Plant Spacing Implications for Grafted Grapevine II. Soil Water, Plant Water Relations, Canopy Physiology, Vegetative and Reproductive Characteristics, Grape Composition, Wine Quality and Labour Requirements

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***Vitis vinifera* L. cv. Pinot noir vines grafted onto rootstock 99 Richter and grown under six plant spacings (3 x 3 m; 3 x 1,5 m; 2 x 2 m; 2 x 1 m; 1 x 1 m; 1 x 0,5 m) were investigated in terms of canopy dimension and microclimate, soil conditions, canopy physiology, vegetative and reproductive growth characteristics, grape composition, wine quality and labour input. Vines were pruned to six buds/m^2 soil surface and supplementary irrigated just after pea berry size and véraison stages. The number of leaf layers, light intensity and air flow generally decreased with closer spacing, whereas relative humidity increased. In contrast to the virtually stable, albeit lower, soil water content of closer-spaced vines, that of wider spacings noticeably decreased from véraison to ripeness. This may be ascribed to the almost continuous seasonal shading of the soil in the case of the narrower spacings, and the generally higher soil temperatures found for the wider spacings. Leaf and bunch water potentials of both wider- and closer-spaced vines decreased during the ripening period. Bunches were more sensitive to water stress. Leaf and bunch water potential coincided with soil water content. The lower photosynthetic activity of closely spaced vines was accompanied by increased transpirational water loss and is mainly ascribed to less favourable canopy microclimate. Despite the supplementary irrigation and slight differences in leaf water potential between spacings, wider-spaced vines apparently grew under less water stress during the ripening period. This was also evident from leaf xylem sap abscisic acid levels at ripeness. Shoot, leaf and berry growth rates apparently increased with narrower spacing, whereas total leaf area per vine decreased. Fresh berry mass of narrow-spaced vines was, however, slightly lower at ripeness. Budding of narrow spacings increased, whereas fertility and bunch mass were reduced, resulting in decreased yield per vine. Optimum berry set and yield per hectare occurred for medium-spaced vines (2 x 2 m, 2 x 1 m); this was also evident on a m^2 soil surface basis. Leaf area per fresh mass of widely spaced vines (3 x 3 m, 3 x 1,5 m) was much lower than the generally required 10 - 12 cm^2 and points to overcropping. Musts of widely spaced vines had less soluble solids and titratable acidity, whereas must pH increased progressively from widely to closely spaced vines. It would seem that widely spaced vines were overcropped due to low cultivar vigour and/or low yielding capacity of the soil, eventually affecting ripening. Grapes from medium-spaced vines had higher anthocyanin levels in the skin. Sensorially, wines made from closer spacings (2 x 2 m, 2 x 1 m, 1 x 1 m, 1 x 0,5 m) scored distinctly higher than those from widely spaced vines. Although yield per hectare was higher, closely spaced vines (1 x 1 m, 1 x 0,5 m) needed significantly higher inputs for canopy management, harvesting and pruning. Considering land utilisation, vine performance, wine quality as well as labour input, medium-spaced vines (2 x 2 m; 2 x 1 m) performed optimally.**

It is generally accepted that the spacing of grapevines may have far-reaching implications for physiological, vegetative and reproductive performance, grape composition, and eventually wine quality (Archer & Strauss, 1990 and references therein; Reynolds, Wardle & Naylor, 1995). Although the choice of a plant spacing may initially be dependent on soil physical and chemical properties, the shape and size of foliage walls, and in particular the number, distribution and exposure of individual leaves, will ultimately also dictate the extent to which a chosen spacing will meet yield and quality requirements (Smart, 1973; Shaulis, 1980). Along with

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training and trellising system, plant spacing has proved to be an effective tool in the accommodation of vigour through an increase in cordon/canopy length, which improves both leaf and fruit microclimate and enhances the even ripening of fruit (Shaulis, 1980; Smart, 1985; Reynolds *et al.*, 1995).

Studies under dryland (Archer & Strauss, 1985, 1989, 1990) and irrigated (Reynolds *et al.*, 1995; Hunter, 1998) conditions showed that plant spacing impacts directly on major physiological processes and is crucial in the optimal utilisation of available soil volume and solar energy. Soil water depletion was found to be a very important regulator of plant performance, particularly under high planting densities. A reduction in water supply was associated with a decrease in photosynthetic rate (Rodriques *et al.*, 1993; Naor, Bravdo & Gelobter, 1994; Naor & Wample, 1994), an inhibition in shoot elongation (Hofäcker, 1977; Van Zyl, 1984; Naor & Wample, 1996) and leaf expansion (Schultz & Matthews, 1993), and berry contraction during the pre-véraison phase (Greenspan, Shackel & Matthews, 1994). Furthermore, dense canopies are created when the number of shoots and the ratio of shoot growth to available soil and spatial growth volume are too high. This was shown to result in interior-canopy shade (Smart, 1985), which is detrimental to photosynthetic activity (Hunter & Visser, 1988), yield, grape composition and wine quality (Smart *et al.*, 1985; Hunter *et al.*, 1995). On the other hand, available land resources will be under-exploited and sub-economic end-product obtained when low vigour is accommodated in excessive growth volumes. Correct plant spacing is therefore of the utmost importance to ensure the utilisation of soil volume to such an extent that the best possible economic benefit can be obtained in terms of yield, grape and wine quality, and labour input.

In an accompanying paper the effect of plant spacing on aboveground and subterranean growth, dry matter partitioning, and dry matter composition was reported (Hunter, 1998). In this paper, the physiological, vegetative and reproductive response of a mature, supplementary irrigated *Vitis vinifera* L. cv. Pinot noir/99 Richter vineyard to different plant spacings on a medium-potential soil is addressed. Effects on soil and plant water relations, wine quality and labour required for pruning, harvesting and canopy management practices are also reported.

MATERIALS AND METHODS

Vineyard and treatments: A 14-year-old *Vitis vinifera* L. cv. Pinot noir (clone BKV)/99 Richter (clone 1/30/1) vineyard on a Glenrosa soil (Soil Classification Working Group, 1991) was used. Before the vines were established, the soil was deep delved in two directions to a depth of 1 m using a wing plough. The vines were planted in an East-West direction and spaced (between-row/in-row) 3,0 x 3,0 m, 3,0 x 1,5 m, 2,0 x 2,0 m, 2,0 x 1,0 m, 1,0 x 1,0 m, 1,0 x 0,5 m. They were trained to a five-strand hedge and spur pruned to six buds/m^2 soil surface area. Over the last five years of the experiment, supplementary irrigation (50 mm) was applied just after pea size and véraison stages, respectively (dryland prior to that - Archer & Strauss, 1985). A cover crop (rye) was sowed between the rows in autumn and killed with a herbicide before bud break. The treatments and five replicates were completely randomised (Hunter, 1998).

Measurements:

Soil conditions: Soil water was measured gravimetrically at three soil depths (0 - 30 cm; 30 - 60 cm; 60 - 90 cm) and at four developmental stages (berry set; pea berry size; véraison; ripeness). Soil temperature was measured weekly from véraison by means of a data-logger.

Canopy physiology: Photosynthetic activity (mg CO_2/dm^2/h) and rate of transpiration (µg H_2O/cm^2/s) of basal leaves just above the bunch zone were measured from mid-morning until midday using a portable photosynthesis meter (ADC) as described by Hunter & Visser (1988). Three leaves were measured per replicate. Leaf and bunch water potential were determined from early afternoon until mid-afternoon using a Scholander pressure chamber (Scholander *et al.*, 1965). Mature leaves fully exposed to the sun were excised from just above the bunch zone. Leaf petioles and bunch stems were re-cut with a scalpel before insertion into the chamber within one minute of removal of leaves/bunches. Three leaves were removed per replicate. Exudate pressed from the leaves was collected with a pasteur pipette and the physiologically active 2-*cis*-(S)-form of the endogenous plant growth regulator, abscisic acid, determined by means of a monoclonal antibody radioimmunoassay technique (Mertens, Deus-Neumann & Weiler, 1983). The exudate was assumed to be representative of xylem sap (cf. also Lang & Düring, 1991).

Canopy dimension and microclimate: The number of leaf layers and canopy width were determined just above the bunch zone according to the point quadrat principle of Smart *et al.* (1985) whereby a thin steel rod is passed horizontally through the canopy and the number of leaves contacted and the width of the canopy recorded. Five canopies were measured on a random basis per replicate and three random passes made per canopy. Photosynthetically active radiation was measured using a Li-Cor Line Quantum Sensor from mid-morning inside as well as outside the canopy and results expressed as % of ambient. Air flow and temperature inside the canopy were measured using a Kane-May 4003 thermoanemometer and relative humidity with a Kane-May 8000 humidity meter. All microclimate measurements were taken just above the bunch zone. Three canopies were measured per replicate. *Physiological* and *microclimate* measurements in the canopy were conducted on the same day and at the different developmental stages mentioned above. In order to determine the vine-spacing effect on shading of between-row soil, and adjacent and opposite vines, shade patterns of representative canopies of the different treatments were measured hourly from 08:00 until 16:30 at the different developmental stages.

Vegetative characteristics: Main shoot length was measured weekly from budding on one vine per replicate. Total leaf area per shoot was measured using a Li-Cor Li 3100 area meter at the different developmental stages; the number of leaves was also recorded.

Reproductive characteristics: Fruitfulness (the number of bunches per number of shoots originating from buds allocated during pruning) as well as budding percentage (number of shoots/number of buds allocated during pruning x 100) were determined at ripeness on all vines. The number of berries per bunch, bunch mass, and total yields were also determined. Fresh and dry (freeze-dried) berry mass were determined fortnightly from pea berry size on one shoot per replicate. Grapes of all treatments were harvested on the same day.

Grape composition: At ripeness, soluble solids, titratable acidity, and pH of the must were determined on a random sample per replicate, according to standard ARC-Nietvoorbij methods. Total anthocyanins of the ripe grape skin were analysed as reported by Hunter, De Villiers & Watts (1991).

Winemaking: Wines were made according to standard ARC-Nietvoorbij procedures. Grapes of replicates 1 and 2, and those of replicates 3,4 and 5, respectively, were combined.

Wine quality: Wines were sensorially evaluated by a trained panel of 12 judges. The acceptability of the wine colour, acidity, hardness and body, as well as total aroma intensity and overall wine quality were evaluated on a percentage basis.

Labour input: The man hours needed for suckering (removal of shoots not located on spurs at 30 cm length), shoot positioning (positioning of shoots in line with spurs twice during the season), topping (just after pea size of all shoots growing in excess of 30 cm above the top wire), harvesting and pruning were recorded.

Statistics: Mean values of 1993/94 and 1994/95 seasons are presented. Significant differences were determined using Student's t-LSD test.

RESULTS AND DISCUSSION

Canopy dimension and microclimate: A general decrease in the number of leaf layers, light intensity and air flow in the canopy occurred with closer plant spacing (Table 1). Relative humidity, however, increased with narrower spacing. The microclimate results can be attributed mainly to the physical between-row spacing. In the case of particularly closely spaced vines (1 x 1 m; 1 x 0,5 m), canopy conditions were more favourable to the occurrence of pests and diseases (Smart *et al.,* 1990; Stapleton & Grant, 1992; Duncan, Stapleton & Leavitt, 1995). This will inevitably lead to a more intensive pest and disease control strategy with greater financial and environmental implications, particularly for graperot-sensitive cultivars and during years when conditions for disease development are optimal.

