# The Effect of Vine Spacing on the Vegetative and Reproductive Performance of *Vitis vinifera* L. (cv. Pinot noir)

E. Archer[1] and H.C. Strauss[2]

1) Department of Viticulture, University of Stellenbosch, 7600 Stellenbosch, Republic of South Africa
2) Viticultural and Oenological Research Institute (VORI), Private Bag X5026, 7600 Stellenbosch, Republic of South Africa

Submitted for publication: April 1991
Accepted for publication: August 1991
Key words: Shoot growth, vine size, bunch mass, berry mass, canopy characteristics, grape quality, wine quality

**Data concerning growth, yield, grape composition and wine quality are presented for five years. Closer spacing reduced cane mass and yield per vine but increased them per hectare. Less dense canopies as well as a larger leaf area:fruit mass ratio with more closely spaced vines augmented grape and wine quality. Given the specific circumstances of this trial, a vine spacing resulting in between 1,0 m$^2$ and 2,0 m$^2$ soil surface per vine proved to be optimum for Pinot noir.**

During the previous century French viticulturists stated that vine spacing, and especially in-row spacing, is a function of soil fertility, genetic vigour and climate (D'Armailhacq, 1867; Guyot, 1867 and Cazenave, 1889). These authors found wider in-row spacing to be necessary for vines with high vigour and *vice versa.* This principle was later supported by the results of Jamain (1901), Anon. (1907), Ravaz (1908) and Perold (1927).

The maximum dry mass of plant material per unit area of soil can only be produced when maximum photosynthetic productivity for that specific soil area prevails. This photosynthetic productivity is directly affected by the efficiency of sunlight interception by the canopy (Branas, 1974). A homogeneous arrangement of effective vine leaves per hectare is a prerequisite for a high efficiency of sunlight interception (Champagnol, 1982). On poor soils this principle can be satisfied with closer vine spacing (Champagnol, 1984) while adapted trellising systems and wider spacing are needed on rich soils (Casteran, Carbonneau & Leclair, 1980).

Conflicting reports on the effect of spacing on vine performance were found in the literature. In situations where denser plantings produced homogeneous effective leaf area without shoot crowding and within-canopy shade, the yield per unit area of soil increased (Kamel, Rifay & Abdel-Kawi, 1972; Wiebe & Bradt, 1973; Brightwell & Austin, 1975; Champagnol, 1979; Hidalgo & Candela, 1979; Turkington, Peterson & Evans, 1980; Morris & Cawthon, 1981a; Morris & Cawthon, 1981b; Reyes & Karcz, 1981; Hedberg & Raison, 1982; Munoz, 1982; Dumartin, *et al.*, 1982; Champagnol, 1982; Jensen, 1983; Atanasov, 1983; Michailov, 1983; Neukom, 1984; Hunter, Wiebe & Bradt, 1985; Liuni, Antonacci & Colapietra, 1985; Brar & Bindra, 1986; Intrieri, 1987). The same phenomenon was also reported for other crops, e.g. oranges (Boswell, Nauer & Atkin, 1982), peaches (Layne, Tan & Fulton, 1981) and soybean (Parks & Manning, 1980).

In situations where closer vine spacing created negative effects on shoot crowding and within-canopy shade, the yield per unit area of soil was surpassed by that of more widely spaced vines (Bioletti & Winkler, 1934; Shaulis & Kimball, 1955; Malan, 1959; Sisson, 1959; Winkler, 1959 and Winkler, 1969).

The abovementioned reports confirmed previous findings that vine vigour directly affected the results of vine spacing trials. The vigour was affected by soil potential, cultivation practices such as irrigation, trellising, pruning, fertilization, etc. and/or genetic vigour of the cultivars used. The stronger the vigour, the wider the vine spacing which produced the best yield and *vice versa.*

