Effect of permanent partial root-zone irrigation on *Meloidogyne ethiopica* parasitising roots of *Vitis vinifera* rootstock SO4

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Summary. In Chile *Meloidogyne ethiopica* often causes death of plants in vineyards with drip irrigation, where the dry season leaves part of the roots in dry soil. The effects of *M. ethiopica* on grapevine were evaluated in conditions of permanent partial irrigation. The study was conducted in series of experiments where roots were divided into two planters with sandy soil under glasshouse condition. The partial irrigation was simulated by watering only one of the two or both of the planters and with water treatments once or twice per day, and some infected with *M. ethiopica*. After 6 months, the quality and weight of roots and size of above ground plant parts were evaluated and measured. The permanent partial irrigation resulted in higher quality and weight of roots; however, it further aggravates the consequences of infection, especially when *M. ethiopica* was present in irrigated soil. *Meloidogyne ethiopica* decreases the ability of the plant to preserve plant roots in areas without irrigation.

Key words: grapevine, host-parasitic relationship, hydraulic redistribution, soil moisture.

During the last decades grapevine (*Vitis vinifera* L.) plantations have tended to be established with a drip irrigation system, which gives them several advantages. Such technology promotes root concentration at the edge of irrigation zone growing towards the inter-row where higher oxygen and less water are found. During rainy season, the zone is bigger and, thus, roots can grow into it; during the dry season, the irrigated area is reduced, consequently causing many active roots to be left out the irrigated area (Magunacelaya, 2009).

It is known that if one part of the root system is in dry soil, the root wets the soil though hydraulic redistribution from the areas with water available for absorption, allowing the plant to cope with water stress (Eissenstat *et al.*, 1999; Domec *et al.*, 2004; Bauerle *et al.*, 2008a; Bayala *et al.*, 2008). However, when the root in the arid region of the soil detects drying, it produces hormonal changes, including an increase of up to 10 fold of abscisic acid (ABA) in the roots (Stoll *et al.*, 2000), even when the amount of water in the plant is enough to meet the demand (Taiz & Zeiger, 2002). The ABA strengthens the root in drying conditions, maintaining growth (Sharp *et al.*, 1994) and increases the hydraulic conductivity (Zhang *et al.*, 1995).

Apart from the effects of irrigation on plant, the presence of root-knot nematodes, *Meloidogyne* spp. should be also considered (Magunacelaya *et al.*, 2005). The effects of root-knot nematodes is proportional to the number of juveniles infesting the roots, which include altering the balance of nutrients, impaired branching and root extension, reducing the rate of photosynthesis, and inhibiting root and shoot growth (Magunacelaya & Dagnino, 1999). The cv. Chardonnay is especially sensitive to the effects of *Meloidogyne* spp. (Aballay *et al.*, 2013; Howland *et al.*, 2015), whereas SO4 rootstock is tolerant to *Meloidogyne* spp. (McKenry & Anwar, 2006).

Meloidogyne ethiopica Whitehead, 1968 is one of the most aggressive species infecting many plant species (Carneiro *et al.*, 2007) and causing severe damage to agriculture (Magunacelaya *et al.*, 2005). This nematode was described from Tanzania and it is considered an invasive species in Chile, where it is found from Copiapó Valley to Talca (Carneiro *et al.*, 2007). This species has also been reported in other South American countries, Brazil (Carneiro *et al.*, 2003) and Perú (Murga-Gutierrez *et al.*, 2012), and in South Africa and several Mediterranean countries, including Greece (Conceição *et al.*, 2012) and Turkey (Aydinli *et al.*, 2013), and in Slovenia (Širca *et al.*, 2004; Strajnar *et al.*, 2009).

Among factors affecting root knot nematodes, irrigation is a main factor (Wallace, 1968). Water is