Soil conditions and canopy physiology: It is evident that soil water of wider-spaced treatments (3 x 3 m, 3 x 1,5 m, 2 x 2 m) noticeably decreased from véraison to ripeness, particularly in deeper soil layers, whereas that of closer-spaced treatments, albeit generally lower, remained relatively stable (Fig. 1). This may partly be attributed to the generally higher soil temperatures of wide - *versus* closer-spaced vines (Fig. 2). The almost continuous shading of between-row soil in closer plantings during the growth season (Fig. 3) may also have prevented excessive evapotranspiration and secured a base level of water. In spite of the above, leaf and bunch water potential of both widely and closely spaced vines decreased during the ripening period, fluctuating more or less in tandem with soil water content (Figs 4 & 5). Reasonably good relationships between leaf water potential and soil water content of different soil layers were found at véraison (Fig. 6); at ripeness these relationships were poor (Fig. 7). The opposite situation occurred for bunch water potential (Figs 8 & 9). In all cases the poorest relationships were found for the shallowest soil layer (0 - 30 cm). The relationship between leaf and bunch water potential was poor at véraison, but reasonably good at ripeness (Fig. 10). Prior to véraison, no differences in water potential were found between spacings (data not shown). During the ripening period differences in leaf water potential were also slight, whereas differences in bunch water potential were more accentuated, particularly at ripeness (Figs 4 & 5). The leaf water potential values of approximately -800 kPa to -1250 kPa found in this study are higher than those reported by Archer & Strauss (1990) under dry land conditions over the midday period and would seem to indicate that the vines were not severely water-stressed. The data nevertheless indicate that despite the supplementary irrigation and slight differences in leaf water potential between spacings, wider-spaced vines generally grew under less water stress than closely spaced vines during the ripening period (cf. also Archer & Strauss, 1990). This is confirmed by the significantly higher abscisic acid levels that occurred in the xylem sap of closely spaced vines at ripeness (Fig. 11). Elevated levels of abscisic acid are known to be associated with water limitation and stomatal closure (Loveys & Kriedemann, 1974).

Given the slight differences in leaf water potential (Fig. 4), the lower light intensity, decreased air flow and higher humidity in the canopies of closer-spaced vines (Table 1) could have largely contributed to their decreased photosynthetic activity (Fig. 12)(cf. also Hunter & Visser, 1988; Hunter *et al.,* 1995). Although water stress has an obvious detrimental effect on photosynthesis (cf. Liu *et al.,* 1978; Rodriques *et al.,* 1983; Naor *et al.,* 1994; Naor & Wample, 1994), it can be reasoned that that was not the major regulating mechanism in this case, but that photosynthetic activity was primarily affected by canopy microclimate. Photosynthetic activity of closer-spaced vines (2 x 1 m; 1 x 1 m; 1 x 0,5 m) was accompanied by progressively increased transpirational water loss, which would have impacted directly on water relations (Fig. 13). Good relationships between photosynthetic activity and soil water content of different soil layers were found at véraison, but evidently not at ripeness (Figs 14 & 15). The data collectively indicate that leaf turgor of closely spaced vines was largely maintained, despite the obvious physiological stress experienced by these vines, as indicated by the decrease in bunch water potential at ripeness (Fig. 5) and increase in leaf abscisic acid levels in particular (Fig. 11). It seems, therefore, that carbon assimilation of vines in this study was largely independent of the osmotic status of the leaf. Similar results were reported by Rodrigues *et al.* (1993). It is also possible that the effects of canopy microclimate were highlighted by the mild water stress and *vice versa.* According to Osório *et al.* (1995) mild water deficits have a marginal depressing effect on Photosystem II photochemical efficiency.

The occurrence of a higher density of particularly fine and extension roots in the case of closer-spaced vines (Hunter, 1998), and therefore the possibility of a larger amount of growth regulators in the xylem sap of these vines (Richards, 1983), could also have affected the aboveground response of the vines to environmental factors and the extent of physiological stress experienced. The higher ratio of thin *versus* thick roots in the soil profile of these vines most likely increased the efficiency of the root system to absorb water and withdraw nutrients from a drying soil. It has been suggested that abscisic acid transported from the leaves to the roots may act as part of a system regulating water potentials and ion transport from the roots to the leaves (Cram & Pitman, 1972; Walton, 1980). Davies *et al.* (1986) also suggested that a decrease in water potential around individual roots, and thus root tip turgor, may reduce the synthesis and transport of cytokinins in the roots and that this, in combination with a reduced uptake of nutrients, may act as chemical signal in affecting the physiology of the shoot independently from its hydraulic status.

Vegetative and reproductive growth characteristics: Shoot elongation rates have previously been found to be sensitive to different soil water regimes (Van Zyl, 1984). Under dryland conditions, shoot elongation rates of closely spaced Pinot noir vines decreased during the last three weeks of ripening at afternoon leaf water potentials of -1200 to -1400 kPa (Archer & Strauss, 1990). Naor & Wample (1996) found internode growth rates to be negatively correlated with shoot stem water potential and suggested that a stem water potential of -750 kPa can be considered as threshold for a decline in shoot elongation rate of Concord grapevines. In this study, afternoon leaf water potentials of up to -1250 at ripeness (Fig. 4) did not affect shoot elongation rates of closely spaced vines (Fig. 16). In fact, shoot elongation rates of closer-spaced vines appeared higher than those of wider-spaced vines. It therefore seems that the reaction of the vines may rather be ascribed to undercropping or overcropping of the respective treatments. A similar tendency occurred for leaf area per shoot (Fig. 17) and area per leaf (Fig. 18); total leaf area/vine, however, still decreased with closer spacing (Fig. 19). According to Patakas, Noitsakis & Stavrakas (1997) the cell wall elasticity of young leaves enables vines to maintain a positive pressure in cells, thereby sustaining enlargement and hence plant growth under mild water stress conditions. Furthermore, a decrease in water potential of mature leaves may help to maintain water uptake from drying soil.

Evidently, the berries of closer-spaced treatments (2 x 2 m, 2 x 1 m, 1 x 1 m, 1 x 0,5 m) had comparatively higher dry mass than those of widely spaced treatments at least up to two weeks before ripeness (Fig. 20). At ripeness fresh berry mass of closer spacings (2 x 1 m, 1 x 1 m, 1 x 0,5 m) was slightly lower (Fig. 21), corresponding to their more negative bunch water potentials (Fig. 5). Given the fact that leaves and fruit compete for water, a higher solid:water ratio in the berry indicates more efficient translocation of assimilates to the berry, berry response to lower vine water status and/or dehydration of the berry, but may also point to a more favourable leaf area:fruit mass ratio. Although mechanisms such as berry transpiration, hydration of the berry at a lower rate than in "non-stressed" vines, and xylem backflow from the berry to the rest of the vine, resulting in berry contraction, are recognised as being involved in the dehydration of the berry, Greenspan *et al.*

TABLE 1

Vine-spacing effect on canopy dimension and microclimate at ripeness.

Spacing (m)	Number of leaf layers	Canopy width (cm)	Light intensity (% of ambient)	Air flow (cm/s)	Relative humidity (%)	Temperature (°C)
3 x 3	3,6 ab	39 a	12,4 ab	26 a	33 b	35 a
3 x1,5	3,8 a	40 a	11,5 b	22 ab	35 ab	33 a
2 x 2	3,3 b	39 a	16,5 a	20 ab	33 b	35 a
2 x 1	3,5 ab	37 a	9,5 b	20 ab	34 ab	34 a
1 x 1	3,3 ab	38 a	11,2 b	18 b	37 a	33 a
1 x 0,5	3,3 b	38 a	7,9 b	19 b	38 a	34 a

Values in columns followed by the same letter do not differ significantly ($p \leq 0,05$)

TABLE 2

Vine-spacing effect on reproductive growth parameters.

Spacing (m)	Budding (%)	Fertility index	Berries set/bunch	Bunch mass (g)	Yield/ vine (kg)	Yield (t/ha)	Yield/m^2 soil surface	Leaf area (cm^2)/fresh mass (g) grapes
3 x 3	79,44 c	1,98 a	83,35 b	109,20 a	10,34 a	11,49 c	1,15	7,84
3 x 1,5	91,66 bc	2,02 a	98,95 ab	123,00 a	5,76 b	12,81bc	1,28	7,14
2 x 2	102,78 bc	1,80 a	100,08 ab	107,20 a	5,55 b	13,88 b	1,39	8,53
2 x 1	110,68 b	1,86 a	108,95 a	114,75 a	2,78 c	13,92 b	1,39	9,07
1 x 1	172,80 a	1,76 a	96,50 ab	98,80 a	1,91 d	19,08 a	1,91	10,24
1 x 0,5	185,40 a	1,62 a	88,96 ab	99,80 a	0,88 e	17,60 a	1,76	19,46

Values in columns followed by the same letter do not differ significantly ($p \leq 0,05$).

(1994) suggested a loss in xylem conductance to be the more obvious explanation during the post-véraison period; this can to a certain extent be balanced by increased phloem conductance. Nevertheless, since the closer-spaced vines in this study were not unduly water-stressed during the pre-véraison period (data not shown) and the diurnal contraction of post vérasion berries displayed a marked resistance to water deficit (Greenspan *et al.*, 1994), berry response at ripeness could have been a normal reaction to inherently lower vine water status. Competition for water between the berries and the shoots could also have contributed to a decline in water content of the berries of closer spacings. Shoots continued to grow during this period (Fig. 16).

Although budding was significantly increased, fertility and bunch mass of closely spaced vines (1 x 1 m, 1 x 0,5 m) were seemingly reduced, resulting in decreased yield per vine, and indicating that the vines were subjected to cumulative stress (Table 2). Yield per hectare still increased with closer spacing (Table 2). However, at medium spacing, more or less stable values occurred, indicating optimum yield per hectare for medium-spaced vines (2 x 2 m, 2 x 1 m). This was also found on a m^2 soil surface basis and corresponds to cane and root mass as well as total vine dry mass results (Hunter, 1998). Leaf area/fresh mass of the widely spaced vines (3 x 3 m, 3 x 1,5 m) was much lower than the 10 - 12 cm^2 generally required to adequately ripen one gram of fruit (Hunter & Visser, 1990 and references therein) (Table 2) and again indicates that these vines were most likely overcropped under the conditions of the experiment.

Grape composition: Musts of widely spaced vines had less soluble solids and titratable acidity, whereas must pH increased progressively from widely to closely spaced vines (Table 3). Considering the differences in fresh berry mass between spacings (Fig. 21), it is evident that the lower soluble solid contents in musts of widely spaced vines cannot solely be ascribed to the slightly higher water status of the berries at ripeness. It would rather seem that, despite the generally better soil and plant water status, canopy microclimate and photosynthetic activity, the widely spaced vines were overcropped; possible reasons are inherently low cultivar vigour, and/or low yielding capacity of the soil, which resulted in these vines being unable to sufficiently support high vigour and crop loads under the cultural conditions of the experiment, eventually leading to delayed ripening. Qualitatively, berries of closer spacings (2 x 2 m, 2 x 1 m, 1 x 1 m, 1 x 0,5 m) had higher anthocyanin contents in the skin (Table 3). Despite their slightly lower fresh mass, the quantitative anthocyanin content in the skin was also higher. Furthermore, since the skin to pulp ratio is inversely related to berry size, colour extraction would increase during pressing of these grapes. This would be a big advantage in the case of Pinot noir vinification in particular.

Wine quality: Sensorial evaluation of the acceptability of the colour, acidity, hardness and body as well as total aroma intensity and overall quality showed that the wines made from grapes of closer-spaced vines (2 x 2 m, 2 x 1 m, 1 x 1 m, 1 x 0,5 m) were distinctly better than those made from grapes of widely spaced vines, irrespective of indicator (Table 4).

TABLE 3
Vine-spacing effect on grape and must composition.

Spacing (m)	Soluble solids (°B)	Titratable acidity (g/l)	pH	Antho-cyanin (A_{520})	Anthocyanin (mg/g dry skin mass)	Antho-cyanin (mg/skin)
3 x 3	21,72 d	7,38 bc	3,07 d	2,07 cd	4,14 cd	0,36 c
3 x 1,5	22,79 c	7,39 bc	3,15 c	1,97 d	3,94 d	0,33 c
2 x 2	23,66 ab	7,05 c	3,20 c	2,45 bc	4,91 bc	0,47 ab
2 x 1	23,33 bc	7,89 a	3,25 b	2,64 b	5,29 b	0,41 bc
1 x 1	23,48 abc	7,53 ab	3,28 ab	2,35 bcd	4,71 bcd	0,39 bc
1 x 0,5	24,16 a	7,71 ab	3,31 a	3,12 a	6,24 a	0,53 a

Values in columns followed by the same letter do not differ significantly ($p \leq 0{,}05$).

TABLE 4
Vine-spacing effect on wine quality.

Spacing (m)	% Acceptability				Total aroma intensity (%)	Overall quality (%)
	Colour	Acidity	Hardness	Body		
3 x 3	71,8 c	82,5 b	77,5 a	63,4 b	61,0 b	54,8 c
3 x1,5	72,8 c	83,4 ab	77,3 a	59,9 b	61,5 b	53,0 c
2 x 2	86,2 b	90,6 ab	80,3 a	73,9 a	65,3 ab	62,0 b
2 x 1	89,3 ab	90,7 ab	79,7 a	76,5 a	69,3 ab	69,6 a
1 x 1	94,0 ab	92,3 a	83,4 a	81,2 a	71,9 a	68,8 a
1 x 0,5	94,2 a	90,9 ab	80,3 a	80,7 a	73,2 a	70,3 a

Values in columns followed by the same letter do not differ significantly ($p \leq 0{,}05$).

