Response of Colombar Grapevines to Irrigation as Regards Quality Aspects and Growth[1)]

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Plant response in terms of root, shoot and trunk growth as well as berry growth and composition, was determined in an irrigation trial with Colombar comprising four soil moisture regimes, moisture stress during five phenological stages and four irrigation systems. All measurements were taken over a period of time to show parameter changes during various stages within a season. A dry 25% soil moisture regime as well as trickle irrigation improved the sugar/acid ratio by lowering the malate and total titratable acid (TTA) concentrations and by increasing the total soluble solids (TSS) compared to soil moisture regimes of 50%, 70% and 90% which showed no significant differences with regard to either juice composition or berry size. Both the 25% moisture regime and water stress during flowering and phase I of berry growth were detrimental to berry size and yielded high tartrate concentrations at vêraison. Tricklers and micro-jets at a 90% soil moisture regime yielded similar curves for cumulative berry growth. Root growth studied *in situ* reached maxima at flowering and in the post harvest period. The 25% soil moisture regime suppressed formation of new roots. Trunk circumference measured annually was a reliable indicator of vine water stress. Daily measurements of trunk radius with the aid of dendographs showed a maximum growth rate in November as well as an unexpected negative rate from vêraison until harvesting. A programme for regulated irrigation according to the growth patterns of the various plant parts is set forth. Suppression of undesirable shoot growth without a deleterious effect on berry growth, and acquisition of a more favourable grape composition seems possible.

The water status of the grapevine can affect grape composition profoundly both directly or indirectly (Smart, 1974; Hidalgo, 1977) and in a positive or negative way depending on the degree as well as the duration of water stress (Amerine, Berg & Cruess, 1972; Hofäcker, 1976; Hofäcker, Alleweldt & Khader, 1976; Fregoni, 1977; Hidalgo, 1977; Hofäcker, 1977; Hardie, 1981). Controlling water supply to the vine in order to obtain optimum results between the two extremes of over-supply at the one end and severe stress at the other, is therefore of great importance. Consequently the objective of this experiment was to investigate the effect of soil moisture regimes, irrigation systems and water stress during particular phenological stages under field conditions and in a hot climate on grape composition and on growth of a few plant organs.

MATERIALS AND METHODS

This study was conducted at Robertson in an irrigation trial consisting of 12 treatments (Table 1) each replicated 6 times in a randomized block design. In 1974 *Vitis vinifera var.* Colombar grafted on 99 Richter was planted in 5 replicates, but the sixth replicate was planted to the cultivar Chenin blanc/ 101-14 Mgt. The planting distance was 3,0 x 1,5 m and the vines trained on a factory system as described by Zeeman (1981).

TABLE 1
Particulars of irrigation treatments applied in a trial with wine grapes.

Treatment	Soil moisture regime (%) during various phenological states					Irrigation system
	Bud burst *1 flowering	Flowering + Phase I*2 of berry growth	Phase II of berry growth	Veraison — Harvesting	Post harvest *3	
T_1	25	25	25	25	+	Micro-jets
T_2	50	50	50	50	+	Micro-jets
T_3	70	70	70	70	+	Micro-jets
T_4	90	90	90	90	+	Micro-jets
T_5	25	70	70	70	+	Micro-jets
T_6	70	25	70	70	+	Micro-jets
T_7	70	70	25	70	+	Micro-jets
T_8	70	70	70	25	+	Micro-jets
T_9*4	70	70	70	70	-	Micro-jets
T_{10}	90	90	90	90	+	Tricklers
T_{11}	50	50	50	50	+	Sprinklers
T_{12}	50	50	50	50	+	Flood

*1 All treatment plots received an irrigation before bud burst.

*2 Berry growth was divided into 3 phases (Winkler, *et al.*, 1974)

*3 Treatments included either one $^{(+)}$ or no $^{(-)}$ water applications between harvesting and end of leaf-fall.

*4 T_9 was ineffective in most years due to untimely rains.

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Irrigation and Cultural Methods: Micro-jets installed upright, 30 cm above ground level with a spacing of 3,0 m and an application rate of 8,6 $mm.h^{-1}$, wetted the total soil surface area. Trickle irrigation was applied at a rate of 4 $l.h^{-1}$ and the spacing between tricklers was 1 m. Sprinkle irrigation was carried out using under-vine sprinklers while flood irrigation took place in 2 m wide furrows with the vine rows down the middle.

Irrigations were scheduled according to predetermined soil moisture levels (Table 1). A soil moisture regime of 25% meant that 75% of the Plant Available Moisture (PAM) contained in the total rooting depth of 1 meter was depleted by evapotranspiration. These regimes were maintained by regular monitoring of soil water status with the aid of tensiometers, gravimetric soil moisture determinations and the neutron backscattering method.

Standard viticultural techniques as regards fertilization, spray programmes and pruning were applied in the experimental vineyard. A minimum cultivation practice consisting of growing a cover crop during winter and sprayed with herbicide before bud burst was followed in order to leave a layer of dead organic matter on the soil.

Berry Samples: Colombar berries were sampled weekly from T_1, T_2, T_3, T_4, T_6, T_8 and T_{10}, vines (Table 1) for three seasons (1978/79 — 1980/81) starting 3 weeks after full bloom and continuing until maturity. Approximately 200 berries were representatively picked from each treatment plot, their mass and volume determined and after maceration in a mortar, squeezed through cheesecloth and the juice centrifuged at 5000 r.p.m. for 10 minutes. Together with determination of its pH the juice was immediately analyzed for total soluble solids, using an Abbé refractometer, total acidity by titration with 0,1 M NaOH to a pH of 8,2, tartaric acid (Rebelein, 1973) and malates by an enzymatic method (Anon., 1976).

Root Studies: The root growth pattern during the growing season was studied on four plots maintained at four soil moisture regimes (T_1 — T_4). This was done with the aid of 4 root chambers consisting of a steel frame covered by wood (Fig. 1). The two opposite sides parallel to the vine rows consisted of 5 mm thick reinforced removable glass panels of 30 cm x 30 cm, fitted into galvanized window frames. Inset in the glass panes is a thin wire grid of 1,2 cm x 1,2 cm spacing. During the winter of 1979 these chambers were installed between two vine rows in pits, dug slightly larger than the size of the chamber. The soil was filled back carefully along the sides of the chambers in the same horison sequence as before and then allowed to stabilise for one year before root studies commenced. The glass-panelled sides were 50 cm away from two opposite vines in two adjacent rows.