Vine spacing also has an important effect on grape and wine quality, mainly through the effect of shoot growth on canopy density (Smart, 1985; Smart, 1987) as well as on competition for photosynthates (Koblet, 1977; Champagnol, 1979; Champagnol, 1984). Ravaz (1908) has proven that different vine spacings induced different rates of shoot growth and that the longer growth period of wider spaced vines exerted a negative effect on grape quality. According to Casteran, Carbonneau & Leclair (1980), there exists a certain vine spacing for each given soil/climate association where between-vine competition will have a direct effect on the physiological processes in the vine. This induced stress could be used to enhance grape quality, but when it surpasses certain levels, the effect on quality is reversed. Because of this phenomenon, grape quality of vigorous cultivars decreased at narrow spacing while that of less vigorous cultivars increased (Reyes & Karcz, 1981; Dumartin *et al.,* 1982). These researchers ascribed the increase in quality to a more favourable leaf area:fruit mass relationship in the case of closer spaced vines. Several researchers report-

*Acknowledgements: The valuable assistance of Mr J.M. Southey and Mr G.W. Fouché is gratefully acknowledged.*

ed an increase in sugar concentration with closer spaced vines (Hedberg & Raison, 1982; Atanassov, 1983; Neukomm, 1984; Remoue & Lemaitre, 1985; Hunter, Wiebe & Bradt, 1985; Liuni, Antonacci & Colapietra, 1985; Intrieri, 1987). On the other hand, Sisson (1959), Winkler (1959) and Wiebe & Bradt (1973) reported a decrease in sugar concentration with a decrease in vine spacing, while Stoev & Bondjoukov (1974), Brar & Bindra (1986) and Murisier & Spring (1986) reported no change in sugar concentration with variations in spacing. Hedberg & Raison (1982) reported a significant decrease in pH, while Winkler (1969) and Liuni, Antonacci & Colapietra (1985) reported an increase in pH with closer vine spacing.

Champagnol (1979, 1984) pointed out that these contradictory results obtained in various spacing experiments can mostly be ascribed to induced variations in vegetative growth rate and canopy microclimate. These variations in canopy density and microclimate can probably explain the variations in yield and quality obtained in the different experiments (see also Archer & Strauss, 1990). The latter authors proved that vine physiology and canopy characteristics are affected by different vine spacings and therefore yield and quality are also expected to change when the vine population per hectare is varied. Because of the many conflicting reports on the effect of vine spacing on yield and quality as well as strong evidence that each soil/climate locality prescribes its own optimal vine spacing, this study was undertaken to quantify and qualify the correct vine spacing for viticulture which is practised under similar conditions as this trial in the Stellenbosch region.

## MATERIALS AND METHODS

**Soil and vineyard:** The soil and vineyard used for this study are described by Archer & Strauss (1985; 1989 and 1990).

**Data collection:** Data were collected over a five-year period and included the following: crop, cane, bunch and berry mass, budburst percentage (number of sprouted buds as percentage of total number of buds left during winter pruning), bud fertility (number of bunches per sprouted bud) and phenology. Date of budburst was recorded when 80% of allocated buds showed signs of green. Flowering was dated at 80% cap-fall. Véraison was dated when 80% of all bunches showed signs of red, and ripeness when a sugar concentration of approximately 23°B was reached.

Cane and crop mass were recorded in the normal manner, while 50 randomly selected bunches from each treatment plot were used to record bunch mass. The berries of 20 randomly selected bunches from each treatment plot were cut, without pedicels, and from these 100 were randomly selected to record berry mass. Leaf area per vine was calculated from measurements of the total leaf area of five shoots each of 10 selected vines per treatment plot. The area of these leaves was measured using a Li-cor portable area meter (Li-3 000). While measuring the leaf area, the area of 50 randomly selected leaves from each treatment plot was noted separately to calculate area per leaf. The leaf layer number (LLN) was measured using the point quadrat method described by Smart (1985). Five vines per treatment plot were randomly selected and 20 probes per vine were made horizontally through the canopy in the fruit zone.

**Skin and wine colour:** The berries not used for berry mass determination were used to measure skin colour according to the method described by Hunter & De la Harpe (1987).