Labour input: Calculating labour input for canopy management, harvesting and pruning, it was evident that closely spaced vines (1 x 1 m, 1 x 0,5 m) needed significantly higher input on a man hours per hectare basis for each practice, whereas the rest of the spacings were not markedly different (Table 5). This is an important consideration in decisions on planting density. In addition, it may also play a big role in the fixing of selling prices of wine and may push prices above the prevailing market prices in order to recover costs.

TABLE 5

Vine-spacing effect on labour input for canopy management, harvesting and pruning practices (man hours per hectare).

Spacing	Suckering	Shoot positioning	Topping and *shoot positioning	Harvesting	Pruning	Total
3 x 3	39,4 b	25,8 c	7,7 d	109,2 c	49,5 d	231,6
3 x1,5	40,4 b	27,1 c	9,3 d	122,7 bc	54,4 cd	253,9
2 x 2	48,6 b	25,3 c	10,2 d	147,1 b	65,2 c	296,4
2 x 1	58,0 b	34,6 bc	15,4 c	144,4 bc	67,5 c	319,9
1 x 1	106,4 a	56,4 b	22,8 b	206,1 a	104,2 b	495,9
1 x0,5	128,2 a	91,5 a	31,1 a	239,5 a	122,6 a	612,9

Values in columns followed by the same letter do not differ significantly ($p \leq 0{,}05$).

*The second shoot positioning was done along with topping just after pea berry size.

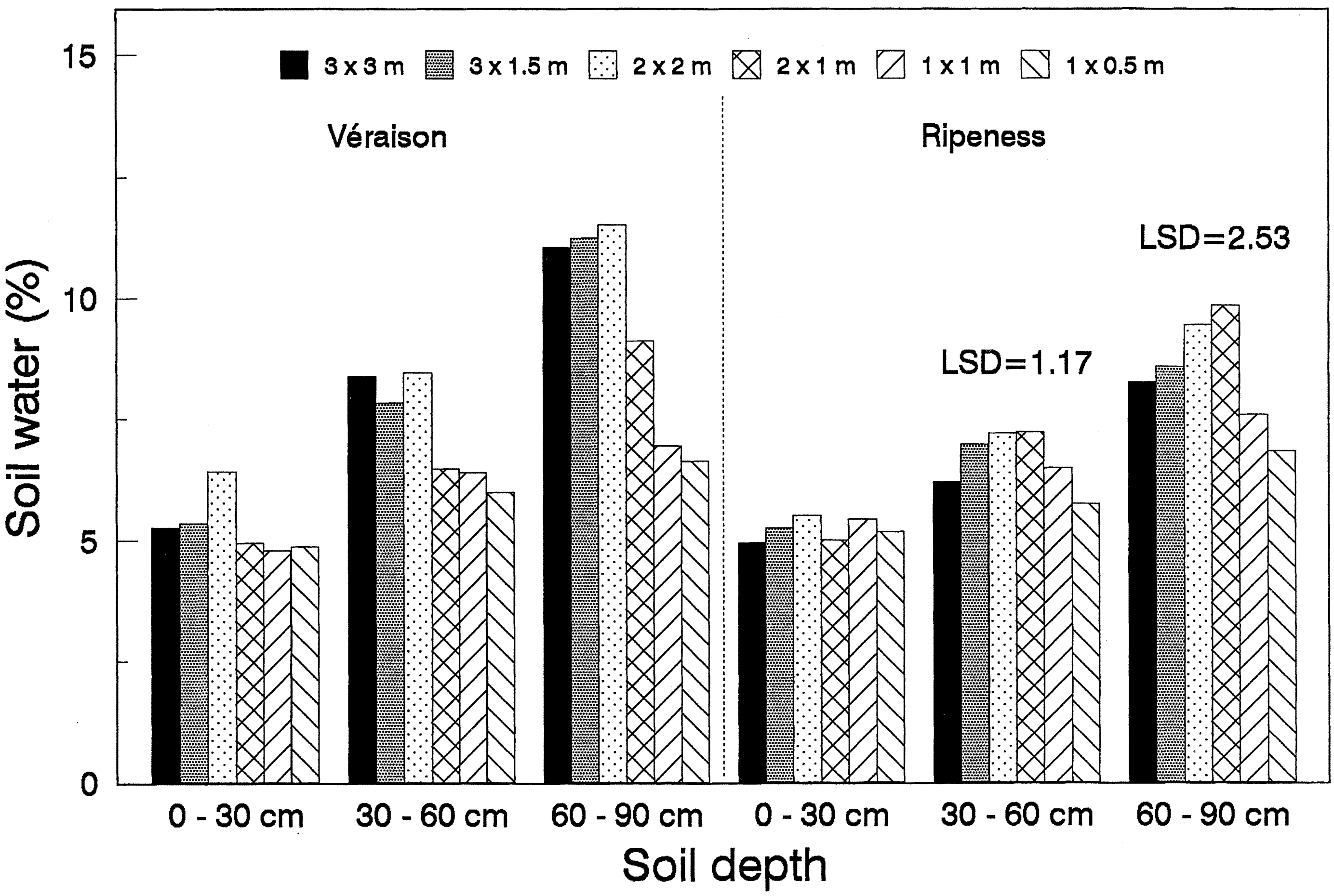

FIGURE 1

Vine-spacing effect on soil water content at véraison and ripeness.

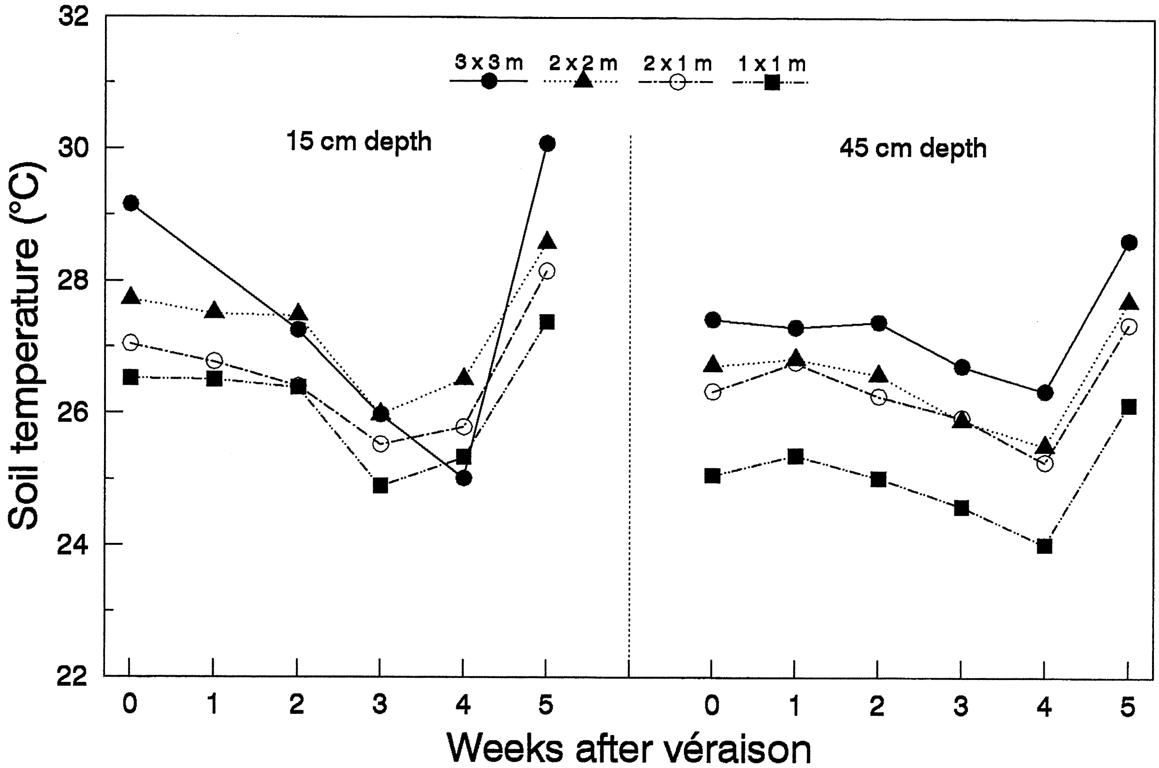

FIGURE 2
Vine-spacing effect on soil temperature at two different depths from véraison to ripeness.

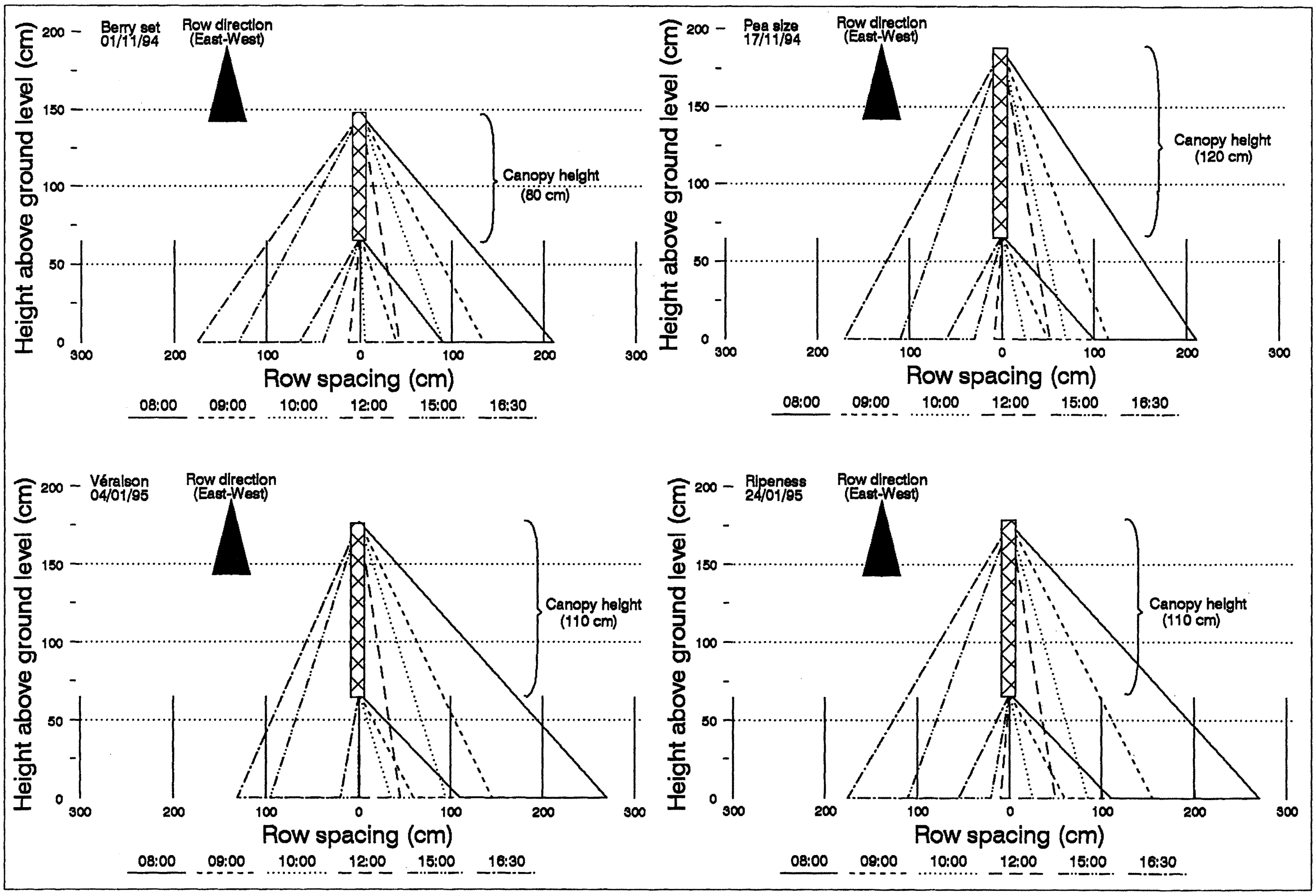

FIGURE 3
Vine-spacing effect on shading of between-row soil and adjacent vines (East-West row direction).