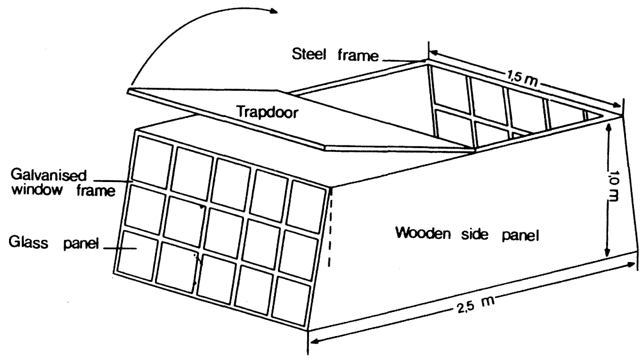

FIGURE 1
Chamber with glass panels for studying root growth *in situ*.

Black plastic sheeting was hung in front of the glass panelled sides to shut out any light. Access to the root chamber was obtained by means of a close fitting trapdoor which was opened only during root investigations.

From winter 1980 onwards root growth was studied weekly in these chambers for two seasons. The number of actively growing root tips against the glass panels were counted as well as the number of intersections between white roots and the wire grid. Root length was calculated using the following equation. (Böhm, 1979):

Root length (cm) = 0,786 x Number of intersections x Grid unit (cm).

Trunk Growth: Trunk circumference was measured annually at pruning after loose bark was removed and measurements taken 40 cm above ground level. Self registering dendographs were installed in November 1979 on 4 plots maintained at 4 soil moisture regimes (T_1, T_2, T_3 and T_4). A metal probe pressing against the trunk conveyed diurnal shrinking and swelling of the trunk as well as more long term effects such as growth, to a chart. Charts were replaced weekly and measurements continued for three seasons.

Shoot Growth: Shoot length was measured on a weekly basis for three seasons on the same treatment plots used for berry sampling. Shoots bearing two bunches and growing in similar positions on lower cordons were selected for this purpose. Measurements commenced when the shoots reached a length of approximately 15 cm and continued until véraison after which time damage to the shoot tips prevented further reliable measurements.

RESULTS AND DISCUSSION

Berry Samples: In order to facilitate interpretation, results of only one representative season and a limited number of treatments are presented in the respective Figures. Irrigation treatments affected physical berry development greatly in all four years of berry sampling as illustrated by the cumulative berry mass for 1979/80 (Fig. 2). The increase in fresh mass as well as volume of berries followed the typical double sigmoid growth curve of grapes and other fleshy fruit (Winkler *et al.* 1974; Coombe, 1976; Alleweldt, 1977). A soil moisture regime of 25% (T_1) yielded smaller berries than all the other treatments in all years. No differences in berry size or mass were found among a 90% (T_4), 70% (T_3) and 50% (T_2) soil moisture regime or between trickle irrigation (T_{10}) and microjets (T_4) (Table 2).

Stressing the vines during flowering and fruit set (T_6) reduced berry mass significantly (T_4 serves as control) and although water applications continued again in the lag phase (phase II) of berry development, berries of this treatment remained small till the end of the season. According to literature moisture stress during this critical berry growth stage (phase I) limits cell division, a limitation which cannot be rectified by favourable moisture conditions at a later stage. In this study fruit set (number of berries which developed in relation to number of flowers) was negatively affected by a dry soil moisture regime (results not shown) in accord with findings of Alexander (1964) and Hofäcker (1976).

Moisture stress during the ripening stage (T_8) had a deleterious effect on berry mass in one season only when compared to T_2, T_3 and T_4, but from observations and

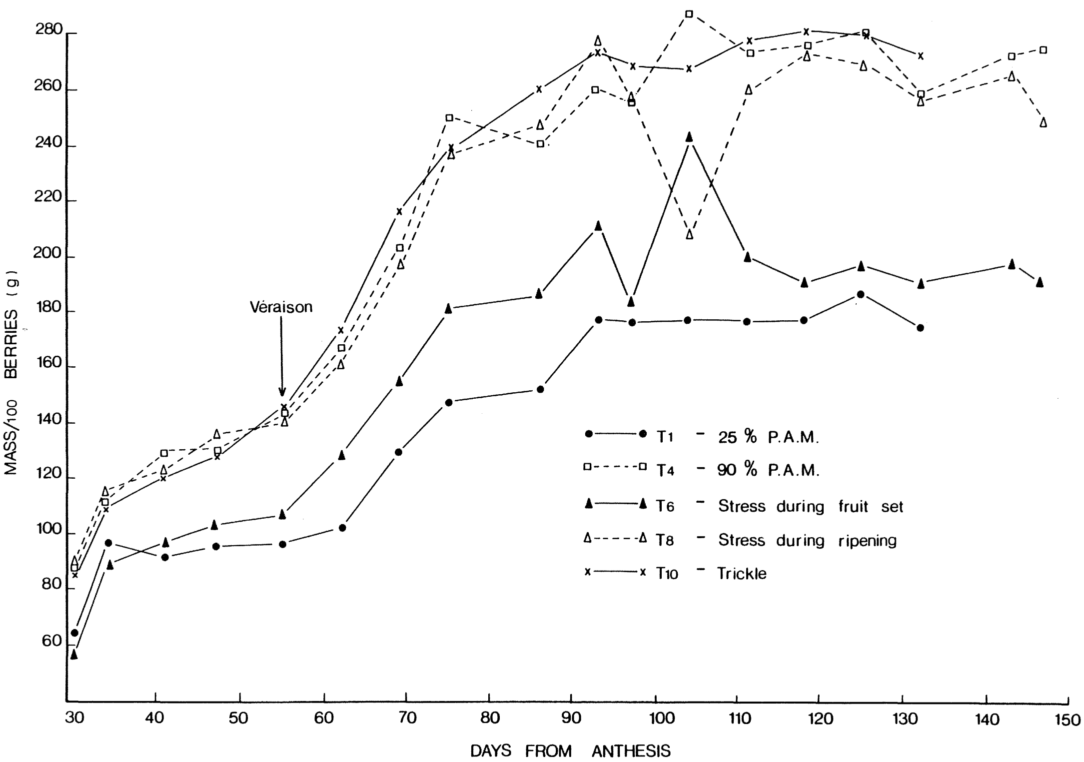

FIGURE 2
Effect of irrigation treatments on cumulative berry mass of Colombar grapes during the 1979/80 season.

