RELATIONSHIP BETWEEN ROOT GROWTH OF 'THOMPSON SEEDLESS' GRAPEVINES AND SOIL TEMPERATURE

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ABSTRACT

With the purpose of characterizing the growth of the root system of table grapes (*Vitis vinifera* L.) cv. Thompson Seedless and its relationship with soil temperature, research was carried out during the 2004-2005 growing season in vineyards in the Copiapó and Huasco Valleys. Four plants were chosen and rhizotrons were used to measure the growth of the root system. Measurements were performed once a week from September 2004 to September 2005, estimating the intensity of root growth and its annual distribution in the ranges of 0 to 40, 40 to 80 and 80 to 120 cm of soil depth. Temperature sensors were installed in four plants at 25, 50, 75 and 100 cm of soil depth, and the temperature was registered every 1 h. The thermal diffusivity of the soil was calculated based on the annual mean temperature and annual thermal amplitude values. Root growth occurred throughout the year, presenting lower intensity in July (winter). Root systems presented different patterns in the distribution of growth intensity in the three soil depths, with variations in the order of five times in maximum annual growth intensity among sites. High thermal diffusivity in soils favored root growth.

Key words: roots, thermal diffusivity, tablegrape.

INTRODUCTION

Research into the architecture, rooting and mortality of roots requires special techniques. In this sense, the use of observation chambers, or rhizotrons, constitutes a non-destructive *in situ* method that allows addressing this task (van Noordwijk *et al*., 1985). Research into grapevine root systems has shown patterns that are dependent on age, cultivar, climate and environmental stress. Two growth peaks have been determined for roots of cv. Thompson Seedless (Ruiz, 2000), the first occurring between 3 to 10 weeks after budding and decreasing in intensity with berry growth (McArtney and Ferree, 1999). The spring growth peak has been related to superficial growth and abundant fine rootlets, with the intensity dependent on the level of reserves of the roots (Terence *et al*., 2002). The second peak, which is less intense than the first, occurs after harvesting the fruit.

The patterns of root growth can vary among different climatic regions, soil conditions, cultural practices or rootstock genotypes (Psarras *et al*., 2000), while changes in root morphology –characterized by differences in root length, dry matter and rooting– are associated with changes in soil temperature (McMichael and Burke, 1998). It has been proposed that if all the factors that affect root development are in optimal conditions, soil temperature would be the main modifier of root growth.

Woodham and Alexander (1966) observed a direct relationship between root growth and the rise in soil temperature from 15 to 30 °C, and established that the optimal soil temperature for grapevines is close to 30 °C, which was corroborated subsequently by Kliewer (1975).

Although it is known that the periodicity of root system growth plays a fundamental role from the perspectives of ecology and fruit production, current information is scarce. There is special interest in the Copiapó and Huasco Valleys, Atacama Region, where the local thermal characteristics can induce behaviors different from those reported to date in other research. Given this, the present study was directed at characterizing root growth of 'Thompson Seedless' grape vines in the Atacama Region, Chile, and its relationship with soil temperature.

MATERIALS AND METHODS

The study was carried out during the 2004-2005 season in vineyards of cv. Thompson Seedless located in the Copiapó and Huasco Valleys (between 27° and 28° S, and 70° W; 973-1223 m.a.s.l.), Atacama Region, Chile.

The climatic grouping is desert highland, with an average annual precipitation of 27 mm (Novoa *et al.*, 1989). The grapevines were cultivated using drip irrigation and were irrigated with approximately 12 000 m³ ha⁻¹ year⁻¹. The plants budded at the beginning of August, flowered by mid-September and were harvested beginning the second half of December.

Four observation chambers or rhizotrons (Table 1) were used to characterize root growth. The rhizotrons were placed over the row at 90 cm of the trunks of randomly selected representative plants at each site. The rhizotrons had observation windows of 1.2 x 1.0 m (8 mm thick). The glass on the windows was divided into a grid with 2.5 x 2.5 cm squares. The intersections of new roots were measured once a week using the grid, at soil depth ranges of 0 to 40, 40 to 80 and 80 to 120 cm. Changes in root growth intensity were determined by graphing the curve that represented the accumulated number of intersections during one year, while the maximum intensity of annual growth was estimated with the value of the maximum slope of the sigmoid equation, adjusted to the graph of the number of accumulated intersections.