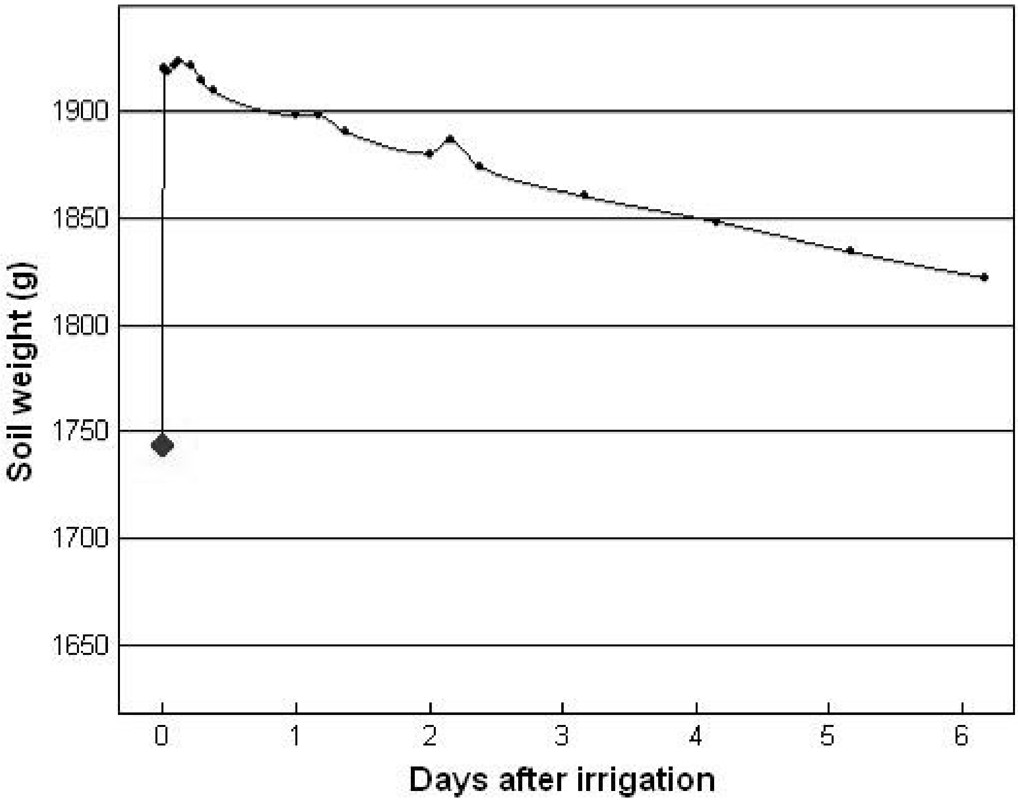

Fig. 1. Water retention in the sandy soil used in this study. In order to assess the soil water retention, three perforated planters with 1.5 l of sandy soil were used. They were weighed dry and irrigated with 250 ml every 5 minutes for 30 min. Subsequent measurements were taken after 1, 2, 3, 5, 7, and 9 h after irrigation. Two days later they were weighed three times a day and the subsequent four days just once a day.

necessary for hatching (Mohawesh & Karajeh, 2014). Water transports soluble root exudates, which induce chemotaxis of juveniles (Reynolds *et al.*, 2011). Juveniles start to search for roots in water films on the surface of soil particles (Fujimoto *et al.*, 2010); host infestation is reduced when there is less water in the soil (Mohawesh & Karajeh, 2014). With alternating partial root zone irrigation it has been shown that the population density of *M. javanica* decreased in comparison to treatments with daily watering (Shin *et al.*, 2007); however, the alternating partial root zone irrigation every 2 weeks might produce a different effect when partial irrigation supplies were continuous.

Our glasshouse study attempted to replicate some of the conditions observed in a vineyard growing cv. Cabernet Sauvignon producing 1 million kilos of fruit, equivalent to the production on 80 ha. The vineyard was located in Talca, in the Maule Region of Chile (35°26'00" S and 71°40'00" W) with a warm temperate climate and annual rainfall between 720 and 730 mm concentrated from May to August, favouring root growth outside the area moistened by drip irrigation. However, after several years of the cumulative effect of drought, in 2008 only one-sixth part of the vineyard was irrigated. This situation leads to the questions: what was happening to the root when irrigation is continuously wetting only one part of the root zone leaving the other part without water, and how does this condition influence the effect of phytoparasitic nematodes on the plant. We hypothesised that *M. ethiopica* will be present in the most watered root zone of a plant, producing greater damage than in the zones with less irrigation, based on the previously described published data.

MATERIALS AND METHODS

Location and preparation of pots. The experiment was conducted in a glasshouse under controlled conditions of temperature and humidity (26ºC and 67% RH on average, respectively) located in Viña del Mar, Chile. A sandy soil was used (particle size see Table 1) with low water retention (Fig. 1) so as to heighten the effects of frequent irrigation and to favour the movement of *Meloidogyne* sp. (Prot & Van Gundy, 1981; Magunacelaya & Dagnino, 1999; Fujimoto *et al.*, 2010; Jaraba *et al.*, 2014). *Vitis vinifera* cv. Chardonnay plants were used on rootstock SO4, described as tolerant to *Meloidogyne* spp. (McKenry & Anwar, 2006). The term tolerance is related to the ability of the host to support or recover from the harmful effects of nematode attack, allowing multiplication but the performance of the plant is not affected (Trudgill, 1991; Dalmasso *et al.*, 1992).

Each vine was planted dividing its roots in two planters. Half of the root system was planted in a first planter, and the other half of the root was planted in a second planter (Fig. 2). Both planters held 2 l of soil with drainage. After planting, seedlings were watered daily for 1 month so that they would establish in the two planters. After a month, irrigation treatment was applied.

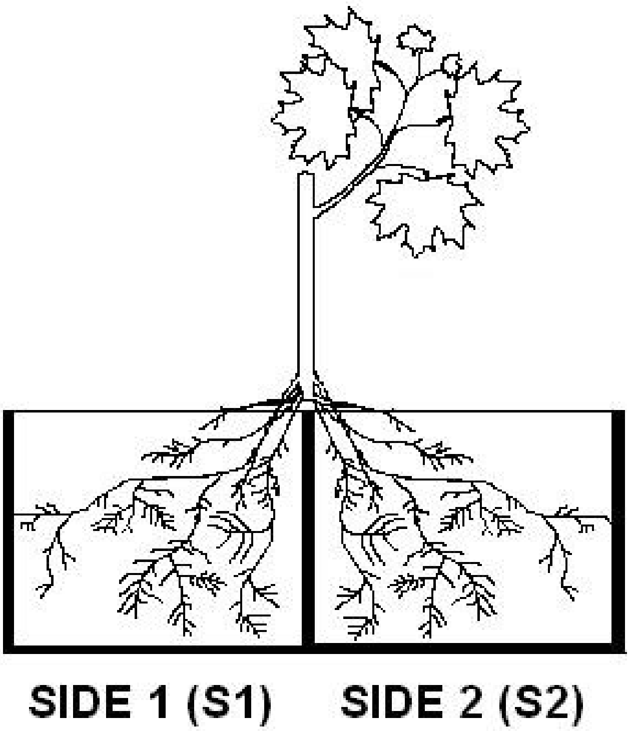

Fig. 2. *Vitis vinifera* with roots divided and tied up in Planter A and Planter B. This figure is a representation of an experimental unit. There were different irrigation management and nematode (*Meloidogyne ethiopica*) inoculations in each planter (see Table 2).