TABLE 2
Significance of differences among treatments with regard to berry size and composition (1979/80).

Berry mass (g)	Berry Volume (cm³)	TSS (° B)	TTA (g. ℓ^{-1})	pH	Tartrate (g. ℓ^{-1})	Malate (g. ℓ^{-1})	Tartrate/ Malate ratio
T_{10} a	T_{10} a	T_{10} a	T_4 a	T_6 a	T_1 a	T_4 a	T_1 a
T_4 a	T_4 a	T_1 a	T_2 a	T_1 a	T_6 a	T_2 a	T_{10} b
T_2 a	T_2 a	T_8 b	T_3 ab	T_8 a	T_3 b	T_3 a	T_6 c
T_8 a	T_8 a	T_2 b	T_6 b	T_2 a	T_2 b	T_8 a	T_8 c
T_3 a	T_3 a	T_3 b	T_8 b	T_3 a	T_8 b	T_6 a	T_3 c
T_6 b	T_6 b	T_4 b	T_1 c	T_4 a	T_{10} b	T_1 b	T_2 c
T_1 c	T_1 c	T_6 b	T_{10} c	T_{10} a	T_4 b	T_{10} b	T_4 c

T_{10}, T_4 .... Treatments decrease in value from top to bottom.

ab .... Means followed by the same letter or combination of letters do not differ significantly at a 5% level using the Newman-Keuls test.

results obtained during some single weeks, it became clear that shrinkage of berries does occur in this stage if irrigations are not scheduled carefully. Berry mass is, however, not nearly as sensitive to moisture stress in the ripening period as in the cell division phase.

With regard to sugar concentration the driest treatment (T_1) and the trickler treatment (T_{10}) were exceptions, having given significantly higher values than the other treatments (Fig. 3). This result can be ascribed to various reasons. T_1 plots not only produced small berries, but also yielded a low shoot growth which permitted sunlight to penetrate much better to the bunches, with a higher temperature, beneficial to sugar accumulation as a result. In addition to low shoot growth on T_{10} plots, trickle irrigated vines contained significantly less nitrogen (J.L. van Zyl, 1983. Unpublished data), which might have contributed to a higher sugar concentration. Water stress during ripening (T_8) significantly enhanced sugar concentration in one of the trial seasons. Berry shrinkage could have played a role in this result since a decrease in photosynthetic activity in T_8 vines was measured towards the dry end of this soil moisture regime (J.L. van Zyl, 1983. Unpublished data). Small berries in the case of the T_6 vines did not contribute to an increase in sugar concentration while soil moisture content in the range 50 — 90% of field water capacity (T_2, T_3 and T_4) did not affect sugar concentration.

The TTA concentration was highest in T_4 and T_2 berries and it decreased significantly with water stress at phase I of berry growth (T_6) and during ripening (T_8). Berries from T_1 and T_{10} plots were however, lowest in total titratable acidity (TTA) compared to all other treatments in 1979/80 (Fig. 4 & Table 2). In this season grapes from the two latter treatments were harvested 3 weeks earlier than those of their counterparts due to a more favourable sugar/acid ratio. The rate of decrease was also most rapid in T_1 grapes after véraison.

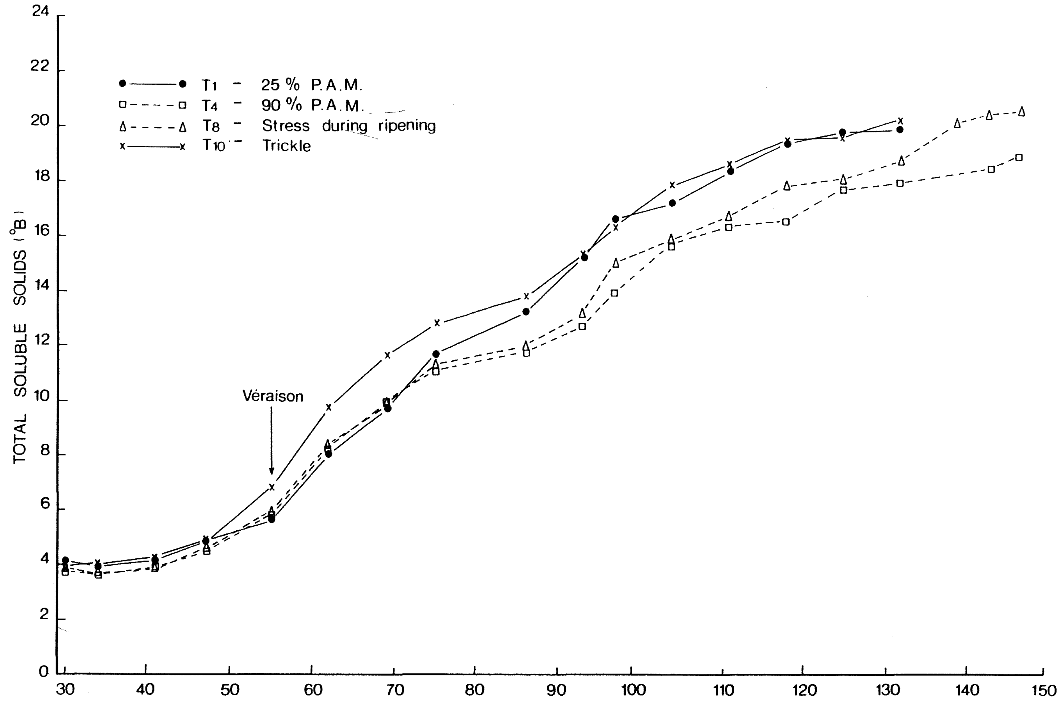

FIGURE 3
Effect of irrigation treatments on the increase of total soluble solids in Colombar grapes during the 1979/80 season.