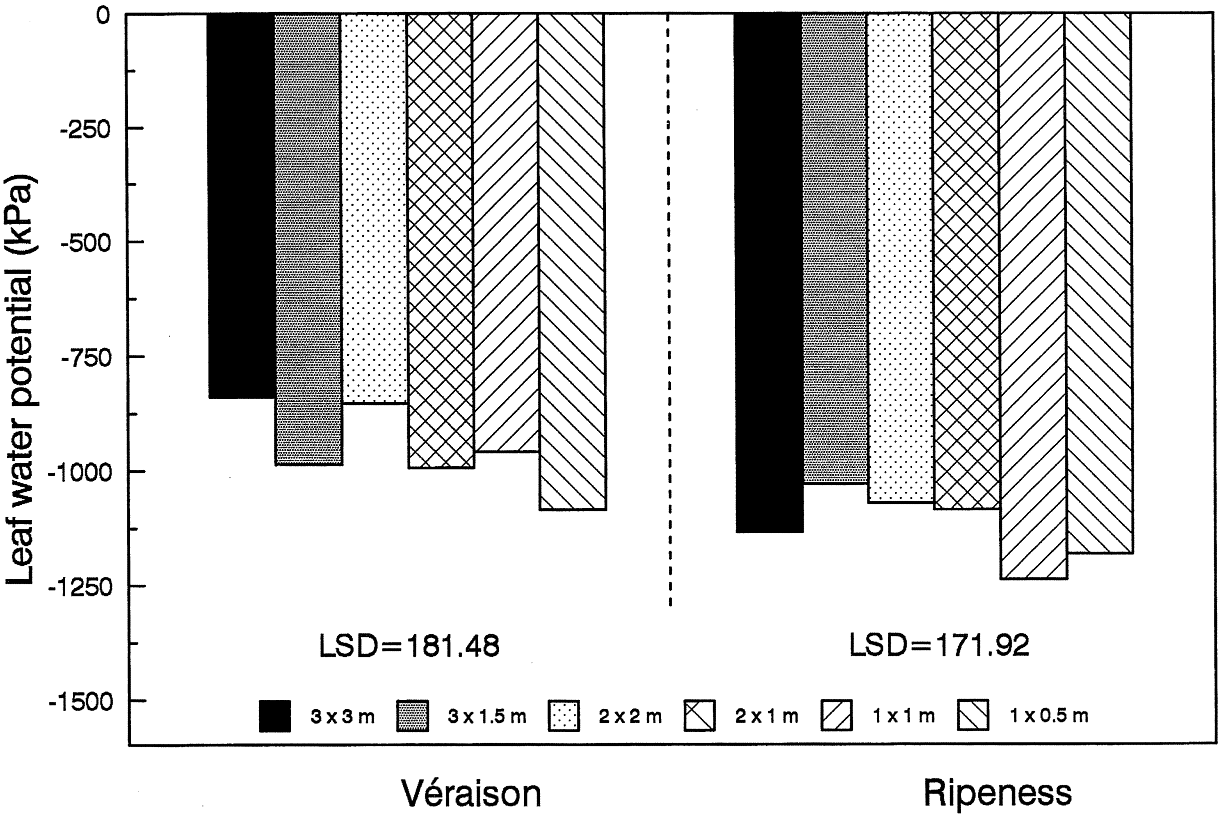

FIGURE 4
Vine-spacing effect on leaf water potential.

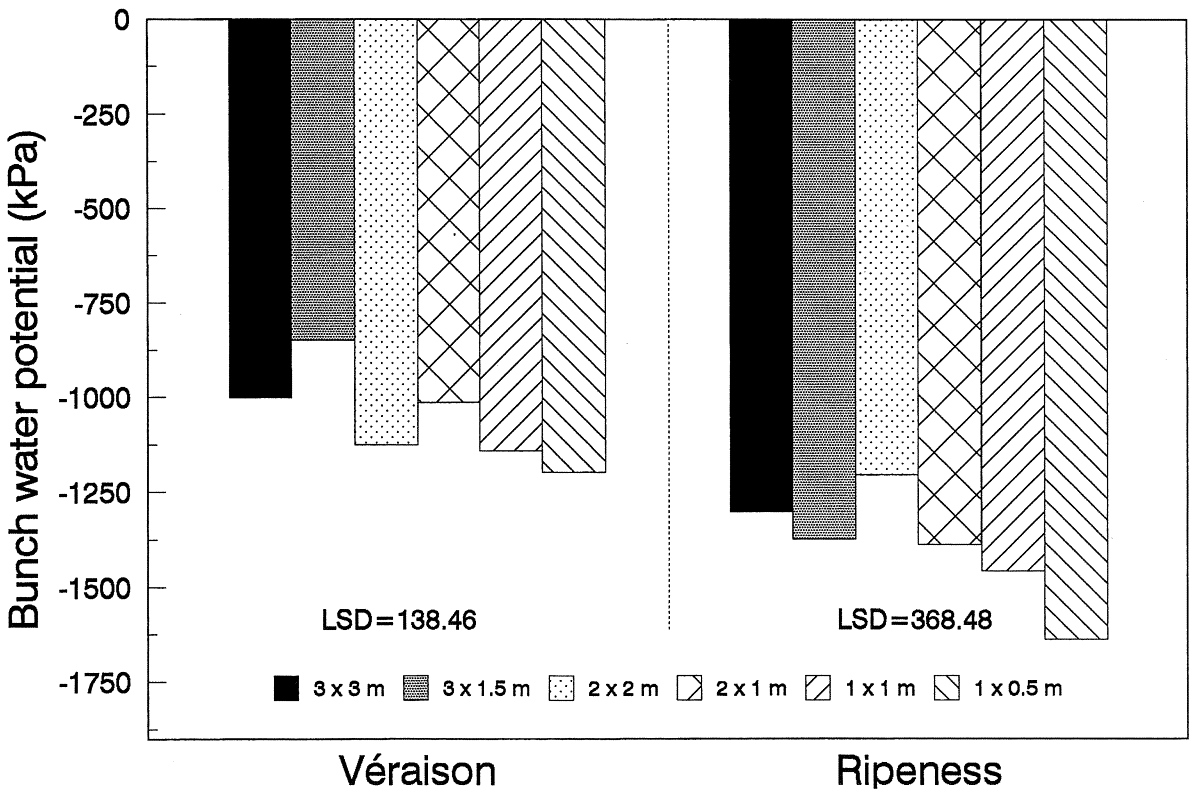

FIGURE 5
Vine-spacing effect on bunch water potential.

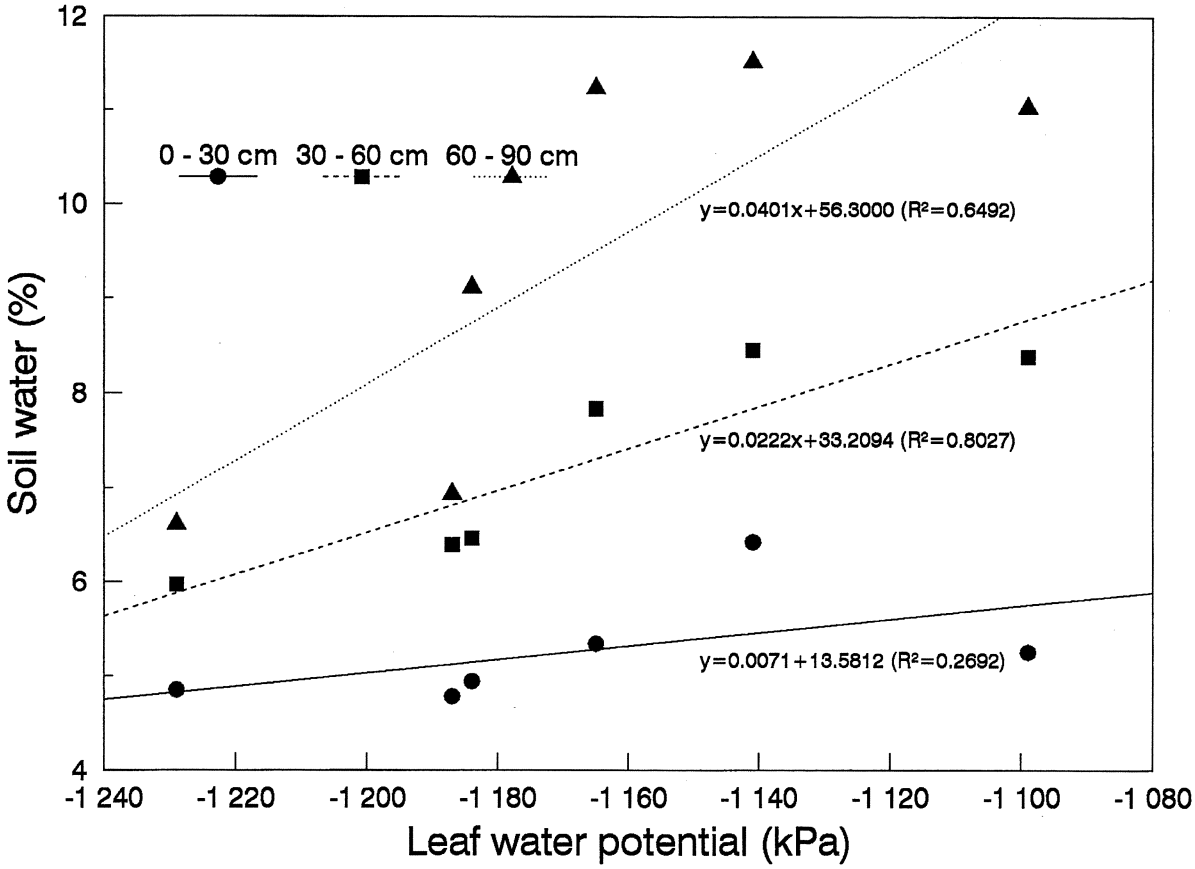

FIGURE 6
Relationship between soil water content of three soil layers and leaf water potential at véraison stage.

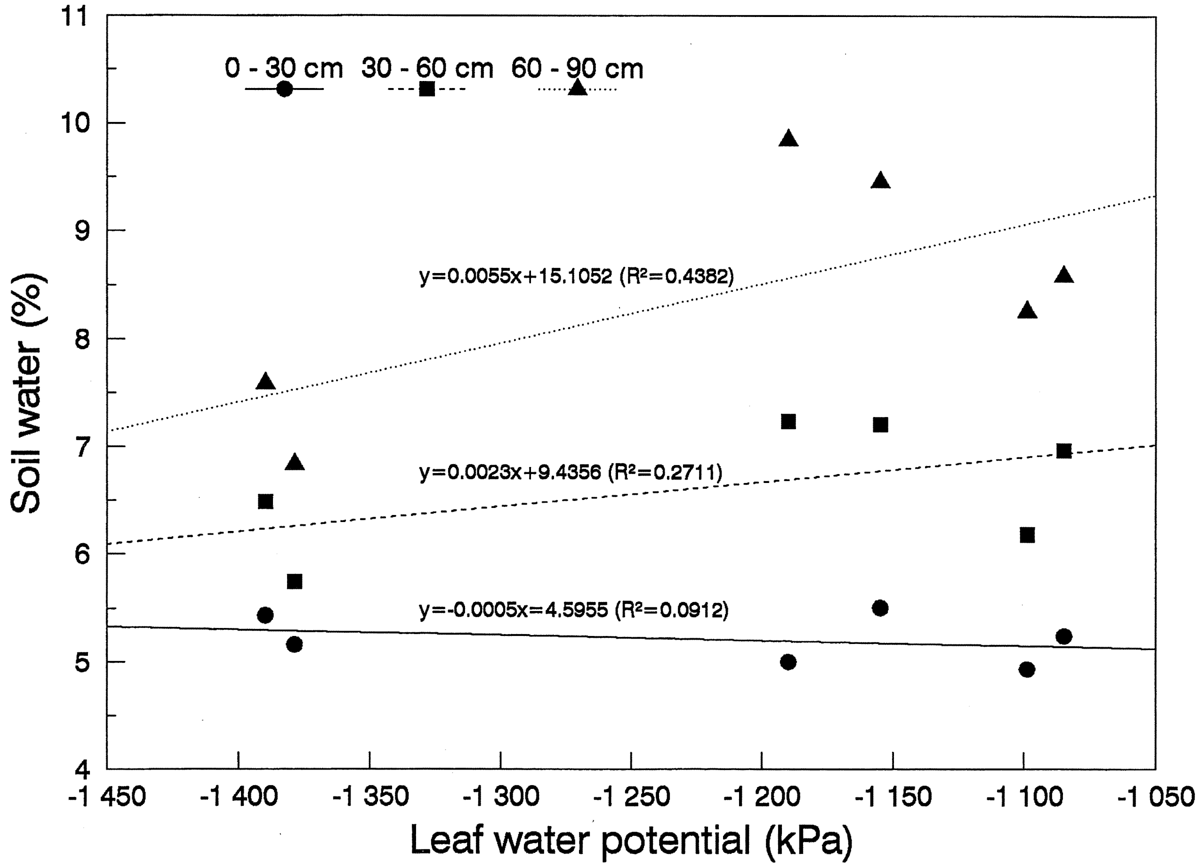

FIGURE 7
Relationship between soil water content of three soil layers and leaf water potential at ripeness stage.