Also, digital soil temperature sensors were installed at depths of 25, 50, 75 and 100 cm (Onset Computer Corporation, HOBO U12-008, Bourne, Massachusetts, USA). Measurements were taken every hour for one year, beginning 1 September 2004. The average daily temperature was used to carry out the calculations. Each temperature series was used to establish, through correlation and in function of the adjustment achieved, the sinusoid equation that describes the values of the temperature in the daily or annual cycle (Equation [1]) (Monteith and Unsworth, 1990).

$$T(z,t) = Tm + A(z) \, seno \, (w{\cdot}t) \qquad [1]$$

Where: $T(z,t)$: value of temperature at depth z at time t; Tm: mean temperature of the cycle at any depth; $A(z)$: thermal amplitude; w: angular frequency of the oscillation. For daily cycles $w = (2\pi/24)$ h⁻¹, and for annual cycles $w = (2\pi/365)$ d⁻¹; t: time in hours of the day or days of the year.

In this manner, the mean annual temperature of the soil was estimated, as well as thermal amplitude at depths of 25, 50, 75 and 100 cm. Equation [2] represents soil temperature at a depth for determined moment of the day or the year.

$$T(z,t) = T^* + A(0) \exp(-z/D) \, seno \, (w{\cdot}t - z/D) \qquad [2]$$

Where: $T(z,t)$: temperature at depth z and time t; T^*: mean temperature of the surface; $A(0)$: thermal amplitude at the surface; D: $(2k'/w)^{0.5}$ damping depth, where k´ is soil thermal diffusivity; w: angular frequency of the oscillation. For daily cycles $w = (2\pi/24)$ h⁻¹, and for annual cycles $w = (2\pi/365)$ d⁻¹; and t: time in hours of the day or in days of the year.

From the Equations [1] and [2] the amplitude of the sinusoid that represents the change of temperature in the soil at a depth z can be expressed as:

$$A(z) = A(0) \exp(-z/D) \qquad [3]$$

Where: $A(z)$: thermal amplitude at depth z; $A(0)$: thermal amplitude at the surface; and D: $(2k'/w)^{0.5}$ damping depth, where k´ is soil thermal diffusivity.

To estimate the value of D in each soil, four annual thermal amplitudes (one for each depth) were calculated for each soil and only the pair that presented the highest determination coefficients was used in the sinusoidal adjustment. A system of Equations [4] was then established, using Equation [3], where the unknown is the term D or damping depth, which is the depth where the value of thermal amplitude of the surface is reduced by a factor of e⁻¹.

$$A(z_1) = A(z_2)/\exp(-z_2/D) \exp(-z_1/D) \qquad [4]$$
$$A(z_2) = A(z_1)/\exp(-z_1/D) \exp(-z_2/D)$$

Where, $A(z_1)$ and $A(z_2)$ are the two thermal amplitudes obtained from the adjusted sinusoidal equations with the highest determination coefficient on each soil.

The value of thermal diffusivity in each soil was

Table 1. Geographic location of rhizotrons and soil temperature sensors in vineyards in the Copiapó and Huasco Valleys, Atacama Region, Chile.

Vineyard	Geographic coordinates		Altitude
	South latitude	**West longitude**	**(m.a.s.l.)**
El Rosario	28°45'11.6"	70°28'18.0"	985
Santa Cecilia	27°59'27.9"	70°00'38.4"	1223
El Tabaco	28°47'50.4"	70°27'47.6"	973
Altar de la Virgen	27°59'48.8"	69°58'43.5"	1182

m.a.s.l.: meters above sea level.

obtained by clearing Equation [5] term k' or thermal diffusivity, defined in Equation [2].

$$k' = D^2 w/2 \qquad [5]$$

Where: k' *is* soil thermal diffusivity; D is damping depth; and w: angular frequency of the oscillation. For daily cycles $w = (2\pi/24)$ h^{-1} and for annual cycles $w = (2\pi/365)$ d^{-1}.

Statistical analysis

The thermal soil variables were adjusted through regression to Equation [1], and the variable of root growth was adjusted in function of time, to a sigmoid through regression analysis. Statistical analysis was done with the statistical computer program SigmaPlot 10.0 (Systat Software, San Jose, California, USA).