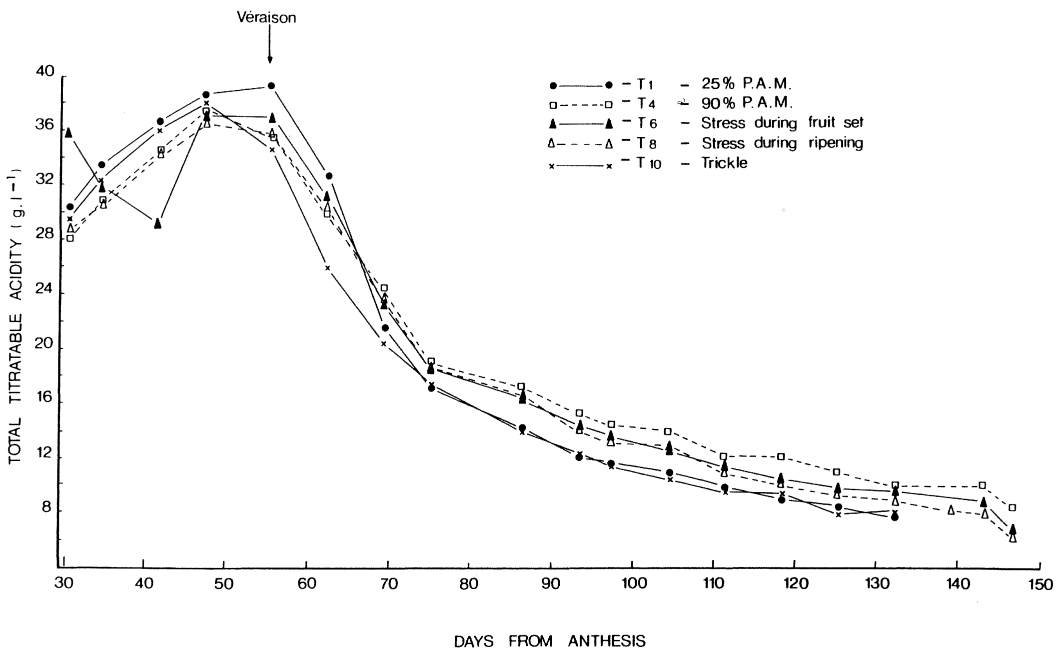

FIGURE 4
Effect of irrigation treatments on the total titratable acidity in Colombar grapes during the 1979/80 season.

The highest tartrate concentration was found in grapes from the dry treatment (T_1) and in T_6 grapes which were stressed during bloom and the cell division period (Fig. 5). Although the decrease in tartaric acid took place at the fastest rate in T_1 grapes, no difference existed at harvesting. Tartrate concentration became fairly constant early in the season in Colombar, irrespective of irrigation treatment in all seasons, contributing to the very slow rate of TTA decrease towards harvesting.

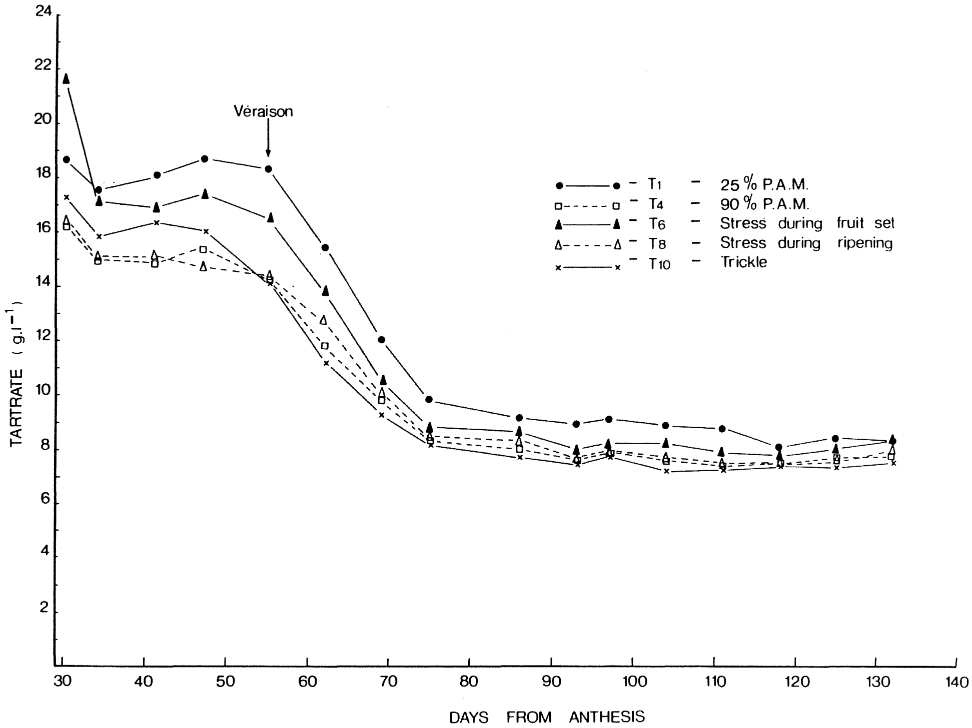

FIGURE 5
Effect of irrigation treatments on tartrate concentration in Colombar grapes during the 1979/80 season.

From vèraison onwards malate concentrations of trickler (T_{10}) and dry treatment plots (T_1) were significantly lower than those of the other irrigation treatments (Fig. 6). These differences may be due to the microclimate inside the vine canopy as affected by shoot growth. The slow decrease in TTA towards the end of the season can largely be attributed to malic acid decomposition which continued till harvesting. The tartrate/malate ratio was highest in the trickler (T_{10}) and dry treatment (T_1) and lowest in grapes grown at higher soil moisture regimes (T_2, T_3 and T_4) with values ranging from 2,58 — 1,50 at harvesting (Fig. 7).