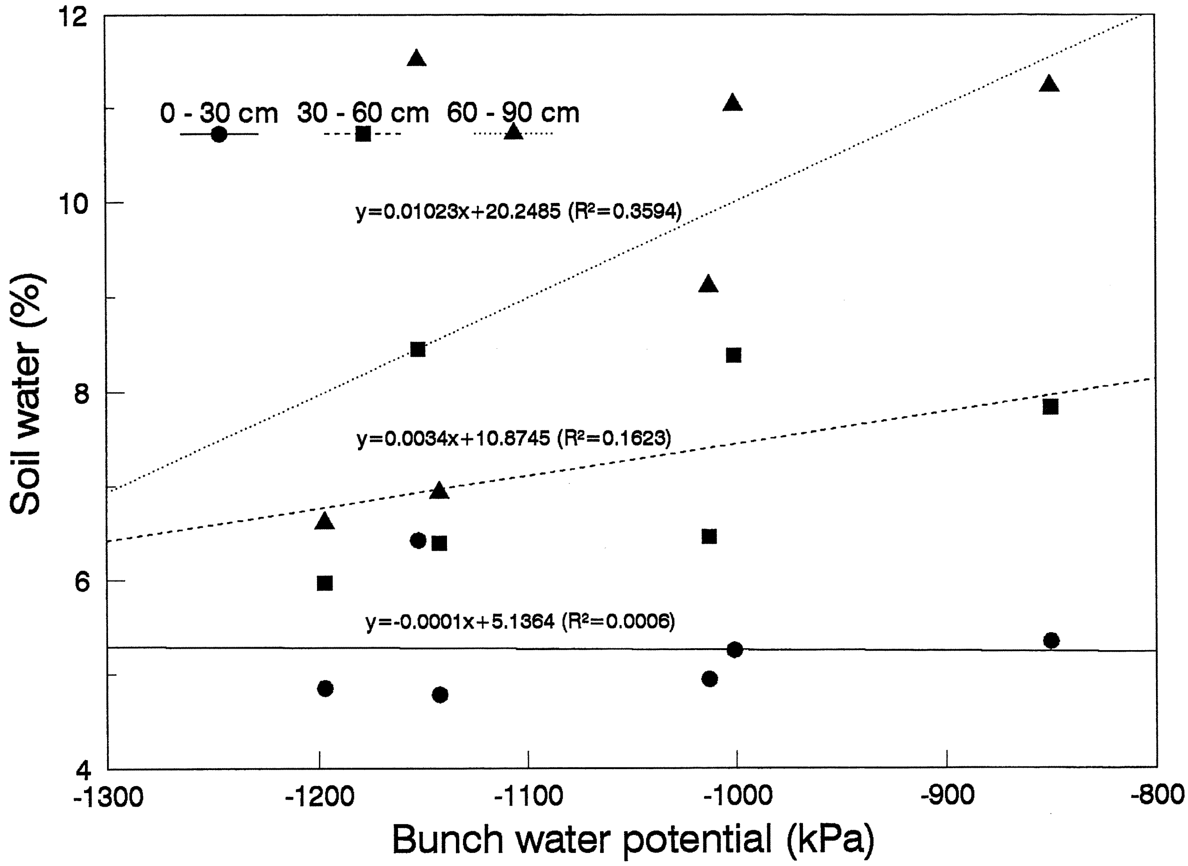

FIGURE 8
Relationship between soil water content of three soil layers and bunch water potential at véraison stage.

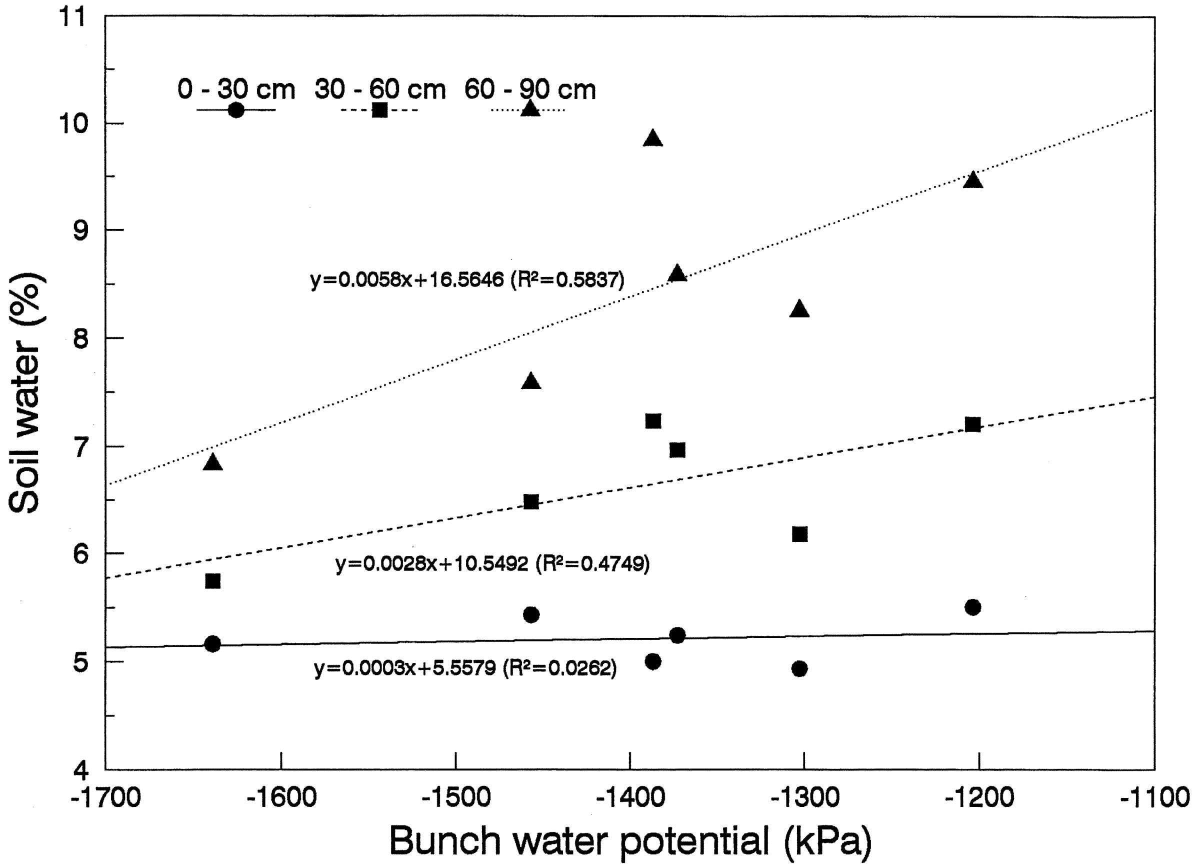

FIGURE 9
Relationship between soil water content of three soil layers and bunch water potential at ripeness stage.

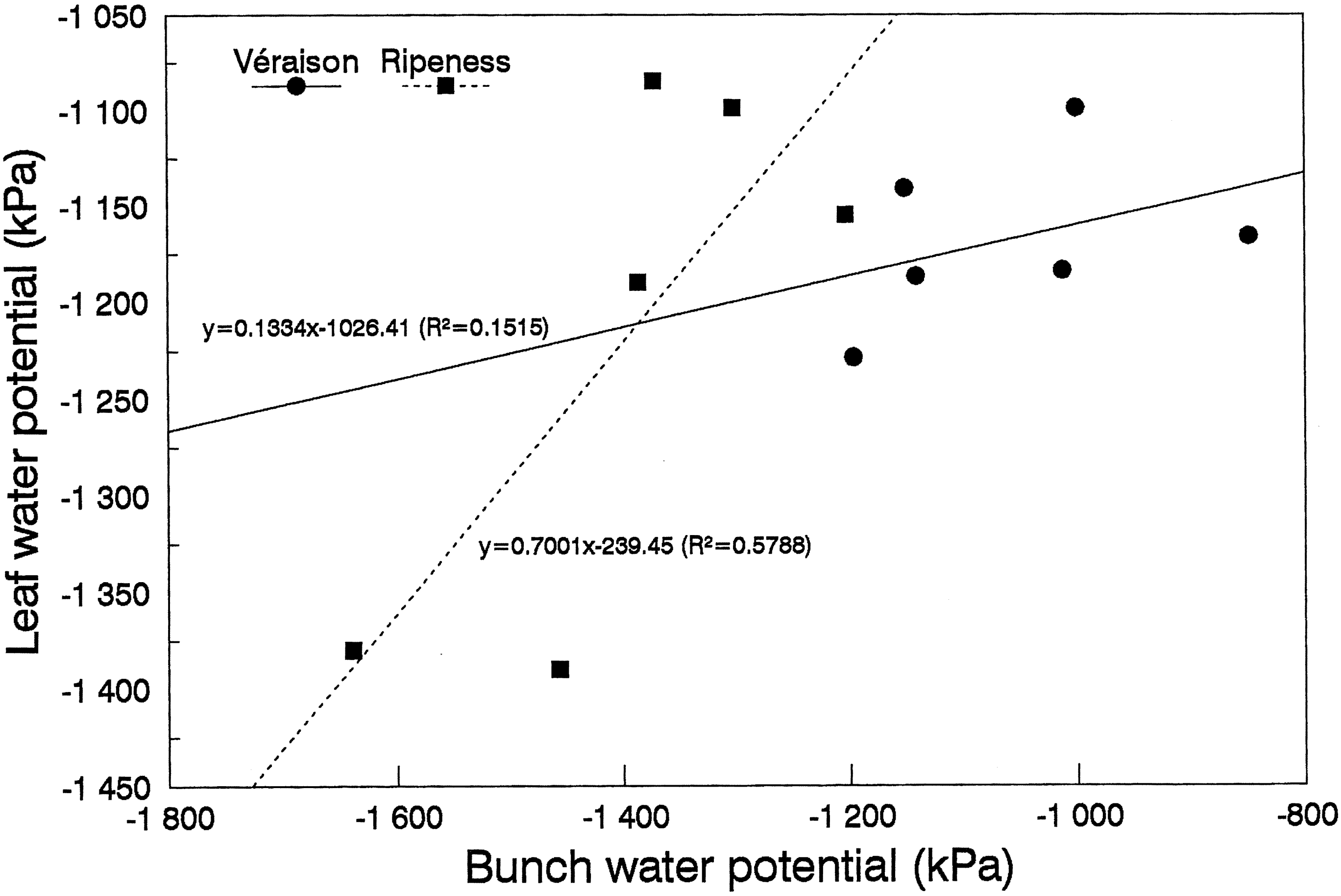

FIGURE 10
Relationship between leaf water potential and bunch water potential at véraison and ripeness stages.