RESULTS AND DISCUSSION

The thermal dynamic of the soils presented a sinusoidal pattern, characteristic of heating and cooling of soil for an annual cycle. Figure 1 presents the average of monthly mean temperatures of four vineyards, registered at four soil depths. From September 2004 the soils presented a homogenous increase in monthly mean temperature throughout the soil profile, reaching a maximum of 21.6 °C in February 2005. Once soil cooling started at the beginning of March 2005, an inversion in the thermal profiles was observed until July, when the lowest temperature in the soil profile was reached, 14.7 °C. Between the months of July and August, the increase in the soil surface temperature was higher than at greater depths, with a homogenous thermal profile being observed in August at a mean temperature of 16 °C. Table 2 presents the mean annual temperature and the annual thermal amplitude for four vineyards. The values and the slight variation in annual mean temperature among the sites represents the thermal condition to which soils are exposed in the Copiapó and Huasco Valleys.

By means of adjustments to sinusoidal models, changes of temperature at depths in an annual cycle were represented, obtaining the values of mean temperature and the thermal amplitude of the adjusted sinusoids. As
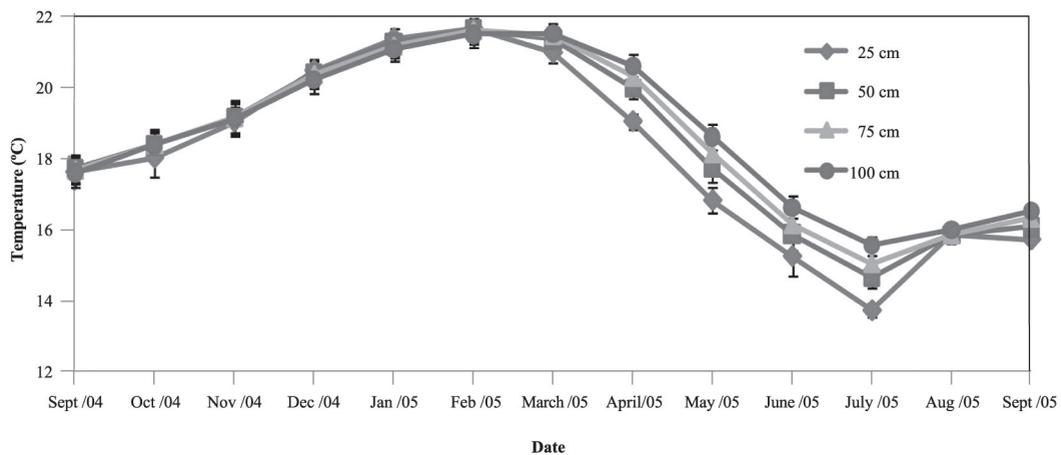

Figure 1. Average monthly temperature at four soil depths in the Copiapó and Huasco Valleys, Atacama Region. Average of four soils. Symbol represents standard error.

Table 2. Average annual temperature and annual thermal amplitude of four soils in the Copiapó and Huasco Valleys, Atacama Region, Chile. Data from September 2004 to September 2005.

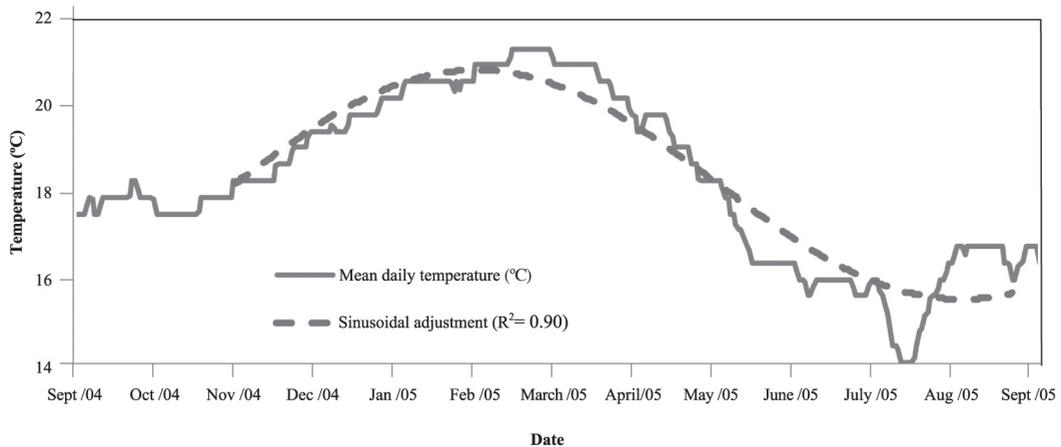| Temperature sensor located at: | Mean annual temperature | | | | Annual thermal amplitude | | | |
	Depth (cm)				Depth (cm)			
	25	50	75	100	25	50	75	100
	°C							
El Rosario	20.1	20.4	20.5	20.4	3.2	3.4	3.1	3.1
Santa Cecilia	19.3	19.6	19.6	19.6	5.2	4.0	3.6	3.2
El Tabaco	18.1	18.3	18.3	18.4	5.4	4.2	4.0	3.8
Altar de la Virgen	17.6	17.8	18.0	18.1	5.6	4.6	4.2	3.6