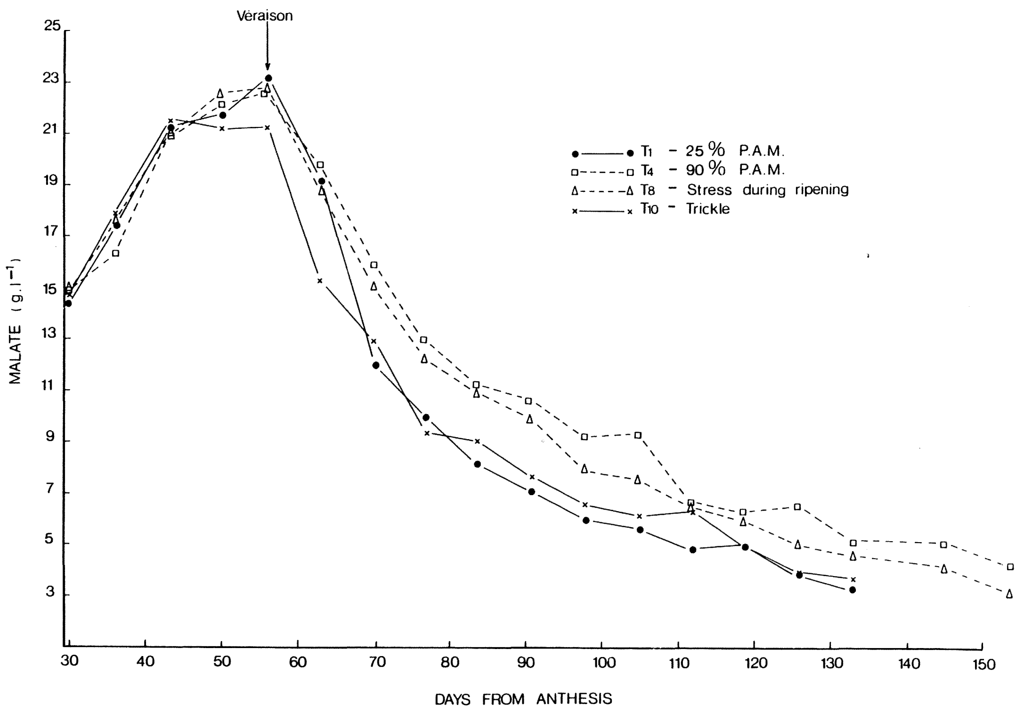

FIGURE 6
Effect of irrigation treatments on malate concentration in Colombar grapes during the 1979/80 season.

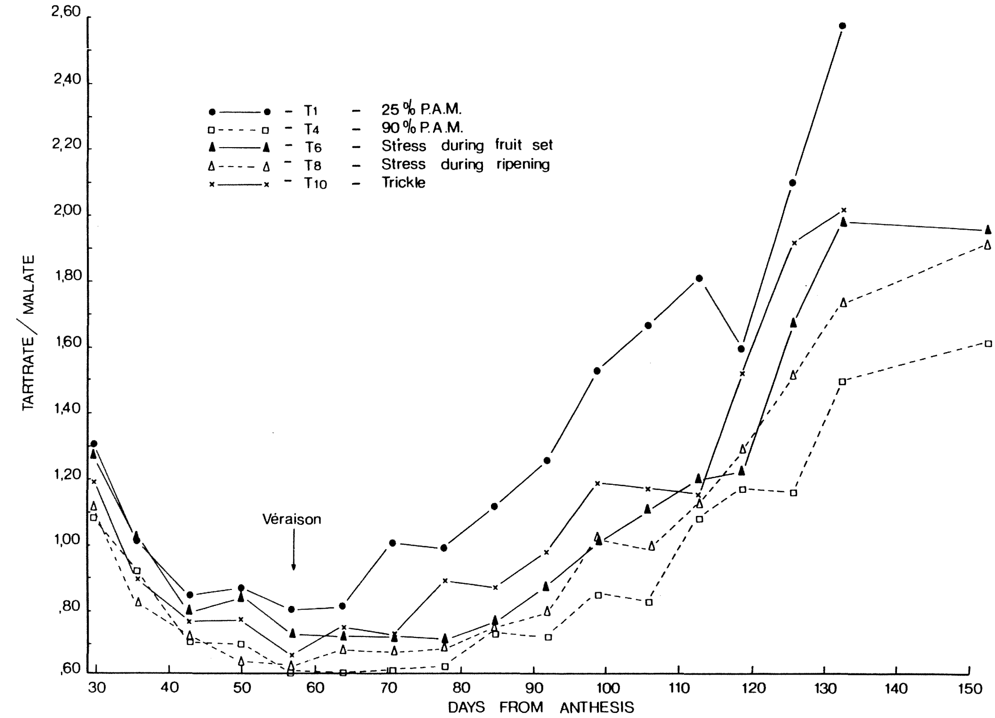

FIGURE 7
Effect of irrigation treatments on tartrate/malate ratios in Colombar grapes during the 1979/80 season.

The pH of the juice did not differ significantly among treatments in the 1979/80 season (Table 2), but T_1 berries showed a tendency, substantiated statistically in other seasons, towards a higher pH than the other irrigation treatments. Trickle irrigation had no effect on the pH of the juice despite its low TTA concentration.

Root Studies: Both, number of actively growing root tips as well as root length followed the same general pattern during the course of the season and were found suitable parameters for quantifying new root growth. Formation of new roots in both investigation years reached maxima in the flowering and postharvest period of the vineyard (Fig. 8) therefore confirming findings in pot experiments (Conradie, 1980), in lysimeters (Van Rooyen, Weber & Levin, 1980) and in a rhizotron, (Freeman & Smart, 1975). Irrespectie of soil moisture regime, very little new root growth occurred before and at the time of bud burst and surprisingly, also during mid-summer (December till February) when water uptake reached a maximum. White unsuberised roots are therefore not the only pathway for water movement from soil to vine. In one of the investigation seasons, the post harvest peak of root growth actually commenced before the grapes were harvested, indicating either that removal of the fruit load was not the only stimulus or that the grapes had already stopped to be the main accumulator of photosynthetic products at that stage.