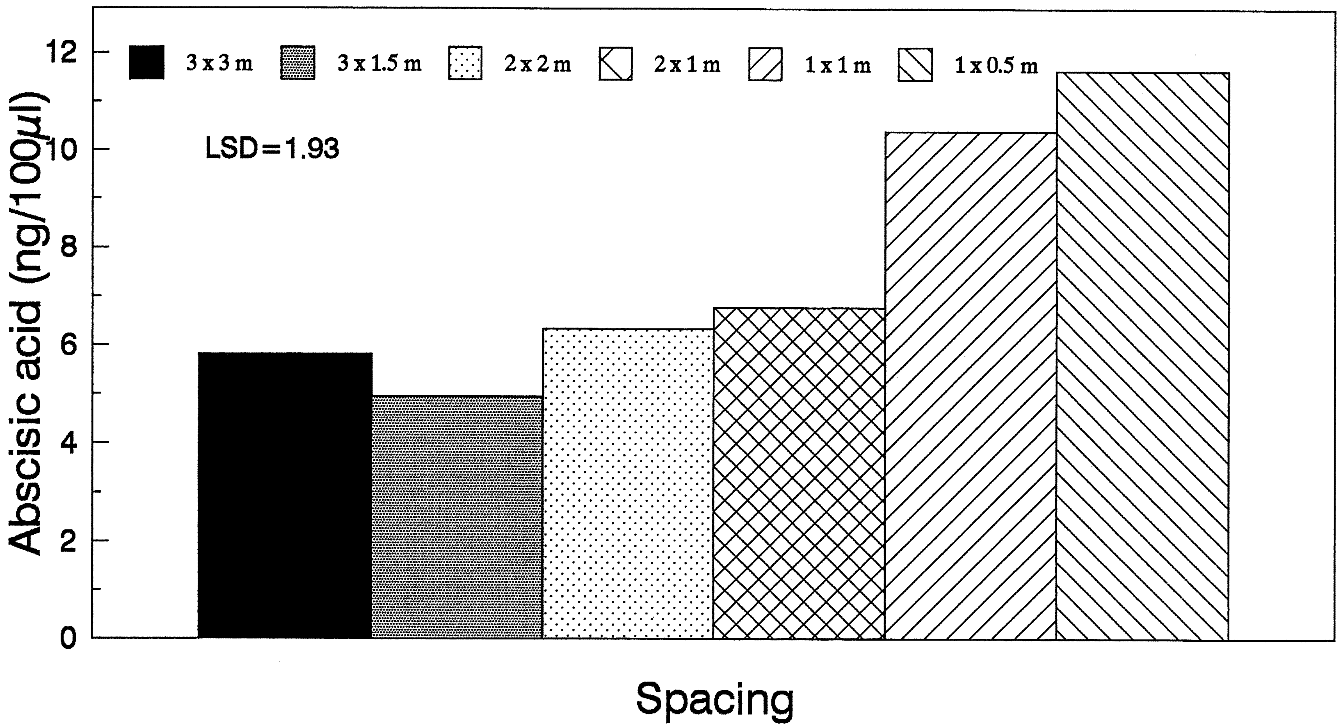

FIGURE 11
Vine-spacing effect on leaf sap abscisic acid concentration.

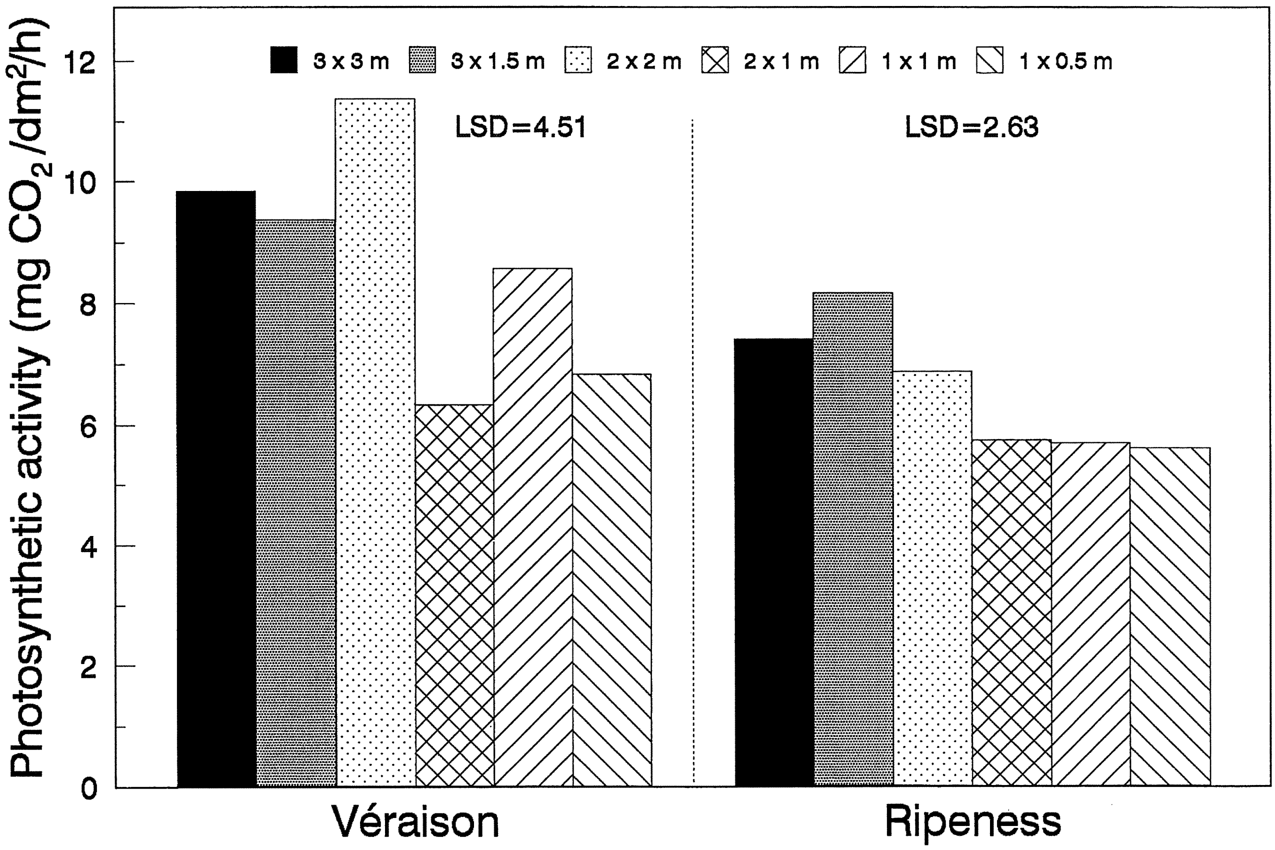

FIGURE 12
Vine-spacing effect on photosynthetic activity.

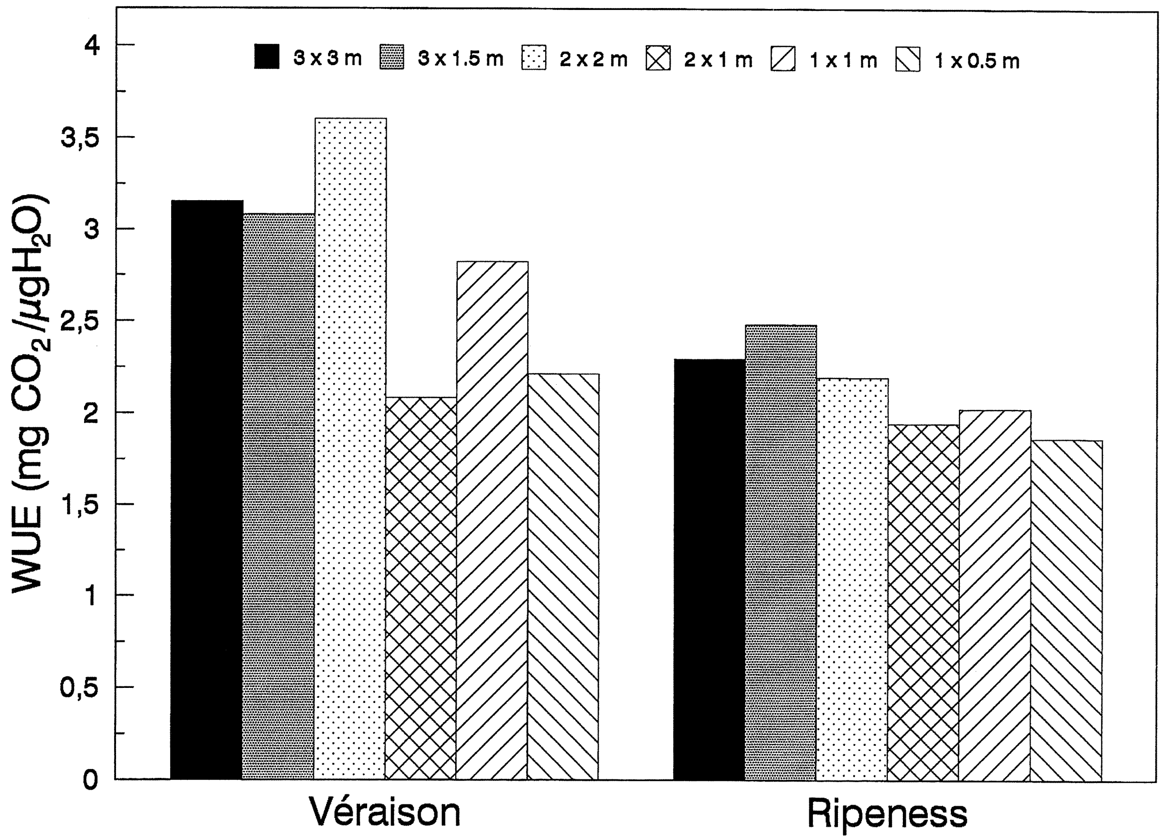

FIGURE 13
Vine-spacing effect on transpiration:photosynthesis ratio, expressed as water use efficiency (WUE).

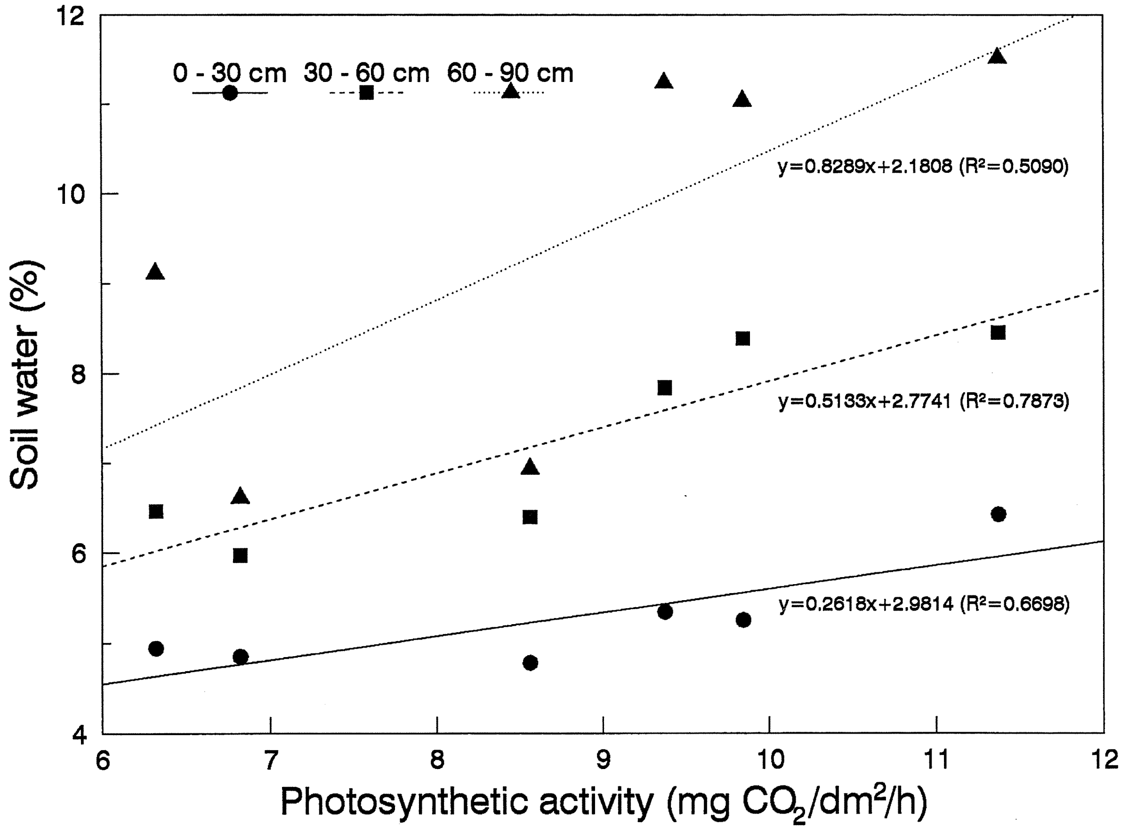

FIGURE 14
Relationship between soil water content of three soil layers and photosynthetic activity at véraison.