Treatments. One plant with root divided in two planters (containers) was considered as an experimental unit of treatment (Fig. 2). The complete list of treatments is given in Table 2. The number of irrigations per day varied from one to two. Each watering included 250 ml of water per container, which is the equivalent of completely wetting the 2 l of soil. The irrigation was performed manually.

***Meloidogyne ethiopica* source and pot inoculation.** *Meloidogyne ethiopica* second-stage juveniles (J2) were obtained from infected vines from the Valle de Casablanca, Valparaíso, Chile by the blender technique (Magunacelaya, 2009) and inoculated 1 month after planting, when the roots were established and likely to be attractive for nematodes. Each planter was inoculated in three holes near the root with 400 J2 concentrated in 3 ml of water.

Measurements. Plants were evaluated after 6 months. The grafting without leaves was weighed to measure the growth of the aerial part of the vine. Live and dead roots were weighed separately. The root was considered dead when symptoms of necrosis were evident outside and inside plant tissues. In order to measure the quality of the roots, a root rating scale of 1-6 was used to assess the damage caused by nematodes (Fig. 3). Scale 1 represents the maximum deterioration, with galls induced by *M. ethiopica* and the absence of fine roots and great proportion of dead roots; scale 6 represents roots without galls and an abundance of fine roots. The roots divided into two planters were evaluated separately. The soil moisture was measured daily during the first month with a Grove Moisture Sensor (SKU: SEN92355P) connected to an Arduino Uno programmed with the open coded software (http: //seeedstudio.com/wiki/Grove_-_Moisture_Sensor) from Seeed Technology Inc. Three perforated planters with 1.5 l of sandy soil were used. They were weighed dry and irrigated with 250 ml every 5 minutes for 30 min. Subsequent measurements were taken after 1, 2, 3, 5, 7, and 9 h after irrigation. Two days later they were weighed three times a day and the subsequent four days just once a day.

Experimental design. The experiment was a completely randomised design with eight replications (plants) per treatment. The program Sigmastat 2.0 (Jandel Corp.) was used to analyse the data. For the statistical analysis of the weight of the live and dead roots, as well as the pruning weight, analysis of variance was used as a pathway with logarithmically data. The Kruskal Wallis test was used to compare the averages of root quality of the treatments ($P \leq 0.05$).

