (°B)			Titratable acidity (g.l^{-1})			pH		
	1992/93	1993/94	1994/95	1992/93	1993/94	1994/95	1992/93	1993/94	1994/95	1992/93	1993/94	1994/95	1992/93	1993/94	1994/95
C120	1.11a(2)	0.98 a	0.97 ab	25.0 a	16.5 a	27.0 ab	21.5 a	21.18 ab	18.54 a	7.6 a	8.46 a	7.18 a	3.38 a	2.94 a	3.20 a
F120	1.43 a	1.41 b	1.07 a	19.8 a	19.5 a	29.5 a	23.2 b	21.84 a	19.12 a	7.8 a	8.82 a	7.42 a	3.37 a	2.95 a	3.22 a
F80	1.25 a	0.97 a	0.58 b	22.4 a	18.5 a	21.0 b	22.6 b	21.04 b	18.88 a	7.9 a	8.82 a	7.52 a	3.35 a	2.90 a	3.16 a
D120	1.16 a	0.83 a	0.48 c	21.6 a	18.3 a	22.0 b	22.9 b	21.62 ab	18.72 a	8.0 a	8.78 a	7.44 a	3.37 a	2.94 a	3.21 a

(1) See Table 2 for details of treatments.

(2) Value within columns followed by the same letter do not differ significanly ($p \leq 0.10$).

equally well to those from F120 (Tables 3 and 6), and the fact that juice contained a similar amount of N (Table 7), suggested that N was still adequately supplied. Petioles from all treatments contained less than 0.6% N, being regarded as the deficiency level for petioles (Conradie, 1986). In general, the values in Table 8 confirm the lack of a reliable relationship between leaf N and grapevine performance (Conradie, 1986).

Potassium levels in blades and petioles did not differ between treatments and exceeded locally accepted deficiency levels of 0.65% and 1%, respectively (Conradie, 1986). This is in agreement with the theory that K uptake will be independent of the K content of soil, unless deficiency levels exist (Boulton, 1980). For F120 and D120, where K was fertigated at the highest level of 80 $kg.ha^{-1}$, uptake of Mg (blades and petioles) was reduced (Table 8). The Mg content of the soil exceeded 0.6 $cmol(+).kg^{-1}$ (Table 4), which can be regarded as high for sandy soil. The fact that Mg uptake was impaired, in spite of a

TABLE 7
Effect of fertilisation and irrigation on the nutrient content of juice for Bukettraube/110 Richter during 1994/95 (third year of the second stage of experiment).

Treatment (1)	N ($mg.l^{-1}$)	P ($mg.l^{-1}$)	K ($mg.l^{-1}$)	Ca ($mg.l^{-1}$)	Mg ($mg.l^{-1}$)	Na ($mg.l^{-1}$)
C120	372 ab (2)	77 a	929 a	35 a	86 a	13.3 a
F120	410 a	88 a	957 a	38 a	80 a	11.1 a
F80	354 b	68 a	809 b	28 a	87 a	12.5 a
D120	396 ab	85 a	980 a	37 a	84 a	11.1 a

(1) See Table 2 for details of treatments.
(2) Values within columns followed by the same letter do not differ significantly ($p \leq 0.10$).

TABLE 8
Effect of fertilisation and irrigationon the nutrient content of leaves, sampled at fruit-set, for Bukettraube/110 Richter during 1994/95 (third year of second stage of experiment).

Treatment (1)	N (%)		P (%)		K (%)		Ca(%)		Mg (%)		Na ($mg.kg^{-1}$)	
	Blades	Petioles	Blades	Petioles	Blades	Petioles	Blades	Petioles	Blades	Petioles	Blades	Petioles
C120	2.47a(2)	0.49a	0.16a	0.24a	1.03a	2.26a	1.13a	0.95a	0.67a	1.50a	787a	1187a
F120	2.47a	0.55b	0.17a	0.28a	0.99a	2.46a	1.20a	1.05a	0.57b	1.38b	773a	1102a
F80	2.55a	0.55b	0.19a	0.32a	1.04a	2.09a	1.24a	1.02a	0.66a	1.55a	823a	1224a
D120	2.47a	0.53ab	0.16a	0.25a	1.06a	2.02a	1.21a	1.04a	0.57b	1.34b	717a	932b

(1) See Table 2 for details of treatments.
(2) Values within columns followed by the same letter do not differ significantly ($p \leq 0.10$).

TABLE 9
Effect of fertilisation and irrigation on wine quality of Bukettraube/110 Richter (second stage of experiment).

Treatment (1)	Cultivar character (%)				Wine quality (%)			
	1992/93	1993/94	1994/95	Average	1992/93	1993/94	1994/95	Average
C120	57.9 a(2)	56.7 a	60.7 a	58.4 a	56.7 a	54.0 a	61.5 a	57.4 a
F120	55.6 a	65.9 b	52.1 a	57.9 a	50.8 a	57.1 a	59.0 a	55.6 a
F80	55.9 a	62.3 b	59.0 a	59.1 a	51.9 a	56.7 a	59.1 a	55.6 a
D120	57.1 a	61.1 ab	59.0 a	59.1 a	53.1 a	53.2 a	59.0 a	55.1 a

(1) See Table 2 for details of treatments.
(2) Values within columns followed by the same letter do not differ significantly ($p \leq 0.10$).

high Mg level in the soil, is in agreement with the practical situation in South Africa, where a Mg-induced K deficiency has not yet been identified, whereas the opposite, viz a K-induced Mg deficiency, is not uncommon (Conradie & Saayman, 1989b). The Na content of petioles also pointed towards lower values for F120 and D120. No lowering of Mg values could be detected for C120, which received the same amount of K as F120. This suggested that fertigation enhances K/Mg antagonism, in comparison to conventional fertilisation. Annual application of 80 kg K.ha^{-1} through the irrigation water appeared excessive, while it could be applied conventionally without affecting the uptake of other elements. Reduced performance of F80 (Table 6) was, therefore, ascribed to N deficiency, while K appeared to be adequately supplied.

The cultivar character of wines did not differ in 1992/93 and 1994/95 (Table 9). In 1993/94 wines from F120 and F80 were regarded as more typical than those from C120. The reason for this is unclear. However, average values for the three-year period showed no significant differences. Fertigation thus had no significant positive or negative effect on wine quality.

CONCLUSIONS

The experiment showed that fertigation can be practised successfully on sandy soils, where the uptake of N and K can be improved. This may lead to improved growth and yield. However, because fertigation can be more efficient than conventional fertiliser applications, over-fertilisation with K may easily occur. This is especially true for sandy soils, having a low nutrient status, where over-application of K may induce Mg deficiencies. Downward adjustments of general norms will be necessary in such cases.

Application of N in regular, small increments holds no particular advantage over larger applications at longer intervals, if combined with well-managed irrigation practices. Even on a sandy soil it should be sufficient to apply N only once every three to four weeks.

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