Figure 2. Average daily temperature at a soil depth of 100 cm and adjusted sinusoidal model. Thermal data obtained from the thermal sensor located at Altar de la Virgen, Copiapó Valley, Atacama Region, Chile.

Table 3. Coefficients of determination of adjusted sinusoidal soil temperature models and time range used. Values from four soil depths (cm) of four soils in the Copiapó and Huasco Valleys, Atacama Region, Chile.

Temperature sensor located at:	Coefficients of determination of the adjusted sinusoidal models at four soil depths				Time range used for the sinusoidal adjustment
	25	50	75	100	
El Rosario	0.87	0.92	0.94	0.83	01/11/2004 to 19/10/2005
Santa Cecilia	0.89	0.92	0.93	0.96	02/10/2004 to 28/08/2005
El Tabaco	0.87	0.93	0.92	0.90	15/11/2004 to 31/08/2005
Altar de la Virgen	0.85	0.90	0.90	0.90	30/10/2004 to 19/10/2005

an example, Figure 2 presents the sinusoid and the degree of adjustment obtained in the soil of the vineyard Altar de la Virgen at a depth of 100 cm. The degree of adjustment achieved by the sinusoidal models and timer period used in each soil is presented in Table 3.

Thermal diffusivity is defined by the coefficient between the thermal conductivity of the soil and volumetric thermal capacity, while the relation between thermal diffusivity and the water content in large measure determine thermal kinetics of irrigated soils. Monteith and Unsworth (1990) propose that very dry soils rapidly increase their thermal conductivity when a small quantity of water is added, implying a major increase in thermal conductivity above the increase in specific volumetric heat. As that the water content in the soil increases, there is less change in thermal conductivity because vapor diffusion decreases as the pores are saturated with water. Similarly, the change in specific volumetric heat began to be greater than the change in soil conductivity, resulting in a decrease in thermal diffusivity. In etween these two regimes (dry and wet), soil thermal diffusivity presents

its maximum value. Wieringa and Lomas (2001) indicate that soil thermal diffusivity is on the order of 10^{-6} m² s⁻¹ for the mineral constituents of the soil and 3 to 8 x 10^{-7} m² s⁻¹ for soils. The values of thermal diffusivity were estimated in soil depth ranges below 50 cm (Table 4), resulting in values on the order of 10^{-6} m² s⁻¹. Also, values for the damping depth were estimated between 3 to 9 m.

In order to represent root system growth of the grapevine cv. Thompson Seedless at different depths, the average of weekly intersections was divided by the highest value observed during the year, obtaining the distribution of annual growth in relative terms. The roots grew throughout the year, presenting minimal values in July and reaching similar growth levels during flowering and harvest (Figure 3). To estimate the intensity of annual growth of root systems, graphs were made of the number of accumulated intersections during a year beginning 1 September 2004. Subsequently, by means of adjustment to a sigmoid model, the equation that represents the number of accumulated intersections in function of time was obtained. The maximum intensity of annual growth

Table 4. Soil thermal diffusivity, soil depth range used and damping depth of four soils in the Copiapó and Huasco Valleys, Atacama Region, Chile.