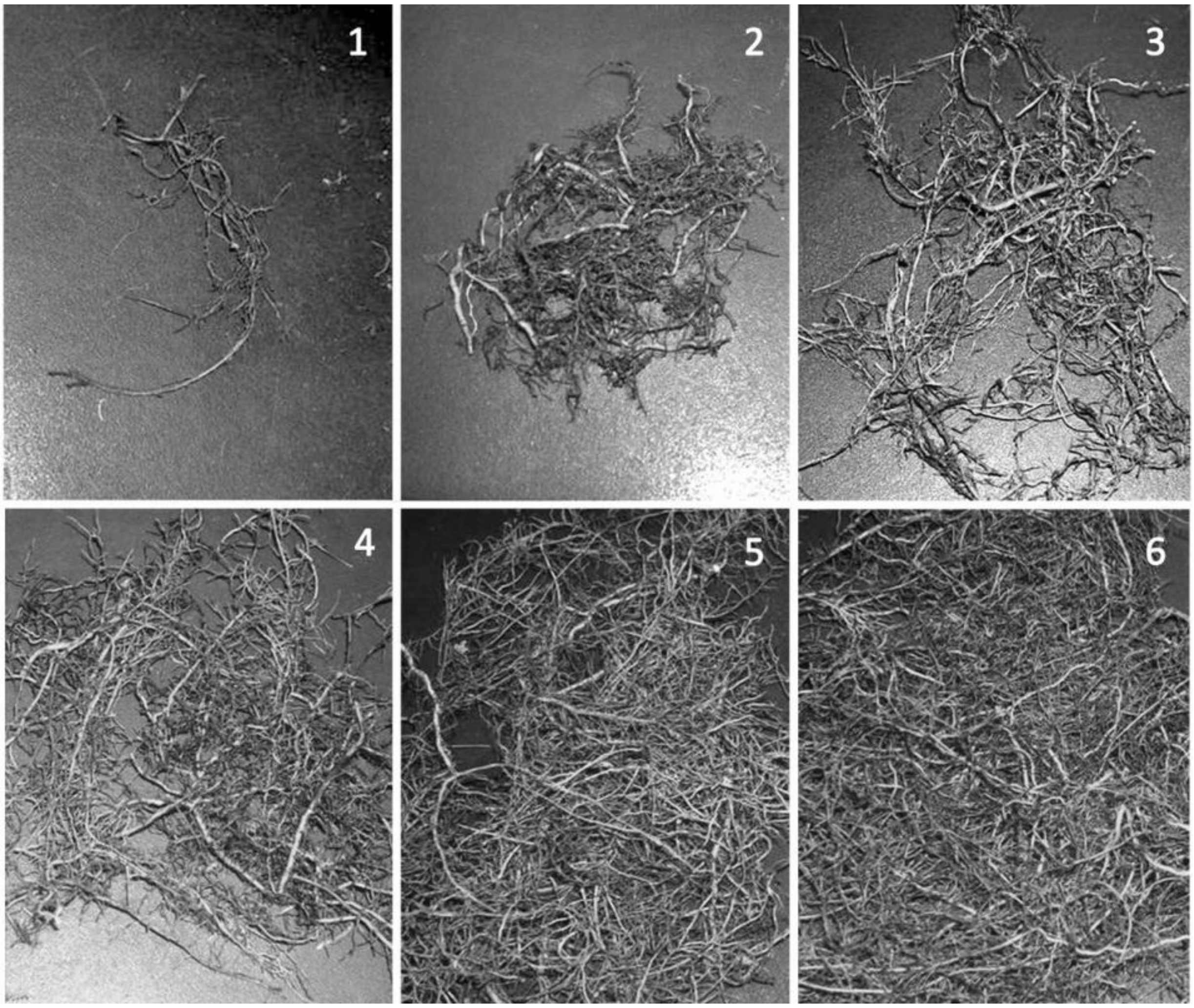

Fig. 3. Qualification scale from 1 to 6 to evaluate root quality, using the criteria: the root system size, abundance of fine roots and branches, proportion of dead roots and the abundance of galls produced by *Meloidogyne ethiopica*. Scale 1 represents the maximum deterioration, with galls induced by *M. ethiopica* and the absence of fine roots and great proportion of dead roots; scale 6 represents roots without galls and an abundance of fine roots. The roots divided into two planters were evaluated separately.

RESULTS

Treatments in which Planter A was irrigated twice daily, while Planter B was not irrigated (PA2i-PBni, PA2i-PBni*Me*, PA2i*Me*-PBni, PA2i*Me*-PBni*Me*). The section of roots that presented the highest quality and weight was that found in the watered Planter A; however, the section of the root that was not watered (Planter B) also achieved good quality: average 4.4 out of 6 (Treatment PA2i-PBni) (Fig. 4).

When only one section of root was infected, the quality of the complete root system was diminished, including the quality of the non-infected part of the root (Treatments PA2i-PBni*Me* and PA2i*Me*-PBni). When the root section in Planter B was infected and without irrigation, its quality decreased and, consequently, there was a significant reduction of quality of the roots in Planter A. The damage in quality and weight of the root was significantly greater when the irrigated zone was with *M. ethiopica* (Planter A) in comparison to when it was infected without watering (Planter B) (Fig. 4).

The lower quality and weight of root in both Planter A and Planter B was obtained in treatment PA2i*Me*-PBni*Me*, where the entire root was infected with *M. ethiopica*. In this case, quality of the root in the irrigated zone was significantly higher than the area without irrigation (Fig. 4). The soil moisture in Planter A ranged between 85-95%, while it ranged 60 to 90% in Planter B.

Table 1. Soil granulometry (sample weight 250 g).

Particle size (in mm)	Particle type	Weight (g)	Percentage (%)
> 2.00	Large particles	3.1	1.3
0.6-2.0	Thick sand	8.1	3.3
0.25-0.59	Medium sand	105.9	43.2
0.106-0.24	Fine sand	111.7	45.6
0.053-0.105	Fine sand	13.4	5.5
0.045-0.052	Wafer-thin sand	2.3	0.9
< 0.045	Silt plus clay	0.5	0.2

Table 2. Treatments of the plants with divided roots in two planters.

Treatments	
Planter A, 2 irrigations/day without *M. ethiopica* - Planter B, no irrigation without *M. ethiopica*	(PA2i-PBni)
Planter A, 2 irrigations/day without *M. ethiopica* - Planter B, no irrigation with *M. ethiopica*	(PA2i-PBni*Me*)
Planter A, 2 irrigations/day with *M. ethiopica* - Planter B, no irrigation without *M. ethiopica*	(PA2i*Me*-PBni)
Planter A, 2 irrigations/day with *M. ethiopica* - Planter B, no irrigation with *M. ethiopica*	(PA2i*Me*-PBni*Me*)
Planter A, 1 irrigation/day without *M. ethiopica* - Planter B, no irrigation without *M. ethiopica*	(PA1i-PBni)
Planter A, 1 irrigation/day without *M. ethiopica* - Planter B, no irrigation with *M. ethiopica*	(PA1i-PBni*Me*)
Planter A, 1 irrigation/day with *M. ethiopica* - Planter B, no irrigation without *M. ethiopica*	(PA1i*Me*-PBni)
Planter A, 1 irrigation/day with *M. ethiopica* - Planter B, no irrigation with *M. ethiopica*	(PA1i*Me*-PBni*Me*)
Planter A, 1 irrigation/day without *M. ethiopica* - Planter B, 1 irrigation/day without *M. ethiopica*	(PA1i-PB1i)
Planter A, 1 irrigation/day with *M. ethiopica* - Planter B, 1 irrigation/day without *M. ethiopica*	(PA1i*Me*-PB1i)
Planter A, 1 irrigation/day with *M. ethiopica* - Planter B, 1 irrigation/day with *M. ethiopica*	(PA1i*Me*-PB1i*Me*)