**Winemaking:** During the first two years of the experiment, wine was made in duplicate from each treatment plot. Thereafter, the grapes from the replicates were pooled for each treatment and wine was then made in triplicate. Grapes were crushed and destemmed and fermentation was allowed to proceed until the sugar concentration of the must decreased by 10°B before skins and juice were separated. During this initial fermentation period the skins and juice were thoroughly mixed twice every 24 hours. After

TABLE 1

Effect of vine spacing on some vegetative characteristics of Pinot noir/99 Richter. Nietvoorbij, Stellenbosch. 1985/86-1989/90.

| Spacing (m) | Cane mass per vine (kg) | Cane mass per ha (kg) | Yield:cane mass relationship | Trunk circumference (mm) |
|---|---|---|---|---|
| 1,0 x 0,5 | 0,164 | 3306 | 3,93 | 712 |
| 1,0 x 1,0 | 0,284 | 2828 | 4,00 | 853 |
| 2,0, x 1,0 | 0,476 | 2384 | 3,95 | 1056 |
| 2,0 x 2,0 | 0,590 | 1480 | 4,90 | 1117 |
| 3,0 x 1,5 | 0,806 | 1796 | 4,39 | 1231 |
| 3,0 x 3,0 | 1,188 | 1379 | 4,75 | 1542 |
| D-value ($p \leq 0,05$) | 0,178 | 581 | ns | 413 |

ns = non-significant.

separation, the skins were pressed at 200 kPa and the press juice was added to the separated juice and allowed to ferment dry. The total fermentation took place at 20°C. An experienced panel of at least nine members was used to evaluate each wine for overall quality with specific reference to colour, bouquet and palate.

## RESULTS AND DISCUSSION

**Shoot growth:** The shoot growth per vine of the closer spaced vines was significantly less than that of the wider spaced vines, while the closer spacings produced a significantly higher shoot mass per hectare than the wider spacings (Table 1). This is in accordance with the findings of Bioletti & Winkler (1934), Branas (1949) and Kamel *et al.* (1972). The yield:cane mass relationship shows that the bud-load applied had not created an imbalance between yield and growth for any of the vine spacings and that possible quality differences could not be ascribed to abnormal cropping levels.

Through the five seasons during which the performance of vines was recorded, no significant differences could be found between either percentage of budburst or fertility of buds in different spacings (data not shown). Furthermore, all phenological stages occurred earlier in the closer than in the wider spacings (data not shown).

**Vine size:** Trunk circumference, as indicator of vine size, is given in Table 1. Closer vine spacing reduced trunk circumference. A decrease in spacing produced smaller vines with a lower yield capacity which is probably a normal vine response to a reduction in available soil space per vine. This is in accordance with results of Winkler (1959, 1969) who also found that trunk circumference and vine size increased with an increase in available soil for vine roots.

**Yield, bunch and berry mass:** Yield per vine decreased and yield per hectare increased with a decrease in vine spacing (Table 2). This is in accordance with the results of most of the researchers quoted in the Introduction. Vines in the 1,0 m x 0,5 m, 1,0 m x 1,0 m and 2,0 m x 1,0 m treatment plots reached full production one year earlier than those in the 2,0 m x 2,0 m and 3,0 x 1,5 m and two years earlier than those in the 3,0 m x 3,0 m treatment plots (data not shown). This verified the findings of Ravaz (1935). The yield per $m^2$ leaf area showed a quality advantage for the closer spaced vines in that fewer grapes per unit leaf area had to be ripened. As will be shown later, this contributed to the quality differences found.

Although there is a significant yield advantage in the case of narrow spacings, the economics of the operation must also be considered. The material costs for a trellising system and grafted vines for the 1,0 m x 0,5 m treatment were more than double that of the 2,0 m x 1,0 m treatment and nearly four times that of the 3,0 m x 1,5 m treatment (data not shown). These higher costs ruled out the highest planting density in this experiment as a viable proposition; these findings are in accordance with those of Gagnon (1973).

An increase in vine spacing tended to increase the bunch mass (Table 2) while no significant differences could be found in berry mass. The higher bunch mass of the wider spacings was, therefore, a result of more berries per bunch and can be related to better fruit set as well as differentiation of bigger cluster primordia.