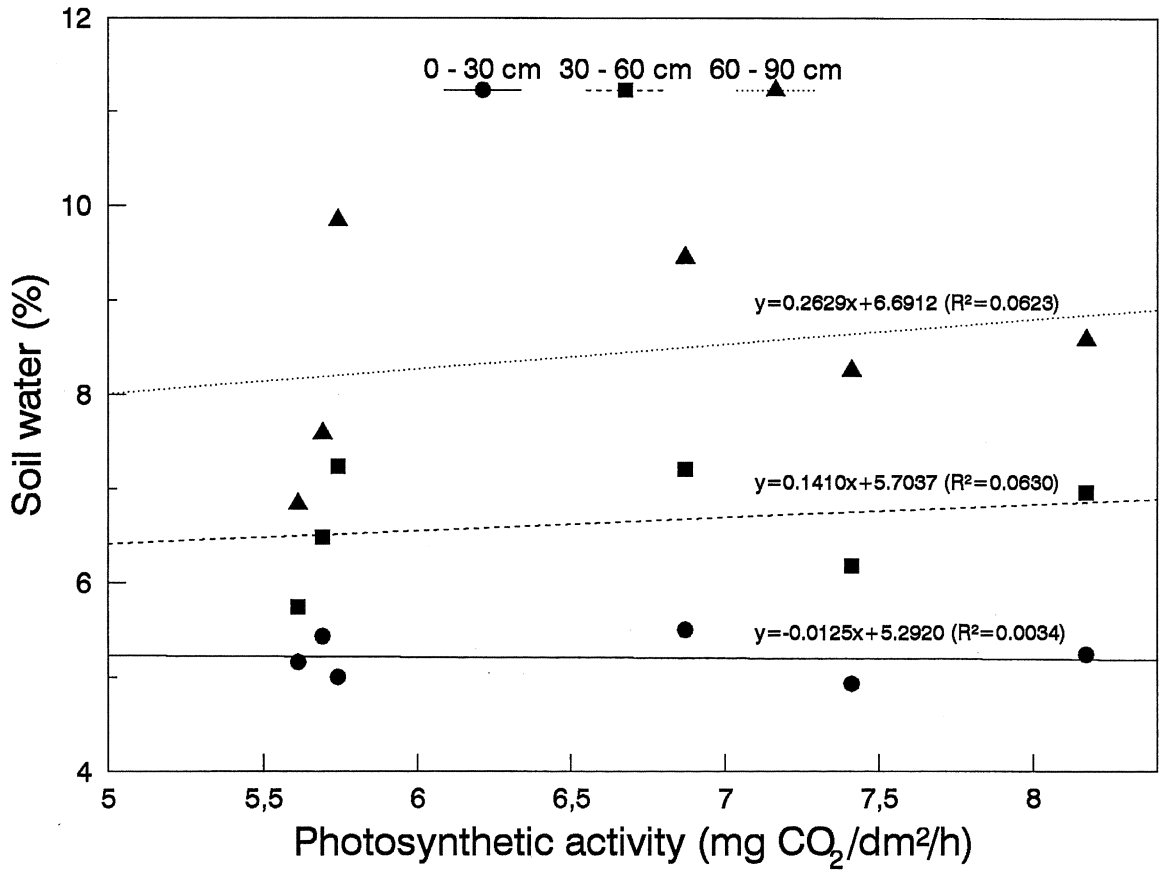

FIGURE 15
Relationship between soil water content of three soil layers and photosynthetic activity at ripeness.

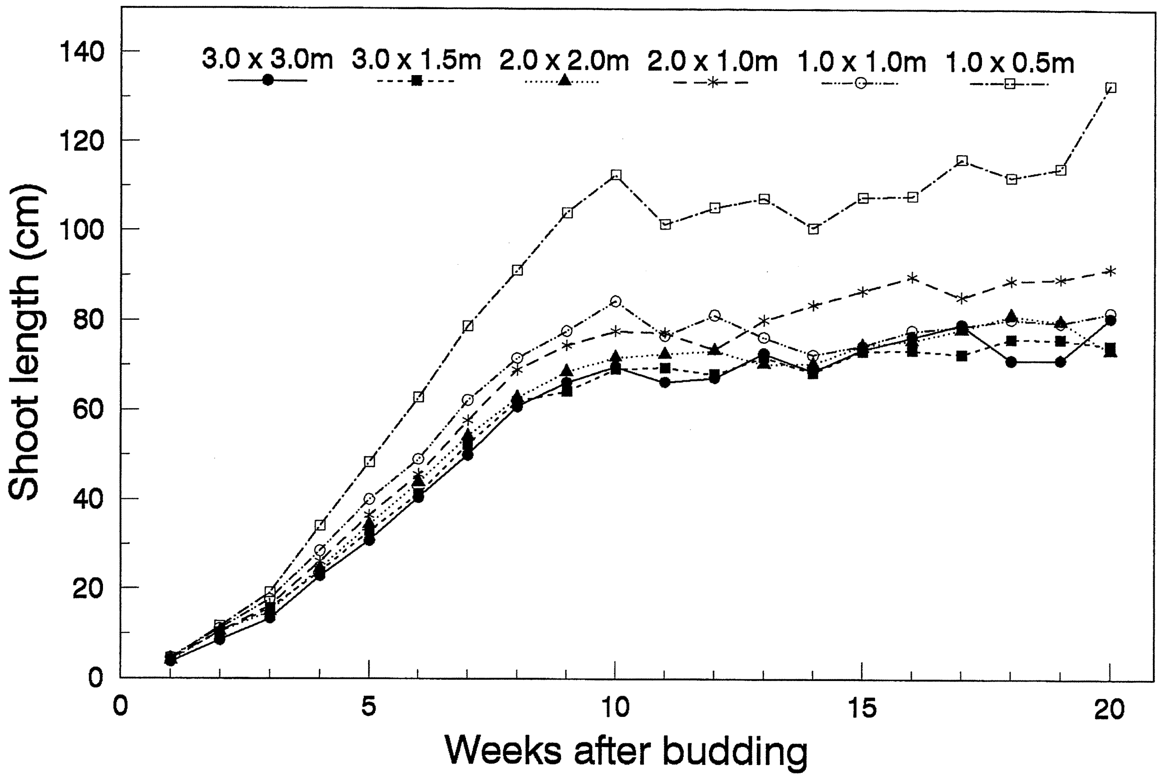

FIGURE 16
Vine-spacing effect on shoot length.

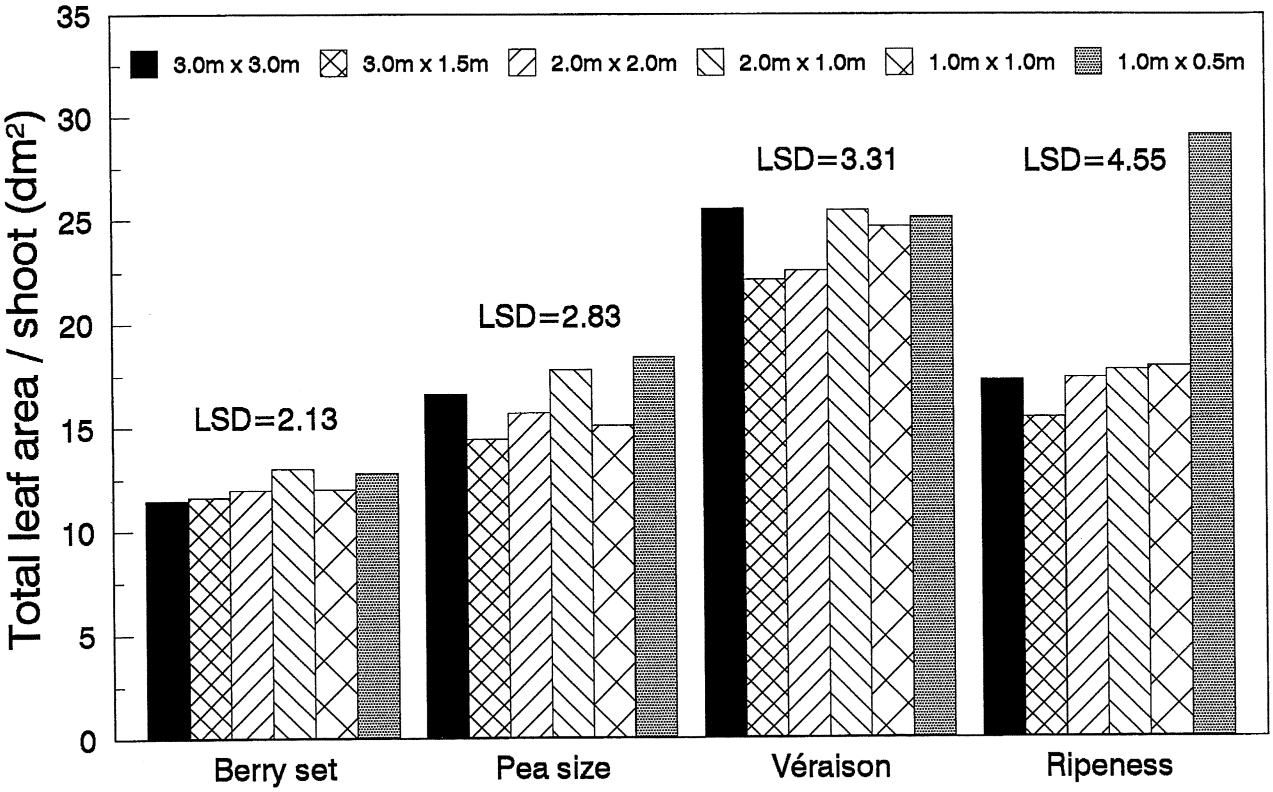

FIGURE 17
Vine-spacing effect on total leaf area per shoot.

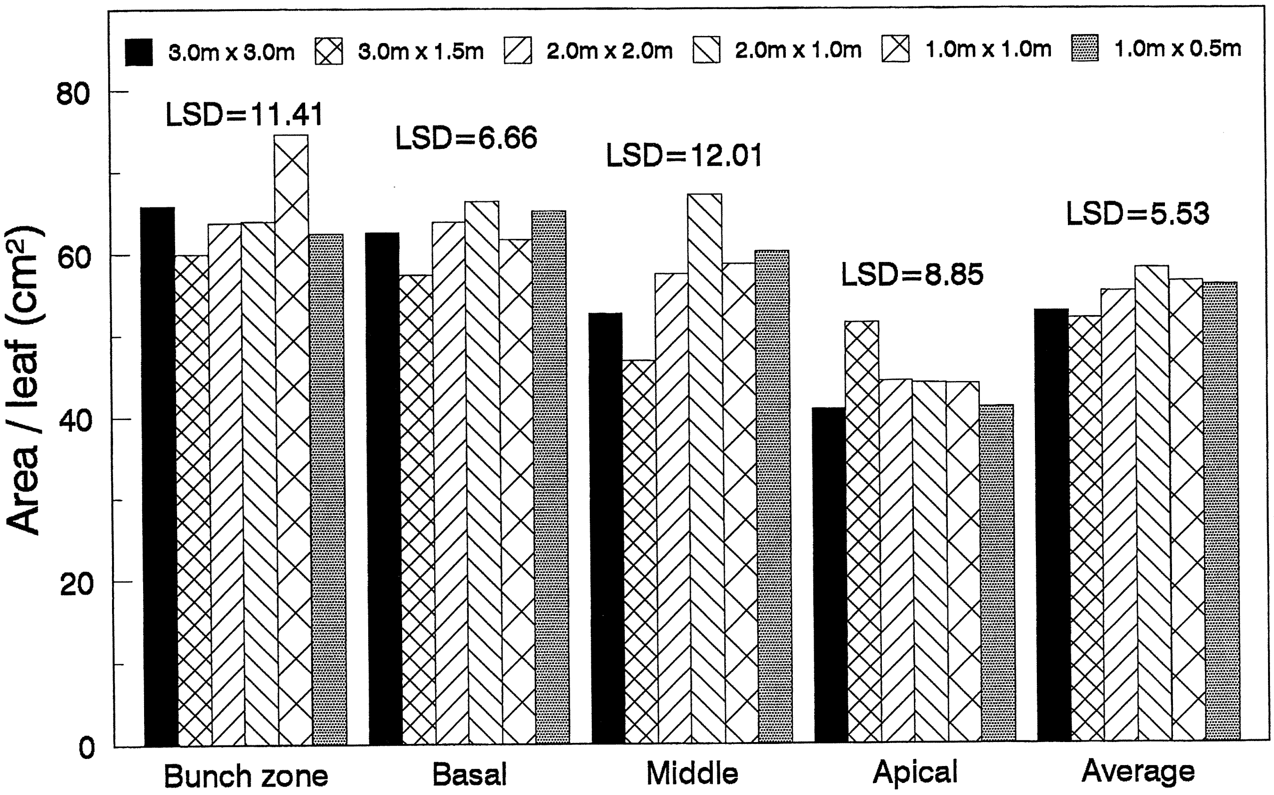

FIGURE 18
Vine-spacing effect on area per leaf.