Treatments in which Planter A was irrigated once a day and Planter B was not irrigated (PA1i-PBni, PA1i-PBni*Me*, PA1i*Me*-PBni, PA1i*Me*-PBni*Me*). When comparing the non-infected treatments in which Planter B had no irrigation, whereas treatments of Planter B had irrigation twice per day (PA2i-PBni) and once per day (PA1i-PBni), results showed that the quality and weight of the roots obtained were significantly lower when Planter A was watered only once. This indicates that irrigation once per day is not the best option (Fig. 4). It should be pointed out that during the treatment period; the moisture on the soil surface was visible in Planter B, which did not receive watering, while Planter A, which held part of root system, was watered twice daily. Planter B was less visibly wet in the treatments where Planter A was watered only once daily.

The quality and weight of root was higher in the portion of roots those were watered (Planter A) with statistical significance equal to the treatments PA2i-PBni, PA2i-PBni*Me*, PA2i*Me*-PBni, PA2i*Me*-PBni*Me*. However, the difference in these treatments is that the mass of the roots was more concentrated in Planter A, with the exception of the treatment where only the root of Planter B was infected with *M. ethiopica*, which significantly decreased the quality of the root in Planter A (watered).

Infection with *M. ethiopica* only in the irrigated Planter A (treatment PA1i*Me*-PBni) produced a higher level of damage in the plant root system than when plants were infected only in the non-irrigated Planter B (treatment PA1i-PBni*Me*). Generally, quality and root weight showed the same trend, but it was less pronounced than that obtained in the treatments in which the Planter A was watered twice per day (Figs 4 & 5).

In treatments where both Planters A and B were infected (PA1i*Me*-PBni*Me*), a high weight of live roots was obtained in Planter A; however, these infected roots had low quality similar to the treatment in which only Planter A was infected. The other part of its root system in Planter B had the lowest root weight in this group of treatments and one of the worst qualities (Figs 4 & 5). The soil moisture in Planter A ranged from 75 to 90% and in Planter B it ranged from 44 to 80%.

Treatments in which Planters A and B were irrigated once a day (PA1i-PB1i, PA1i*Me*-PB1i, PA1i*Me*-PB1i*Me*). The root quality and root weight was similar in Planters A and B (Figs 4 & 5). It serves to highlight that the total root mass in both containers was much more inferior to that found only in Planter A (watered) from treatments PA2i-PBni and PA1i-PBni. Soil moisture in both planters ranged between 81 and 96%.

Aerial part weight. There were no significant differences between treatments (Table 3), the mean weight of the aerial part was generally low and highest weight was obtained from plants watered twice per day in the non-infected Planter A (treatments PA2i-PBni and PA2i-PBni*Me*).

Table 3. Aerial part results.

Treatment	Aerial part weight (g)
PA2i-PBni	3.5a
PA2i-PBni*Me*	3.63a
PA2i*Me*-PBni	2.63a
PA2i*Me*-PBni*Me*	2.75a
PA1i-PBni	3.13a
PA1i-PBni*Me*	1.75a
PA1i*Me*-PBni	3.25a
PA1i*Me*-PBni*Me*	1.63a
PA1i-PB1i	2.75a
PA1i*Me*-PB1i	2.0a
PA1i*Me*-PB1i*Me*	2.0a

Note. Each number represents the average of the 8 repetitions. Numbers are followed by the same letter do not differ significantly.