**Canopy characteristics:** Leaf area per vine increased with an increase in plant spacing, but the leaf index (leaf area/unit area of soil) decreased (Table 3). The leaf area per g of grapes also decreased with an increase in vine spacing. The total interception of radiant energy per hectare vine-

TABLE 2

Effect of vine spacing on the bunch mass, berry mass and yield of Pinot noir/99 Richter. Nietvoorbij, Stellenbosch. 1985/6 - 1989/90.

| Spacing (m) | Bunch mass (g) | Berry mass (g) | Yield/vine (kg) | Yield/$m^2$ leaf area (kg) | Yield/ha (t) |
|---|---|---|---|---|---|
| 1,0 x 0,5 | 94,62 | 1,18 | 0,633 | 0,459 | 12,66 |
| 1,0 x 1,0 | 115,13 | 1,18 | 1,090 | 0,423 | 10,90 |
| 2,0 x 1,0 | 126,80 | 1,23 | 1,842 | 0,436 | 9,21 |
| 2,0 x 2,0 | 124,05 | 1,24 | 2,975 | 0,696 | 7,44 |
| 3,0 x 1,5 | 130,55 | 1,24 | 3,485 | 0,650 | 7,75 |
| 3,0 x 3,0 | 134,89 | 1,23 | 5,701 | 0,793 | 6,33 |
| D-value ($p \leq 0,05$) | 31,41 | ns | 0,601 | 0,190 | 2,17 |

ns = non-significant.

TABLE 3
Effect of vine spacing on some canopy characteristics of Pinot noir/99 Richter. Nietvoorbij, Stellenbosch. 1985/86-1989/90.

| Spacing (m) | Leaf area/ vine ($cm^2$) | Leaf index | Lef area/g grapes ($cm^2$) | Canopy density (LLN) |
|---|---|---|---|---|
| 1,0 x 0,5 | 15465 | 3,09 | 27,06 | 1,26 |
| 1,0 x 1,0 | 27087 | 2,71 | 25,66 | 1,91 |
| 2,0 x 1,0 | 44139 | 2,21 | 23,92 | 1,92 |
| 2,0 x 2,0 | 48047 | 1,20 | 16,27 | 3,93 |
| 3,0 x 1,5 | 59182 | 1,31 | 16,25 | 5,51 |
| 3,0 x 3,0 | 74162 | 0,82 | 13,26 | 6,20 |
| D-value ($p \leq 0,05$) | 6752 | 0,86 | 6,272 | 0,914 |

TABLE 4
Effect of vine spacing on grape composition of Pinot noir/99 Richter. Nietvoorbij, Stellenbosch. 1985/86-1989/90.

| Spacing (m) | Sugar concentration (°B) | Acid concentration TTA (g/l) | pH | Delayed harvest* | |
|---|---|---|---|---|---|
| | | | | TTA (g/l) | pH |
| 1,0 x 0,5 | 23,92 | 8,60 | 3,04 | - | - |
| 1,0 x 1,0 | 24,03 | 8,65 | 3,08 | - | - |
| 2,0 x 1,0 | 23,60 | 8,84 | 3,09 | - | - |
| 2,0 x 2,0 | 22,42 | 9,49 | 3,09 | 7,92 | 3,29 |
| 3,0 x 1,5 | 22,48 | 9,44 | 3,10 | 7,81 | 3,32 |
| 3,0 x 3,0 | 22,06 | 9,41 | 3,09 | 7,57 | 3,37 |
| D-value ($p \leq 0,05$) | 0,79 | 0,42 | ns | 0,50 | 0,07 |

ns - non-significant.
* D-value calculated between original data for closer spacings and new data for wider spacings.

yard was impaired by the small, heterogeneous nature of the leaf surface of the wider spacings. The closer spaced vines on the other hand, had a definite advantage because of a more homogeneous arrangement and a higher leaf index resulting in a higher leaf area:fruit mass ratio. Furthermore, the closer spaced vines had a lower leaf layer number (LLN) than the wider spaced vines (Table 3), indicating better canopy density properties than wider spaced vines. The better microclimatic conditions thus obtained probably ensured better ripening conditions than was the case with wider spaced vines. With a decrease in vine spacing, under the conditions of this experiment, thinner, vertical canopies were obtained which resulted in a more homogeneous leaf surface per unit area of land, while leaves and grapes were better exposed to ambient factors.