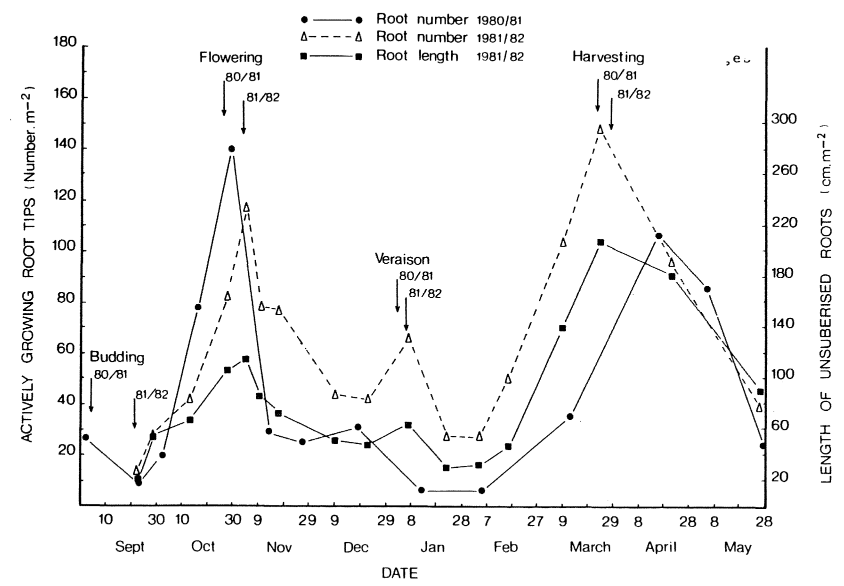

FIGURE 8
Fluctuation in root formation in terms of root number and root length for Colombar/99R during the course of two seasons.

Significantly fewer active growing root tips were counted in the soil of the driest treatment (T_1) in both years in comparison with the other three irrigation treatments, among which the 50% moisture regime (T_2) had more actively growing root tips than the T_4 plots (90% moisture regime) in 1981/82 (Fig. 9). However, when the total length of unsuberised white roots is compared, only T_1 had a significantly lower value than the other treatments due to the fact that the white unsuberised length per root was more on T_1 and T_4 plots than on T_2 and T_3 plots. No explanation can be given for the atypically high values of new root growth for T_3 vines in November and December 1981 when compared to those of the previous season or to the other treatments of the same season.

Trunk Growth: Trunk circumference and diurnal trunk movement have been used by researchers to assess vine response to irrigation treatments (Vaadia & Kasimatis, 1961; Smart, 1974). Trunk circumferences of the four irrigation regimes (T_1 — T_4) tested in this trial are depicted in Fig. 10. T_1 trunks were significantly thinner than those of T_3 and T_4 both of which had comparable values. Trunk circumferences of the T_2 vines assumed the expected position relative to the others although not significantly different from them.

The growth rate of vine trunks increased from budding and reached a peak at the end of October, remained high till December but dropped sharply to a negative value at the end of December (Fig. 11). This negative growth rate

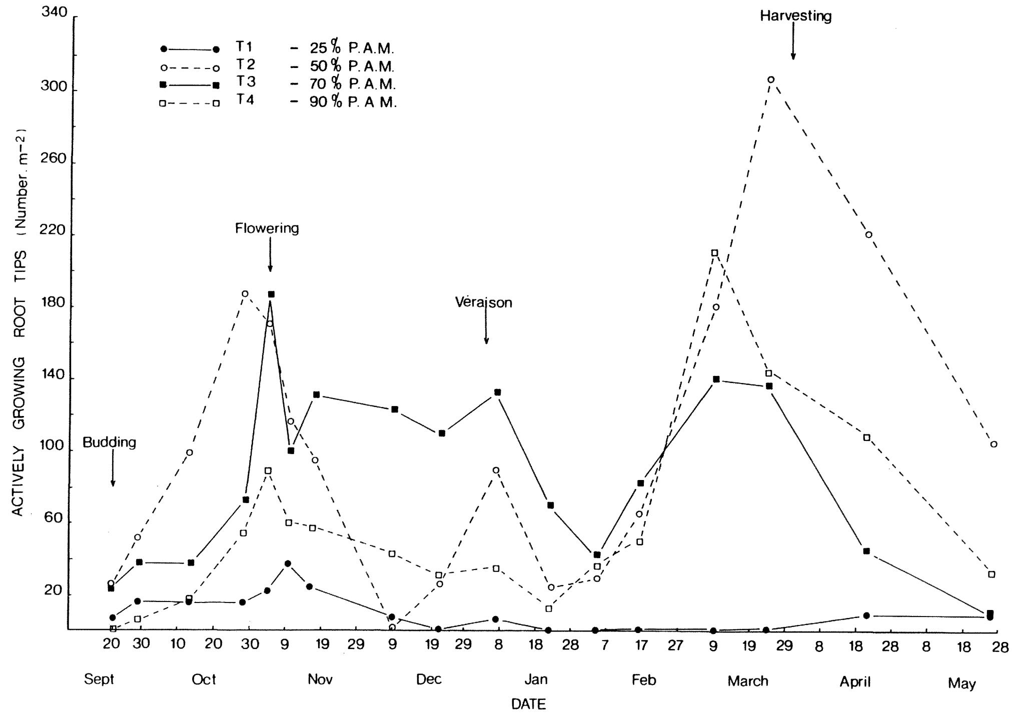

FIGURE 9
Effect of irrigation treatments on root formation of Colombar/99R during the course of the 1981/82 season.

On average new root growth in terms of number of growing tips occurred mainly in the soil layers nearest to the soil surface viz., 50 — 45% in the 0 — 30 cm soil layer, 34 — 35% in the 30 — 60 cm layer and 21 — 25% at the 60 — 90 cm soil depth. This distribution neither fits the dry (T_1) nor the wet (T_4) irrigation treatment. For both these treatments the second horizon contained the largest number of actively growing root tips. This was most probably due to too dry or too wet conditions near the soil surface for T_1 and T_4 respectively. Total white unsuberised root length did not differ significantly among depths when irrigation treatments were grouped together, though for the treatments individually the 0 — 30 cm soil layer of the T_2 plot contained a significantly greater length of these roots than at a 60 — 90 cm depth.

during ripening was measured in two seasons and indicated a decrease in trunk diameter. Mobilisation of starches which is needed for the lignifying of above ground parts of vines (Branas, 1974) may be one cause for this finding. The coincidence of decrease in trunk diameter at vêraison however, suggest that the grapes itself may be involved. Measurements also suggest, though not conclusively, that trunks decrease in thickness at bud burst, probably for the same reason as stated above.

In this study no differentiation was possible among treatments with regard to either weekly trunk growth rate or diurnal change in trunk diameter due to a lack of replicates and insensitivity of the dendrographs respectively.