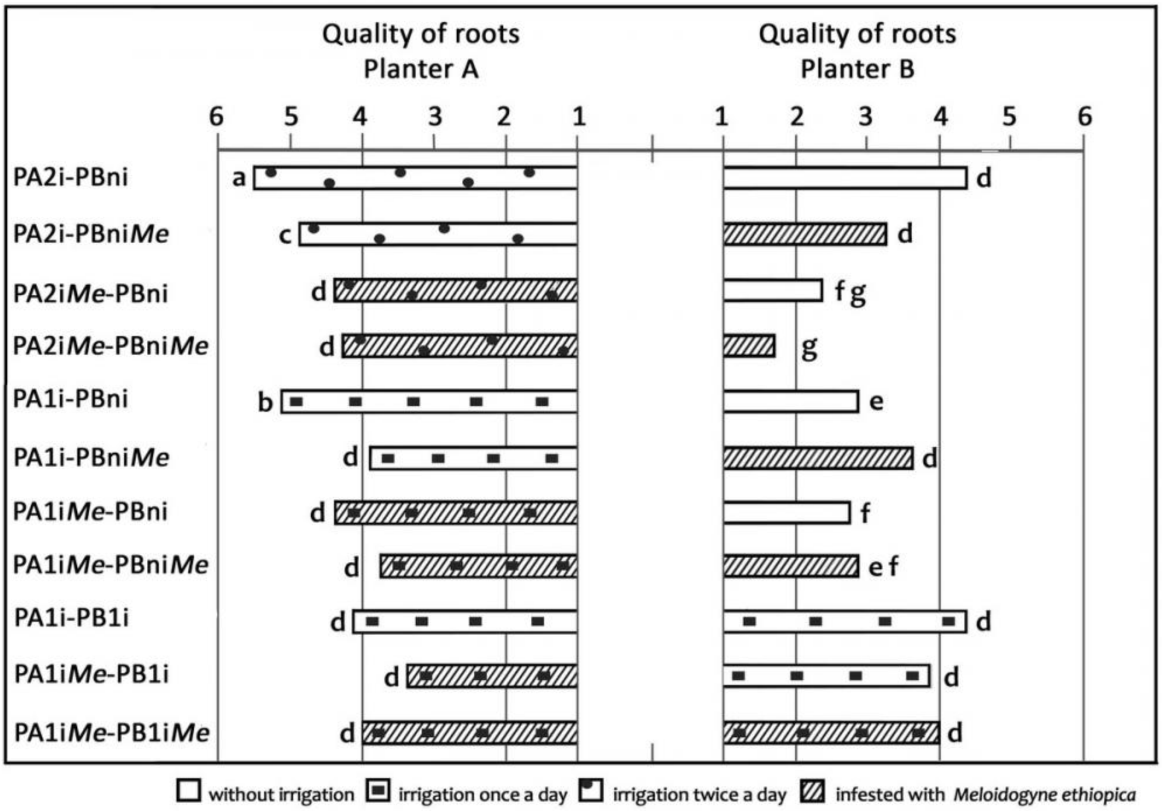

Fig. 4. Quality of roots of both Planter A and Planter B for each treatment, evaluated on a scale of 1-6 (see Fig. 3 legend). Bars followed by the same letter do not differ significantly.

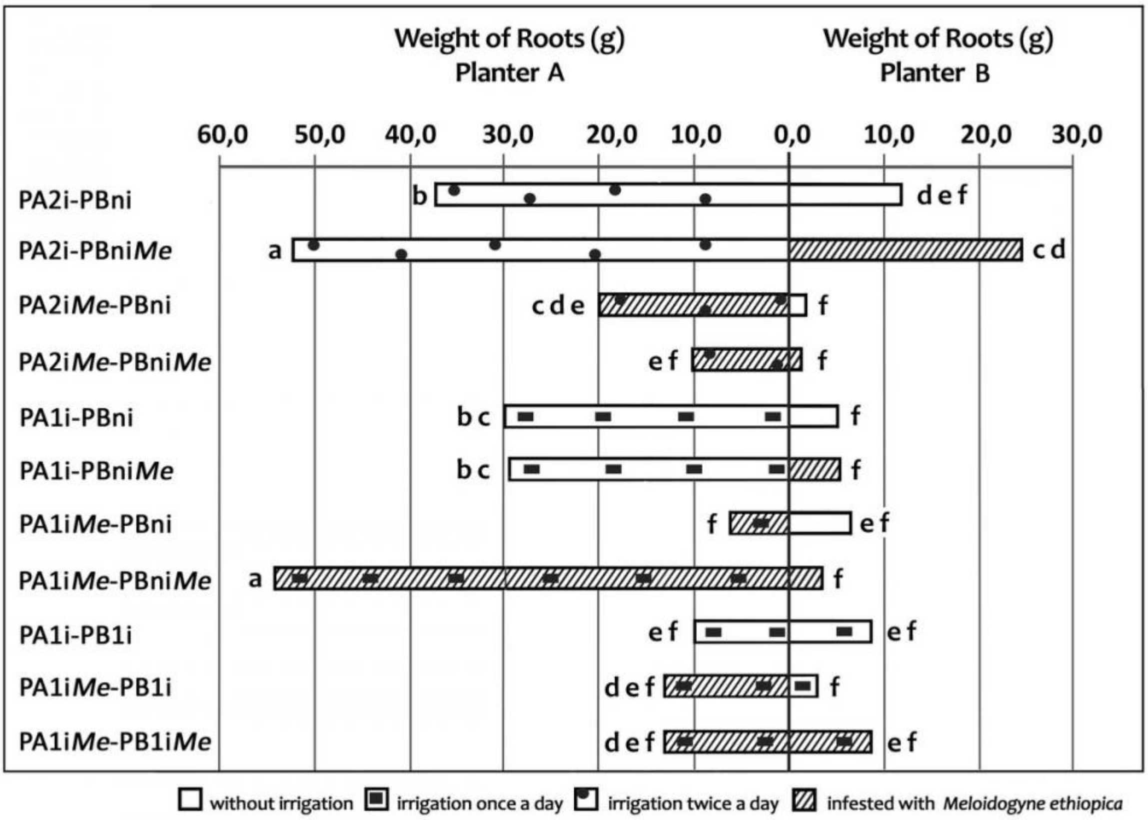

Fig. 5. Weight of live roots of both Planter A and Planter B for each treatment. Bars followed by the same letter do not differ significantly.

DISCUSSION

Our study showed that the weight of roots does not always correlate with their quality. Heavy root systems were obtained but had an excess of thick roots or galls; by contrast, roots with a lighter weight had an abundance of fine roots and branches, without galls.

The root system. Treatments in which Planter A were irrigated twice daily, while Planter B was not irrigated (PA2i-PBni, PA2i-PBni*Me*, PA2i*Me*-PBni, PA2i*Me*-PBni*Me*). The irrigation process in this group of treatments allowed the highest root quality, which is explained by the fact that watering Planter A twice a day was enough to cover the demand in both the aerial portion and the roots that were also in the soil that did not receive irrigation; however, the roots in Planter B without irrigation presumably detected a water deficit triggering the synthesis of ABA (Barceló Coll *et al.*, 1990), which stimulated the root growth (Waisel *et al.*, 2003) explaining the excellent root quality.