**Grape and wine quality:** The sugar concentration, acid concentration and pH of grapes from the different vine spacing treatments are given in Table 4. The measurements were made when the grapes from the closer spaced treatments reached optimum maturity (approx. 23°B). The advantage of the closer spacings in terms of homogeneity of leaf surface and leaf area:fruit mass relationships was expressed in higher sugar concentration which was associated with earlier ripening. As could be expected, the grapes from the wider spaced vines - with their denser canopies - had a higher acid concentration than the grapes from the closer spaced vines (Table 4) at the stage when the latter were harvested.

The grapes on the wider spaced vines were left until ca. 23,5°B was reached and again analysed for sugar and acid

TABLE 5
Effect of vine spacing on the colour expression of grapes and wine and on wine quality of Pinot noir/99 Richter. Nietvoorbij, Stellenbosch. 1985/86-1989/90.

| Spacing (m) | Skin colour 520 nm | Wine colour 520 nm | Wine colour 420 nm | Wine quality (%) |
|---|---|---|---|---|
| 1,0 x 0,5 | 0,287 | 2,008 | 1,503 | 64 |
| 1,0 x 1,0 | 0,244 | 1,539 | 1,203 | 63 |
| 2,0 x 1,0 | 0,255 | 1,655 | 1,107 | 69 |
| 2,0 x 2,0 | 0,169 | 1,383 | 1,014 | 56 |
| 3,0 x 1,5 | 0,153 | 1,243 | 0,917 | 52 |
| 3,0 x 3,0 | 0,133 | 1,010 | 0,902 | 46 |
| D-value ($p \leq 0,05$) | 0,096 | 0,187 | 0,284 | 8,4 |

concentration as well as pH. Significant differences in acid concentration and pH occurred (Table 4). At this stage the acid concentration in grapes from wider spaced vines was lower and the pH higher than was the case with the grapes harvested earlier. The higher pH probably originated from the more dense canopies of the wider spaced vines. Smart (1987) and Smart, Smith & Winchester (1988) reported that an increase in the pH of grapes ripening in shade might be ascribed to the inhibition of phytochrome-driven enzyme reactions. Because of the large differences in canopy densities of the different spacing treatments (see LLN in Table 3), grapes on the wider spaced vines ripened in denser shade than grapes from closer spaced vines.

The effect of vine spacing on the colour expression of grapes and wine is presented in Table 5. The closer spaced vines produced grapes with better colour than the wider spaced vines for all five seasons. This skin colour advantage resulted in better coloured wines at both 520 nm and 420 nm. Red wine production from Pinot noir grapes is still an intriguing problem for winemakers in most New World countries mainly because sufficient colour is difficult to obtain (Lacasia, 1980). The positive effect of closer vine spacing on both grape and wine colour for this cultivar may have an advantage especially in warmer wine countries.

Insufficient colour production in grapes is mainly due to negative shade effects created in too dense canopies (Rojas-Lara & Morrison, 1989). The high canopy densities of the wider spacings (Table 3) created within-canopy shade (Archer & Strauss, 1990) which impeded colour development in the grapes. On the other hand, the better exposed grapes of the closer spaced treatment plots developed a higher sugar concentration as well as better colour which eventually resulted in better overall wine quality (Table 5). The closer spaced treatment plots produced better wine over all five seasons during which wine was made. This quality advantage arose from better canopy characteristics, on the one hand (Table 3), and the qualitative effects of stress physiology, on the other hand (Archer & Strauss, 1990). Furthermore, a similar leaf area had to ripen fewer grapes in the case of closer spaced vines than in the case of wider spaced vines.

## CONCLUSIONS

Shoot growth per vine was decreased and shoot growth per hectare was increased by closer vine spacing. This could be expected because vine size was reduced by a smaller soil volume available to closer spaced vines. The closer spaced, smaller vines had a detectable advantage over larger, wider spaced vines in terms of homogeneity of leaf covering per hectare as well as canopy density per vine. Furthermore, the closer spaced vines had to ripen fewer grapes per unit leaf area than wider spaced vines. This brought about a definite quantitative and qualitative yield advantage for closer spaced vines. Although the yield per vine increased nine-fold from the narrowest to widest spacing, the yield per hactare decreased two-fold. It is not certain that these advantages will be enough to cover higher material costs per hectare in the case of 20 000 vines per hectare.