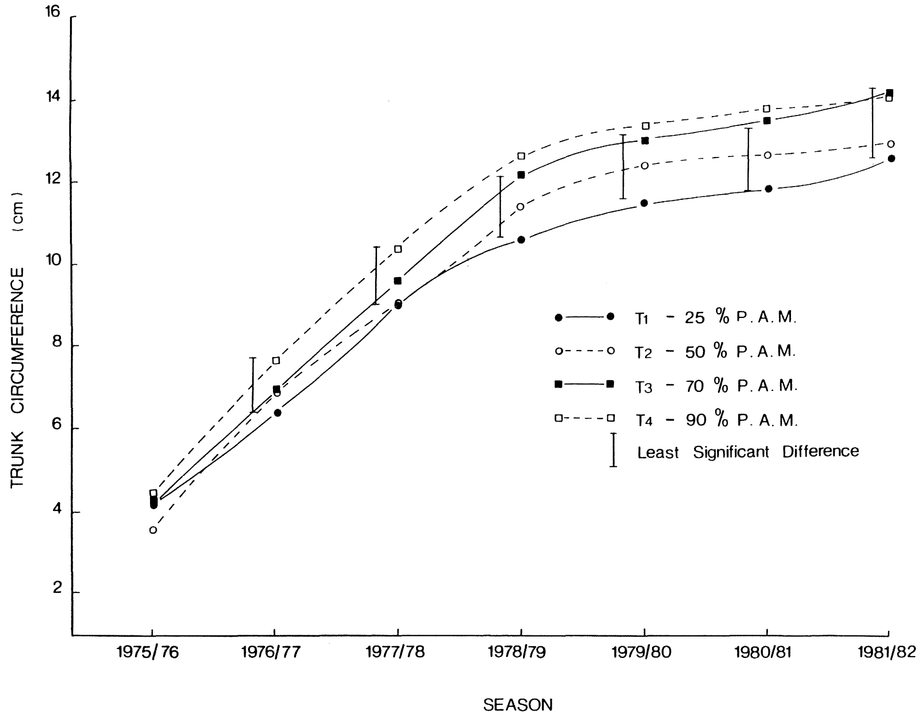

FIGURE 10
Long term effect of irrigation treatments on trunk circumference of Colombar/99R.

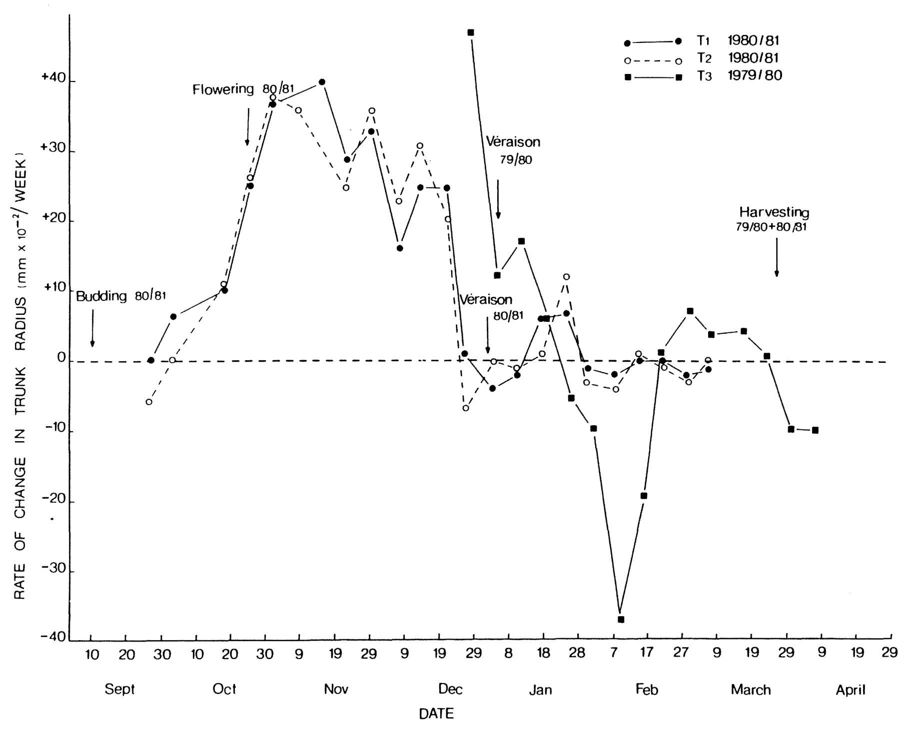

FIGURE 11
Change in trunk radius due to phenological stage of Colombar/99R in an irrigation trial at Robertson.

Shoot Growth: Shoot elongation rates for a few irrigation treatments are presented in Fig. 12. Corresponding to the results of other seasons, T_4 and T_3 vines yielded relatively similar shoot elongation rates. These rates were significantly higher than those of T_1 (25% soil moisture regime). Results for T_2 vines (50% soil moisture regime) which did not differ from any of the other treatments in this respect, are in accord with those of other seasons and also correspond with trunk circumference data (Fig. 10). The shoot elongation rates of T_6 vines which were only stressed during bloom and phase I of berry growth, immediately responded to the decreasing soil water content and were already significantly lower than those of the T_3 and T_4 vines by the middle of November. These data clearly illustrate that shoot elongation rate is sensitive to water stress and can be manipulated by irrigation. Results obtained in pot experiments (J.L. van Zyl, 1983. Unpublished data) showed an even more marked effect of moisture stress on shoot elongation rate.

CONCLUSION

Perusal of growth rates of vine shoots, roots, trunks and berries (Fig. 13) as well as sugar and acid concentrations of berries within the course of a season, clearly shows maxima and low values at different parts of the season for the various parameters. Since it has been proven that irrigation can affect each of these parameters individually it can be anticipated that judicious irrigation management could be used as a powerful tool to suppress unnecessary and even harmful growth and to improve growth of fruit and quality aspects. Chalmers, Mitchell & Van Heek (1981) succeeded in obtaining this result in an experiment with peaches. A prerequisite to make regulated irrigation really effective would require management systems that concentrate root systems such as limited wetted zones as in trickle irrigation, natural (or even artificial) barriers such as in shallow soils, and dense planting. Large soil reservoirs such as provided by deep medium textured soils, put too much water at the disposal of the plant to respond quickly to irrigation strategy.