However, by including *M. ethiopica* in treatments, the water condition in the soil became a factor that aggravated the condition of the root. The state of the root was very different if the infected portion was the root received irrigation (Planter A) than if the infected area was the part of the root without irrigation (Planter B). This can be explained though the sensory and motor system of the *M. ethiopica* J2, which use water for movement, facilitating the capture of soluble root exudates and increases survival (Magunacelaya & Dagnino, 1999). Once installed in their feeding sites, root-knot nematodes substantially decrease the absorption of water and nutrients by the host plants (Caillaud *et al.*, 2008).

When the non-irrigated root in Planter B was infected, damage to the entire root of the plant resulted and functionality was affected because the irrigated portion was not able to sustain the entire root system; it is difficult to explain how J2 moved to damage the root system in the absence of water in the soil. The redistributed water can passively leave the root into the dry soil and hydrate the rhizosphere (Richards & Caldwell, 1987; Caldwell *et al.*, 1998). Therefore, the hydraulic redistribution could be low enough in the soil of Planter B to allow the mobility of the J2 nematodes to invade the roots and eventually form galls. Hans-Holger & White (2008) consider that the water escaping from the roots for hydraulic redistribution may benefit soil organisms.

The hydraulic redistribution has the ability to mitigate the water stress of the portion of the root without irrigation, increasing the survival of the roots and allowing the fine roots to continue their functions (Williams *et al.*, 1993; Matzner & Richards, 1996; Warren *et al.*, 2007), similar to the results of Bauerle *et al.* (2008a) where the root's survival in the non-irrigated zone was similar to the watered root zone.

In treatment infected with *M. ethiopica* in the irrigated planter (PA2i*Me*-PBni and PA2i*Me*-PBni*Me*), the quality of roots in Planter A was significantly reduced. Such roots with reduced quality and weight would have less capacity for water absorption and less water available to redistribute to the non-irrigated part of the roots. This interpretation is supported by comparing the results of Planter B's roots, where there were no statistical differences between treatments PA2i*Me*-PBni, PA2i*Me*-PBni*Me*, and PA1i-PBni, the last treatment being non-infected.

Treatment PA2i*Me*-PBni shows that the most damaged part of the root is not necessarily the nematode infected part. This may explain why the translocation of water decreases the resistance to water flow generated by the hypertrophied cells of the feeding sites of *M. ethiopica* (Magunacelaya & Dagnino, 1999), when the lack of water results in the hydraulic redistribution to the roots in Planter B becoming more difficult (Bauerle *et al.*, 2008a).

Treatments in which Planter A was irrigated once a day and Planter B was not irrigated (PA1i-PBni, PA1i-PBni*Me*, PA1i*Me*-PBni, PA1i*Me*-PBni*Me*). The plants in these treatments, while receiving only one watering per day, have less water available than the plants in treatments PA2i-PBni, PA2i-PBni*Me*, PA2i*Me*-PBni, PA2i*Me*-PBni*Me*. Root growth of these plants was stimulated in the soil that received a watering, which is consistent with the results of Bauerle *et al.* (2008b), demonstrating that a plant of enhanced vigour has greater morphological plasticity in response to lateral heterogeneity in soil moisture, but similar tolerance to moisture stress as indicated by root survivorship in dry soil.

The hydraulic redistribution could not have been as high as it was in treatments PA2i-PBni, PA2i-PBni*Me*, PA2i*Me*-PBni, PA2i*Me*-PBni*Me*, since watering only once daily means less stock of water to redistribute to the roots of Planter B which received no irrigation. In this regard, Bauerle *et al.* (2008a) considered that the plants with a higher level of hydric stress would have greater difficulty to rehydrate the dry tissue overnight. This could explain the lower root mass in Planter B, equivalent to the root mass in Planter B from treatments PA2i*Me*-PBni and PA2i*Me*-PBni*Me*, which also would have received less water due to the nematode infection in Planter A.

The effect of *M. ethiopica* in the root quality of this group of treatments is less drastic than in treatments PA2i-PBni, PA2i-PBni*Me*, PA2i*Me*-PBni and PA2i*Me*-PBni*Me*, the water conditions based on irrigation performed only once per day in Planter A, disadvantaged the nematode, preventing expression of a higher level of damage as seen in the treatments with the highest frequency of irrigation in Planter A. The more frequent irrigation facilitates movement and host location by *M. ethiopica* (Magunacelaya, 2009; Magunacelaya & Dagnino, 1999, Van Gundy *et al.*, 1967).

Comparison of the quality of roots of Planter B from treatments PA1i-PBni and PA1i-PBni*Me* shows that the presence of *M. ethiopica* in the Planter B resulted in significant increase in the quality of the root in the Planter B; this observation warrants further studies to explain the link between partial irrigation and the effect of the nematodes.