Wine quality was improved by narrower vine spacings mainly because of better colour and lower pH. These originated from better canopy characteristics producing less shaded leaves and bunches. These advantages would be expected to hold true for all conditions similar to those of the experiment. More fertile conditions will alter the results obtained with this experiment mainly because of the more vigorous vegetative growth and dense canopies, giving rise to a decline in fruit and wine quality with closer spacings.

Where viticulture is practised under relatively poor growing conditions, closer vine spacing may have important economical advantages for the wine farmer. These advantages are brought about through higher yield per hectare as well as better wine quality. For conditions similar to those under which this trial was conducted, a vine spacing resulting in between 1,0 $m^2$ and 2,0 $m^2$ soil surface per vine is feasible.

**LITERATURE CITED**


ANONYMOUS, 1907. Manuel du viticulteur. Neuchatel, Impr. Attinger, Attinger Frères, Neuchatel.

ARCHER, E. & STRAUSS, H.C., 1985. Effect of plant density on root distribution of three-year-old grafted 99 Richter grapevines. *S. Afr. J. Enol. Vitic.* **6,** 25-30.

ARCHER, E. & STRAUSS, H.C., 1989. The effect of plant spacing on the water status of soil and grapevines. *S. Afr. J. Enol. Vitic.* **10,** 49-58.

ARCHER, E. & STRAUSS, H.C., 1990. The effect of vine spacing on some physiological aspects of *Vitis vinifera* L. (cv. Pinot noir). *S. Afr. J. Enol. Vitic.* **11,** 76-87.

ATANASSOV, Y., 1983. Influence de la distance de plantation sur la croissance et la productivité des vignes du cepage Cabernet Sauvignon. *Hort. Vitic. Sci.* **20,** 96-100.

BIOLETTI, F.T. & WINKLER, A.J., 1934. Density and arrangement of vines. *Hilgardia* **8,** 179-195.

BOSWELL, S.B., NAUER, E.M. & ATKIN, D.R., 1982. Effect of tree density on fruit quality, temperature, light penetration, growth and production of old-line "Atwood" navel orange trees. *J. Amer. Soc. Hort. Sci.* **107,** 60-65.

BRANAS, J., 1949. Récherchés sur la densité et la disposition des plantations. *Progrès agric. Vitic.* **66,** 285, 350-369.

BRANAS, J., 1974. Viticulture, Dèhan, Montpellier.

BRAR, S.S. & BINDRA, A.S., 1986. Effect of plant density on vine growth, yield, fruit quality and nutrient status in Perlette grapevines. *Vitis* **25,** 96-106.

BRIGHTWELL, W.T. & AUSTIN, M.E., 1975. Influence of plant spacing on yield of Muscadine grapes. *J. Amer. Soc. Hort, Sci.* **100,** 374-376.

CASTERAN, P., CARBONNEAU, A. & LECLAIR, P., 1980. Structure de populations de vigne: Analyse des phénomènes de compétition entre plants. *Vitis* **19,** 121-133.

CAZENAVE, A., 1889. Manuel pratique de la culture de la vigne dans la Gironde. 2me éd. G. Masson, 120 boulevard Saint-Germain, Paris.

CHAMPAGNOL, F., 1979. La densité de plantation en viticulture. *Progrès agric, Vitic.* **96,** 185-195.

CHAMPAGNOL, F., 1982. Choix de l'orientation des rangs et de la densité de plantation des vignes. *Progrès agric. Vitic.* **99,** 564-570.

CHAMPAGNOL, F., 1984. Eléments de physiologie de la vigne et de viticulture générale. F. Champagnol, B.P. 13 Prades-le-Lez, 34980 Saint-Gely-du Fesc, France.