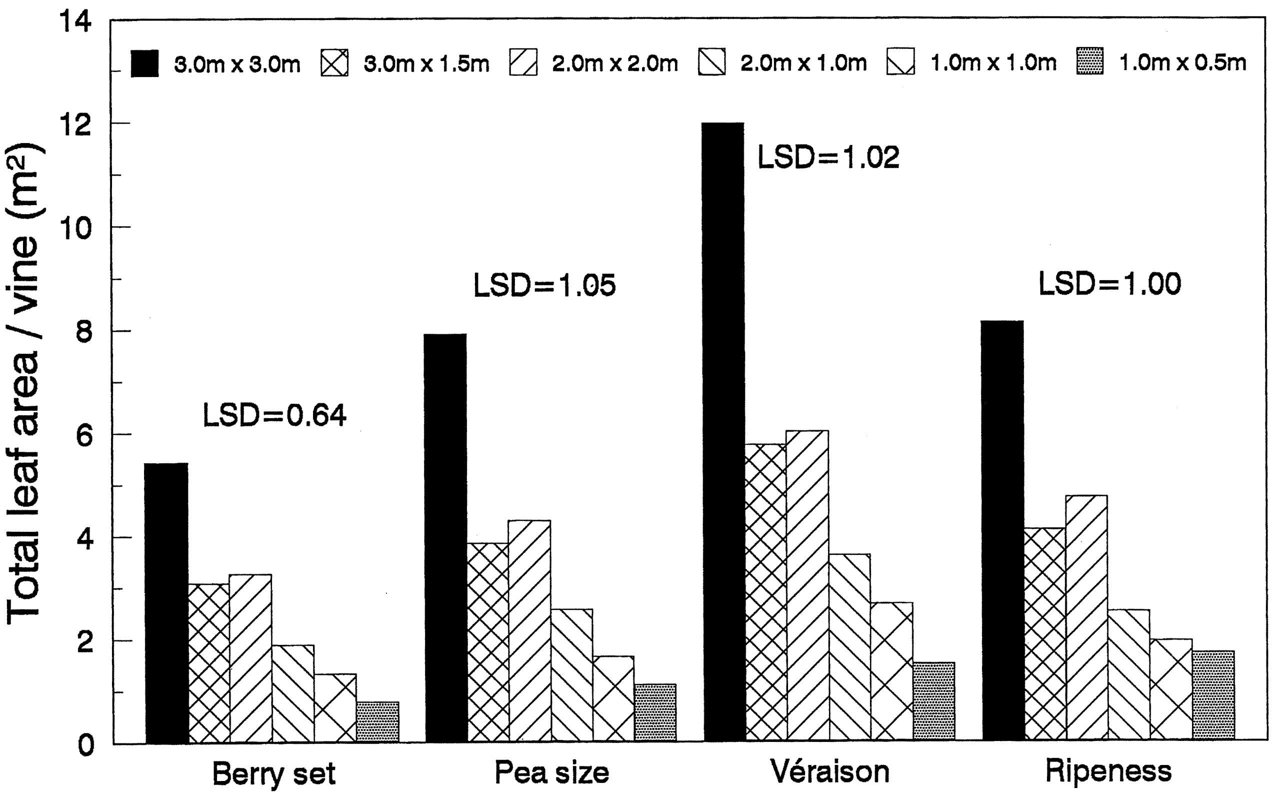

FIGURE 19
Vine-spacing effect on total leaf area per vine.

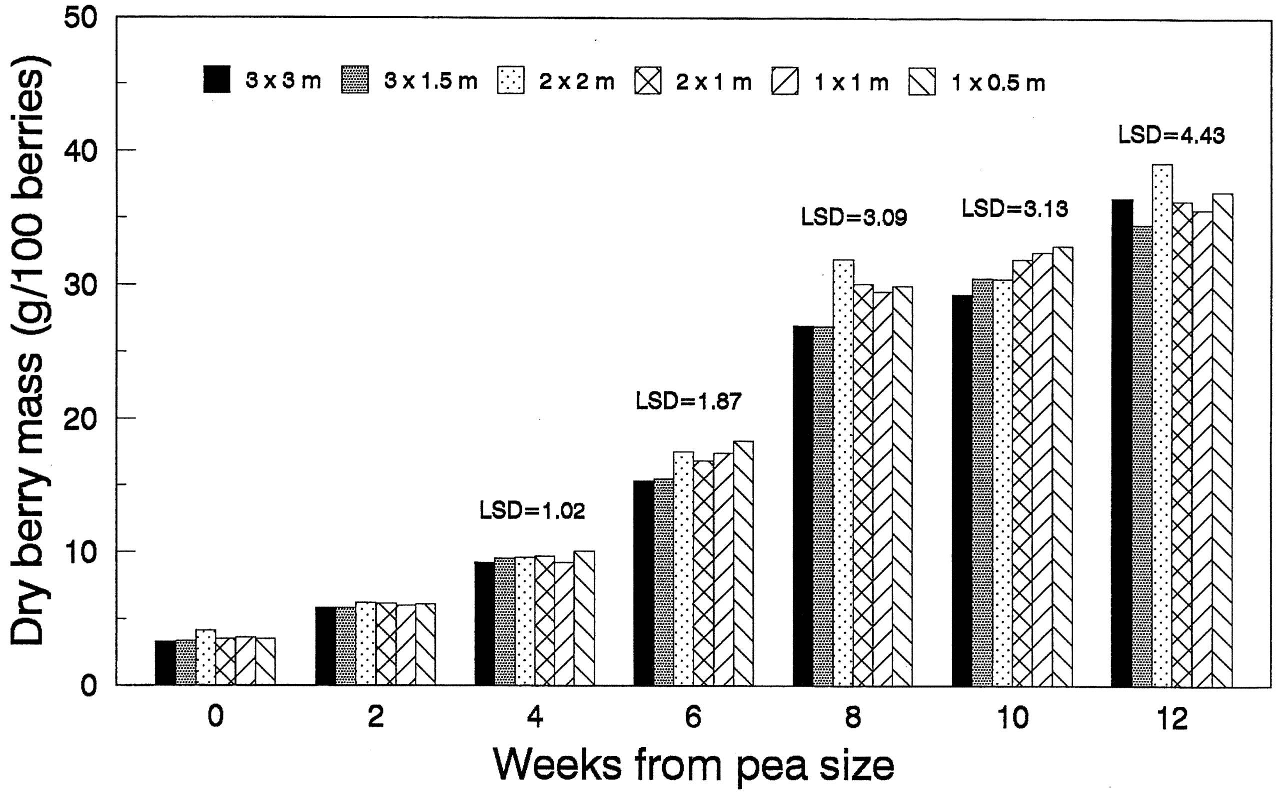

FIGURE 20
Vine-spacing effect on dry berry mass.

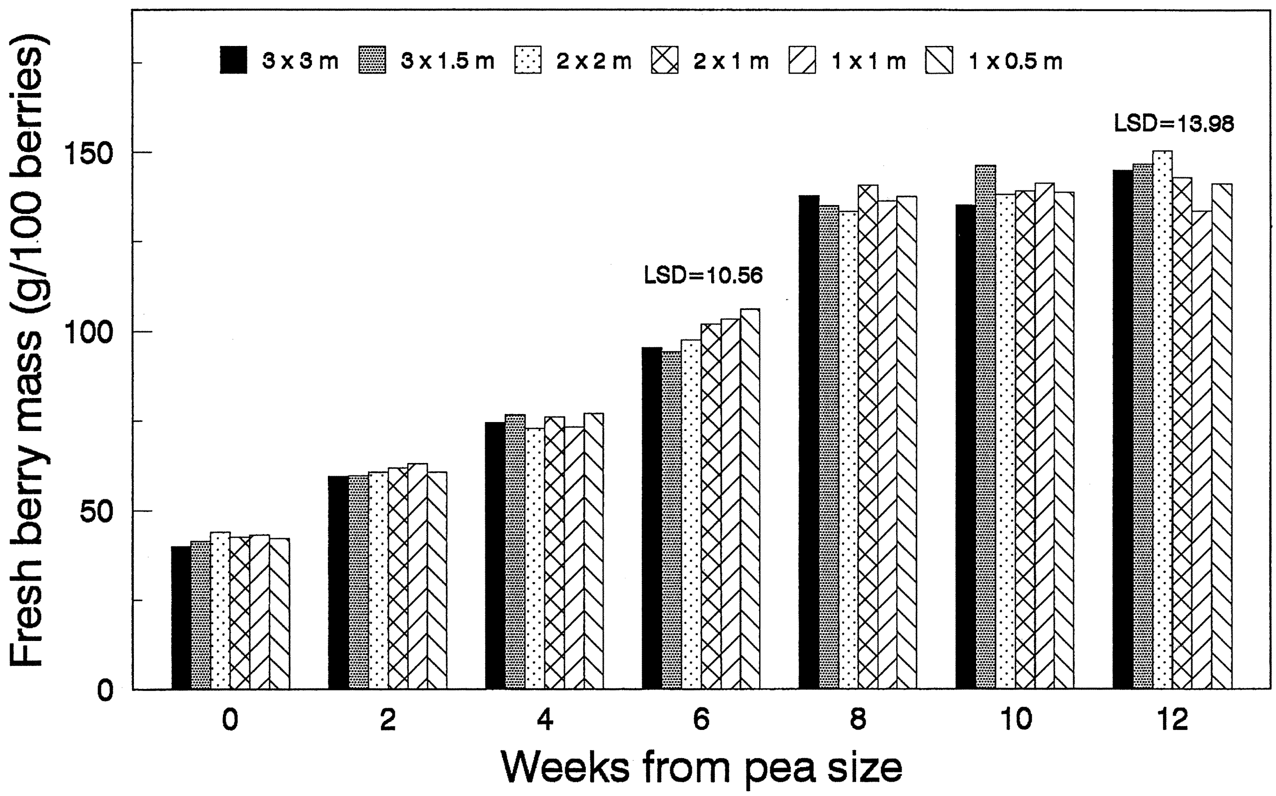

FIGURE 21
Vine-spacing effect on fresh berry mass.

CONCLUSIONS

It is clear that decisions on which plant spacing to use have far-reaching effects and should not be taken lightly. The correct plant spacing is critical in order to utilise the available soil volume to the best possible economic benefit. Physical between-row distance had a major direct effect on soil conditions and on canopy microclimate parameters such as light intensity, air flow and humidity throughout the whole season, regulating photosynthetic activity. The greatest effect on the physiology of the vines was exerted from véraison onwards.

Although vegetative growth parameters indicated that closely spaced vines were not severely stressed, they nevertheless showed physiological symptoms normally associated with water stress, whereas widely spaced vines showed definite signs of overcropping. In addition, the microclimate of closer-spaced vines was less favourable than that of widely spaced vines; their physiological status nevertheless led to better grape composition and wine quality. However, considering all parameters, including land utilisation, yield, wine quality and labour input, it is evident that medium-spaced vines (2 x 2 m, 2 x 1 m) consistently performed optimally. These spacings can therefore be used as guidelines for recommendations under similar soil conditions and viticultural practices. The data can also be extrapolated to conditions other than those described in this paper.

It should be borne in mind that factors such as soil potential, cultivar vigour, rootstock, irrigation, fertilisation, trellising system, and mechanical pruning and harvesting may affect the choice of a particular plant spacing for a given situation. In general, narrower spacing can be considered under conditions where low vigour is expected and/or localities are marked by poor soils. In contrast, high vigour and/or rich, heavy soils will require wider spacing. The colour and texture of the soil play an important role in the absorption and reflection of solar energy, with implications for root growth, vegetative development, and colour and flavour of grapes. It should be stressed, however, that efficient accommodation of aboveground growth is of the utmost importance under all circumstances in order to obtain maximum and continued production, grape and wine quality, as well as longevity of the grapvine.

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