Shoot growth can be suppressed by limited irrigation in the period bud burst to flowering. Root growth which also shows a peak in this stage will not be unduly decreased by such a schedule since a large part of root growth occurs after harvesting and it is further less sensitive to moisture stress than growth of the aerial parts of the vine. During flowering and phase I of berry growth the highest possible soil moisture regime must be maintained to insure maximum fruit set and cell division.

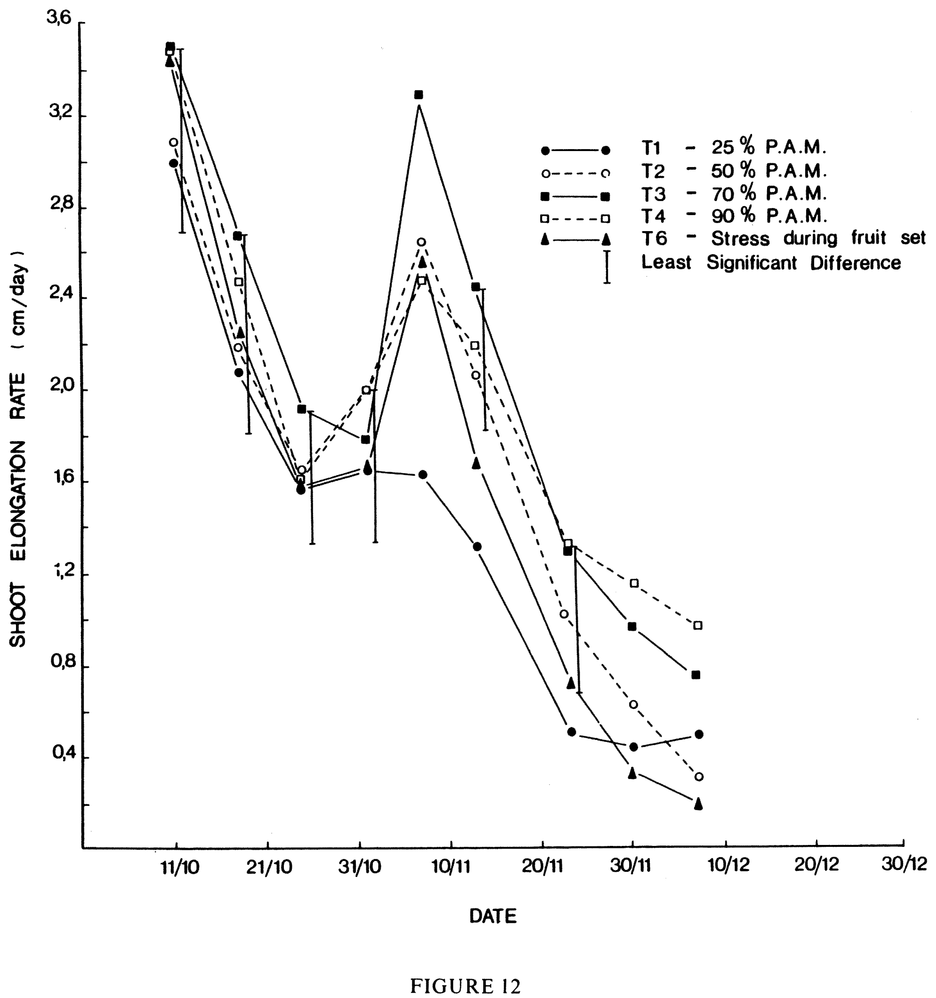

FIGURE 12
Effect of irrigation treatments on shoot elongation rates of Colombar/99R in the 1979/80 season.

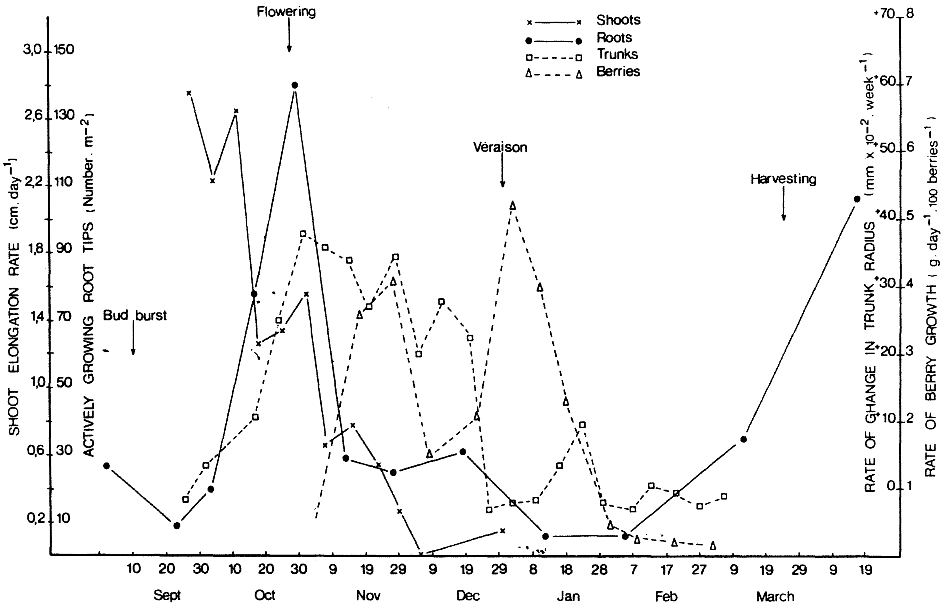

FIGURE 13
Interrelationship among the growth rates of various plant parts as determined in an irrigation trial with Colombar/99R at Robertson.

Shoot growth rate would have dropped by then, while trunk growth will benefit from a high soil moisture content in November. Though well developed trunks are not a sought after characteristic of the vine at present, its value as a storage organ may still be under-estimated. During phase II of berry growth, irrigation can be reduced to curb shoot growth further while the growth of berries are not very sensitive to moisture stress. Continued irrigations at limited quantities during the ripening period will ensure increased sugar contents, a low malate and TTA concentration without decreasing the yield. It is therefore clear that optimum growth, grape yield and grape quality can be obtained by integration of controlled irrigation and phenological stage in a natural harmonious manner.

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