D'ARMAILHACQ, A., 1867. De la culture des vignes dans le Médoc. 3me ed. P. Chaumas, Libraire-éditeur, Fossés du Chapeau-Rouge, 34 Bordeaux.

DUMARTIN, P., BONIFACE, J.-C., DUCASSE, R., CASSIGNARD, R., BARRERE, R., ARTIGAU, J., CORDEAU, J. & PRADIER, L., 1982. Essais de densité de plantation en Médoc. *Vignes & Vins* **312,** 3-6.

GAGNON, A.J., 1973. Effect of vine spacing: An analysis. *Wines & Vines.* Dec.1973, 32-33.

GUYOT, J., 1867. Etude des vignobles de France. Tome 1 (2me ed.). Impr. Nationale, Paris.

HEDBERG, P.R. & RAISON, J., 1982. The effect of vine spacing and trellising on yield and fruit quality of Shiraz grapevines. *Am. J. Enol. Vitic.* **33,** 20-30.

HIDALGO, L. & CANDELA, M.R., 1979. Contribucion al conocimiento de la densidad de plantacion en la zona meridional de la Rioja Baja. *An. Inst. Nac. Invest. Agr. Prod. Veg.* **11,** 191-199.

HUNTER, J.J. & DE LA HARPE, A.C., 1987. The effect of rootstock cultivar and bud load on the colour of *Vitis vinifera* L. cv. Muscat noir (Red Muscadel) grapes. *S. Afr. J. Enol. Vitic.* **8,** 1-5.

HUNTER, D.M., WIEBE, J. & BRADT, O.A., 1985. Influence of spacing on fruit yields and quality of grape cultivars differing in vine vigour. *J. Amer. Soc. Hort. Sci.* **110,** 590-596.

INTRIERI, C., 1987. Experiences on the effect of vine spacing and trellis-training system on canopy micro-climate, vine performance and grape quality. *Acta Hort.* **206,** 69-87.

JAMAIN, P., 1901. La vigne et le vin. Octave Doin (ed). 8, place de l'Odéon, Paris.

JENSEN, F., 1983. The effects of row spacing, variety and trellis on yields of three wine varieties. Unpublished Report, Ext. Off. Parlier.

KAMEL, A., RIFAY, A.-E.-H. & ABDEL-KAWI, A.E.-S., 1972. The effect of spacing on the yield and vigour of grapevine. *Agric. Res. Rev.* **50,** 43-49.

KOBLET, W., 1977. Translocation des produits de la photosynthése dans la vigne. Proc. Int. Sym. on the Quality of the Vintage. 14 - 21 Feb. 1977, Cape Town. pp. 45-52.

LACASIA, R., 1980. Pinot noir: a tough one to grow. *Wines & Vines.* Sept., 28-29.

LAYNE, R.E.C., TAN, C.S. & FULTON, J.M., 1981. Effect of irrigation and tree density on peach production. *J. Amer. Soc. Hort. Sci.* **106,** 151-156.

LIUNI, C.S., ANTONACCI, D. & COLAPIETRA, M., 1985. Influenza esercitata dal numero dei ceppi per ettaro e dalla disponibilita irrigua sulla produzione della vite nell'ambiente caldo-arido. *Riv. Vitic. Enol. Conegliano* **3,** 150-162.

MACVICAR, C.N., *et al.,* 1977. Soil classifiaction. A binomial system for South Africa. S.I.R.I., Dept, A.T.S., Pretoria.

MALAN, A.H., 1959. Wider espacement of table grapes advisable. *Farming in S.A.* **35,** 19-20.

MICHAILOV, A., 1983. Effect of training system, fruiting wood length and within-row planting distance on yield, leaf size and leaf area productivity in the grapevine cultivar Muscat Ottonel (Bulg.). *Grad. lozar. Nauka* **20,** 92-99.

MORRIS, J.R. & CAWTHON, D.L., 1981a. Effect of vine spacing on yield and juice quality of Concord grapes. *Ark. Farm Res.* **30,** 3.

MORRIS, J.R. & CAWTHON, D.L., 1981b. Effect of soil depth and in-row vine spacing on yield and juice quality in a mature Concord vineyard. *J. Amer. Soc. Hort. Sci.* **106,** 318-320.