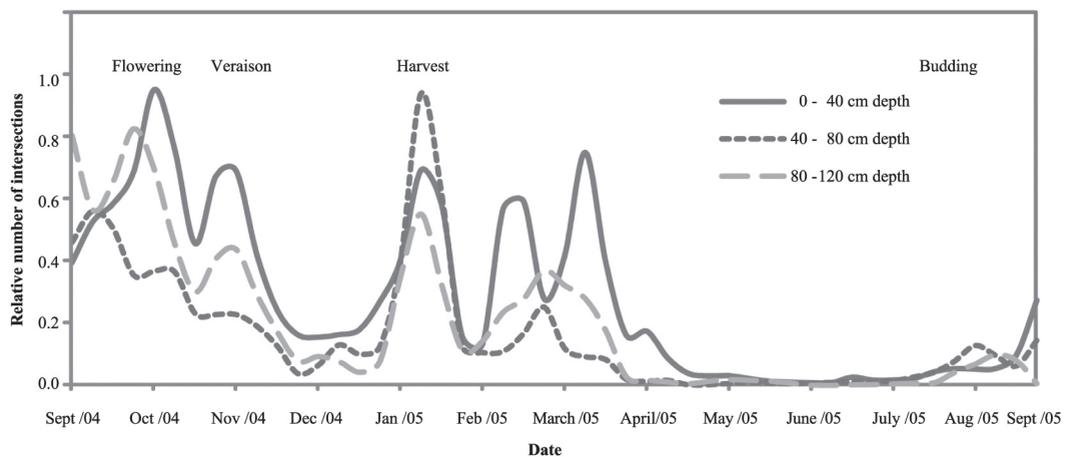| Temperature sensor located at:	Soil thermal diffusivity	Depth range used for the estimation	Damping depth
	10^{-6} m² s⁻¹	cm	
El Rosario	8.9	50 – 75	947
Santa Cecilia	2.5	75 – 100	505
El Tabaco	5.5	50 – 75	335
Altar de la Virgen	1.7	75 – 100	345

Figure 3. Relative number of root intersections with the grid lines at three soil depth ranges. Average of four rhizotrons installed in 'Thompson Seedless' grapevines at the Copiapó and Huasco Valleys, Atacama Region, Chile.

corresponded to the value of the maximum slope for the adjusted sinusoid model. For example, Figure 4 shows the graph of the accumulated number of intersections and the adjusted sigmoid model for the Altar de la Virgen rhizotron for the range of 0 to 40 cm of soil depth. The maximum
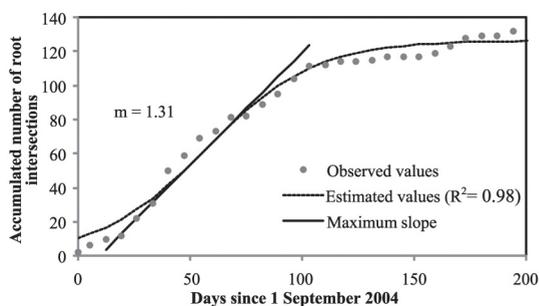

Figure 4. Accumulated number of root intersections. Observed and estimated values, and maximum slope (m) of rhizotron Altar de la Virgen (soil depth range of 0 to 40 cm), installed in 'Thompson Seedless' grapevines in the Copiapó Valley, Atacama Region, Chile.

intensity of annual growth presented by the root systems and their distribution in three depth ranges are presented in Table 5. The degree of adjustment by sigmoid models and the period of time used are presented in Table 6.

The root system of the grapevine is characterized by a high level of exploration and low root density (Nagarajah, 1987; Morano and Kliewer, 1994). Silva *et al*. (1991) estimated that the majority of 'Thompson Seedless' roots are found at depths of 40 to 60 cm. As well, it has been reported that grapevine roots have the potential to grow to depths of 600 cm (Seguin, 1972). The differences between the maximum and minimum intensities of annual root system growth (Table 5) were on the order of five times when considered at the depth range of 0 to 120 cm. As well, particular patterns of root growth were observed in each rhizotron during the season.

Ibacache and Lobato (1995) determined a significant linear relationship between the intensity of root growth of the grapevine cv. Gold and soil temperature at depths of 20 and 50 cm. The present study determined that root growth in the spring of 2005 started at the beginning of July, characterized by an increase in the number of

Table 5. Maximum annual root growth rate distribution of four 'Thompson Seedless' grapevines within three soil depth (cm) ranges and soil profile, at the Copiapó and Huasco Valleys, Atacama Region, Chile.

Rhizotron located at:	Maximum intensity of root system growth in three ranges of soil depth and profile			
	(Number of root intersections d^{-1})			
	0 - 40	40 - 80	80 - 120	0 - 120
El Rosario	3.0	4.6	3.7	10.7
Santa Cecilia	1.5	1.3	1.0	3.1
El Tabaco	3.7	3.3	4.6	9.7
Altar de la Virgen	1.3	0.8	0.2	2.1

Table 6. Coefficient of determination of sigmoid models adjusted to the accumulated number of intersected roots and time range used. Values of three soil depth (cm) ranges and soil profile of four root systems of 'Thompson Seedless' grapevine in the Copiapó and Huasco Valleys, Atacama Region, Chile.