MUNOZ, H.I., 1982. Efecto de la distancia de plantación sobre el crecimiento y producción del cv. Cabernet Sauvignon (*Vitis vinifera* L.). *Agric. Tec.* **42,** 303-308.

MURISIER, F. & SPRING, J.-L., 1986. Influence de la hauteur du tronc et de la densité de plantation sur le comportement de la vigne. *Rev. Suisse Vitic. Arboric. Hort.* **18,** 221-224.

NEUKOMM, H., 1984. Optimaler Pflanzabstand bei Reben. *Schweiz. Zeitschr. Obst. Weinb.* **120,** 491-492.

PARKS, W.L. & MANNING, C.D., 1980. The effect of row spacing and plant population on the fruiting characteristics and yield of four soybean varieties. *Tennessee Farm Home Sci.* **115,** 6-7.

PEROLD, A.I., 1927. Treatise on viticulture. Pro Ecclesia, Stellenbosch.

RAVAZ, L., 1908. Influence des opérations culturales sur la végétation et la production de la vigne. *Ann. E.N.A. Montp.* **8,** 232-291.

RAVAZ, L., 1935. Les facteurs de la qualité et les pratiques culturales. *Progres agric. Vitic.* **47,** 489-494.

REMOUE, M. & LEMAITRE, C., 1985. Comparaison de différentes densités de plantation et methodes de culture du sol. *Conn. Vigne Vin.* **19,** 197-206.

REYES, J.L. & KARCZ, B., 1981. Atlas densidades de plantacion en los cultivares de vid Carignane, Grenache y Bola Dulce en la comarca lagunera. *Agric. Tec. Mex.* **7,** 51-64.

ROJAS-LARA, B.A. & MORRISON, J.C., 1989. Differential effects of shading fruit or foliage on the development and composition of grape berries. *Vitis* **28,** 199-208.

SAAYMAN, D. & VAN HUYSSTEEN, L., 1981. Grondvoorbereiding. In: BURGER, J.D. & DEIST, J. (eds.). Wingerdbou in Suid-Afrika, VORI, 7600 Stellenbosch, Republic of South Africa. pp. 120-140.

SAURE, M.C., 1985. Dormancy release in deciduous fruit trees. *Hort. Rev.* **7,** 239-300.

SHAULIS, N. & KIMBALL, K., 1955. Effect of plant spacing on growth and yield of Concord grapes. *J. Amer. Soc. Hort. Sci.* **66,** 192-200.

SISSON, R., 1959. Yield and quality response of some respaced North Coast vineyards. *Am. J. Enol. Vitic.* **1,** 44-47.

SMART, R.E., 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. A review. *Am. J. Enol. Vitic.* **36,** 320-239.

SMART, R.E., 1987 Influence of light on composition and quality of grapes. *Acta Hort.* **206,** 37-47.

SMART, R.E., SMITH, S.M. & WINCHESTER, R.V., 1988. Light quality and quantity effects on fruit ripening for Cabernet Sauvignon. *Am. J. Enol. Vitic.* **39,** 250-258.

STOEV, K. & BONDJOUKOV, D., 1974. Influence de la densité de plantation des vignes du cepage Cabernet Sauvignon, conduites en formation haute, sur la recolte et la croissance des rameaux herbaces. *Hort. Vitic. Sci.* **11,** 83-92.

TURKINGTON, C.R., PETERSEN, J.R. & EVANS, J.C., 1980. A spacing, trellising and pruning experiment with Muscat Gordo Blanco grapevines. *Am. J. Enol. Vitic.* **31,** 298-302.

WIEBE, J. & BRADT, O.A., 1973. Fruit yields and quality in the early years of a grape spacing trial. *Can. J. Plant Sci.* **53,** 153-156.

WINKLER, A.J., 1959. The effect of vine spacing at Oakville on yields, fruit composition and wine quality. *Am. J. Enol. Vitic.* **10,** 39-43.

WINKLER, A.J., 1969. Effect of vine spacing in an unirrigated vineyard on vine physiology, production and wine quality. *Am. J. Enol. Vitic.* **20,** 7-15.