Rhizotron located at:	Determination coefficient of sigmoid models adjusted to the accumulated number of root intersections				Time range used in the sigmoid adjustment
	0 - 40	40 - 80	80 - 120	0 - 120	
El Rosario	0.97	0.95	0.95	0.97	02/09/2004 to 28/03/2005
El Tabaco	0.99	0.98	0.96	0.99	02/09/2004 to 24/11/2004
Santa Cecilia	0.98	0.96	0.96	0.98	07/09/2004 to 12/07/2005
Altar de la Virgen	0.98	0.98	0.99	0.98	01/09/2004 to 28/03/2005

intersections (Figure 3), coincided with an increase in soil temperature (Figure 1). While the optimal temperature for grapevine root growth has been described as 25 to 30 ºC (Kliewer, 1975), in this study the maximum intensity of annual root growth was not related to mean annual temperature, but rather to soil thermal diffusivity through a lineal model (Figure 5). The results obtained indicate that the soils present apt temperatures for the development of the root system throughout the year, estimating that the soils of the Copiapó and Huasco Valleys, with high thermal diffusivities, present favorable thermal conditions for the development of grapevine root systems.
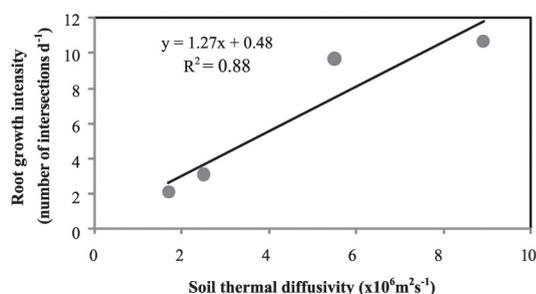
Figure 5. Annual root growth rate of 'Thompson Seedless' grapevines, according to soil thermal diffusivity. Values of four rhizotrons in the Copiapó and Huasco Valleys, Atacama Region, Chile.

CONCLUSIONS

In accordance with the conditions under which the study was carried out, it was concluded that in the highlands of the Copiapó and Huasco Valleys (desert highland climate) cv. Thompson Seedless presents continuous root growth at different soil depths, increasing in intensity at flowering and harvest and decreasing to minimal levels in July.

The maximum intensity of annual root growth of this cultivar is highly variable, as is the depth of root distribution.

The average annual soil temperature was not related to the maximum intensity of annual root growth of 'Thompson Seedless'.

Variation in annual root growth varied correlated with soil thermal diffusivity.

RESUMEN

Relación entre el crecimiento radical de vid 'Thompson Seedless' y la temperatura del suelo. Con el objetivo de caracterizar el crecimiento del sistema radical de la vid (*Vitis vinifera* L.) cv. Thompson Seedless y su relación con la temperatura del suelo, durante la temporada 2004-2005 se llevó a cabo un estudio en parronales ubicados en los valles de Copiapó y Huasco. Se instalaron cuatro cámaras de observación de raíces o rizotrones en plantas homogéneas, en plena producción, pie franco, sanas, y ubicadas en diferentes localidades de la región. Las mediciones del crecimiento de las raíces se efectuaron semanalmente, desde septiembre de 2004 hasta completar 1 año, estimándose la intensidad de crecimiento radical anual y su distribución en los rangos de 0 a 40, 40 a 80 y 80 a 120 cm de profundidad. Adicionalmente, se instalaron sensores de temperatura a 25, 50, 75 y 100 cm de profundidad y se registró la temperatura cada 1 h. Con los valores de temperatura media anual y amplitud térmica anual se calculó la difusividad térmica de los suelos. Se observó crecimiento radical durante todo el año presentando menor intensidad en el mes de julio (invierno). Las raíces mostraron diferentes patrones en la distribución de la intensidad de crecimiento en los tres rangos de profundidad, con variaciones entre los sitios de hasta cinco veces en la máxima intensidad de crecimiento anual. Suelos con difusividades térmicas altas presentaron ambientes favorables para el crecimiento de raíces.

Palabras clave: raíces, difusividad térmica, uva de mesa.

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