In treatment PA1i*Me*-PBni*Me*, with both planters infected with *M. ethiopica*, a greater weight of concentrated roots was obtained in Planter A; however, the other measurements indicate that it was not a vigorous root. The combination of high weight and low quality in Planter A of treatment PA1i*Me*-PBni*Me* could be explained by a combination of the effects of a lack of water in the Planter B, and the stimulated root growth in the areas with access to water (Bauerle *et al.*, 2008b) and the infestation with *M. ethiopica* that caused an increase in the root's weight (Magunacelaya & Dagnino, 1999). In this treatment, in addition to the increased weight in Planter A, the lowest pruning weight of the plant of all treatments was obtained.

Treatments in which Planters A and B were irrigated once a day (PA1i-PB1i, PA1i*Me*-PB1i, PA1i*Me*-PB1i*Me*). Statistically, *M. ethiopica* did not affect the results of the quality and weight of the roots, which proves the hypothesis that the damage caused by *M. ethiopica* is greater when part of the root system is in the non-irrigated soil. When the entire root system with access to water does not tend to be concentrated in one place and roots can be more widespread and reach more nutrients (Keller, 2005), the nematodes may also be dispersed in the roots and not concentrated in the damaged part. In the treatments, in that part of the root system that was not watered, the infection was more damaging in the roots that were only absorbing water. The total mass of the root system obtained in these treatments is less than that of the partial irrigation treatment PA1i-PBni*Me*, which indicates that when part of the root system is in the non-irrigated soil, the root grows more, possibly due to the lack of water detected by the non-irrigated roots that stimulates root growth (Barceló Coll *et al.*, 1990; Waisel *et al.*, 2003; Bauerle *et al.*, 2008b).

Aerial part weight. Although no statistically significant differences were demonstrated, one can predict that the root condition would eventually be expressed in the aerial part of the plant if the study had lasted longer. The aerial part of plant is an expression of the functionality of root, it is known that if the roots have difficulty absorbing water and nutrients, a lower pruning weight is produced (Gregory, 2006) and if a water deficit induces the production of ABA, this will reduce growth of the aerial part of plant (Barceló Coll *et al.*, 1990; Waisel *et al.*, 2003; Shellie, 2006) favouring the root (Azcon-Bieto & Talón, 2000; Taiz & Zeiger, 2002; Waisel *et al.*, 2003). In the case where the plant is infected with *M. ethiopica*, it will diminish aerial growth (Magunacelaya & Dagnino, 1999). Dry & Loveys (1999) have shown that in drying part of root, leaving one part very well irrigated so that the hydric state of the buds are not altered, the vegetative growth is reduced significantly and the stomatic conductivity changes. Based on these precedents, one can expect that if the treatments had been for several seasons, differences in root condition between treatments eventually would be presented in the weight of aerial part.

The risk of phytosanitary problems using the drip irrigation system is higher than when watered in the traditional fashion, by irrigation trenches or by flood irrigation. The risk is by providing water when it is unnecessary, thereby affecting the activity of the roots. The highest quality and weight of roots is obtained by leaving a portion of the soil without watering, compared to when the entire root zone is irrigated, possibly because partial irrigation takes advantage of the mechanisms to stimulate plant root growth (Barceló Coll *et al.*, 1990; Waisel *et al.*, 2003; Bauerle *et al.*, 2008b). It is important that the irrigated zone has good aeration so as to allow growth of the roots.

However, when *M. ethiopica* is added to the system, permanent partial irrigation becomes a less attractive option, since the quality and weight of roots is decreased significantly compared with a full watering of the root zone is performed. These latter conditions can be found in the vineyards irrigated with drip irrigation during a dry season, which could better protect the roots of the plant from a parasitic nematodes attack by applying a homogeneous irrigation to wet the entire root zone. The nematode generates more damage when found in soil that receives more frequent irrigation, given that the nematode is favoured by the constant presence of water in the soil (Magunacelaya & Dagnino, 1999; Fujimoto *et al.*, 2010; Reynolds *et al.*, 2011, Mohawesh & Karajeh, 2014); thus, to decrease the level of nematode damage, irrigation should be conducted less frequently to allow good root production. When a root section is infected with *M. ethiopica*, the quality and weight of the entire root system can be jeopardised, including the roots of the plant that are not within reach of nematodes.

Roots that are more frequently watered may maintain parts of the root system that is in a non-irrigated zone, thus producing higher quality and root weight through hydraulic redistribution (Bauerle *et al.*, 2008a). These roots can be crucial for the plant, which allows them to use soil nutrients more effectively (Caldwell *et al.*, 1998). However, *M. ethiopica* drastically reduces the ability of plants to maintain root growth in dry areas, so infested vineyards should seek to irrigate the maximum volume of the soil as possible.

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J.C. Magunacelaya, C. Ramírez and S. González-Bernal. Воздействие постоянного орошения части корневой зоны на развитие нематод *Meloidogyne ethiopica* на корнях *Vitis vinifera* с подвоем группы SO4.

Резюме. В Чили *Meloidogyne ethiopica* вызывает гибель растений винограда на плантациях с капельным орошением, если в сухой сезон часть корней остается в сухой почве. Вредоносность *M. ethiopica* на винограде оценивали в условиях постоянного орошения части корней. Были поставлены эксперименты с разделением корней одного растения между двумя емкостями с песчаной почвой. При этом, капельное орошение было подведено либо к обеим, либо лишь к одной емкости с почвой, в которые вносили или не вносили инвазионный материал *M. ethiopica*. После 6 месяцев оценивали и измеряли состояние и вес корней, а также размер надземной части растений. Постоянное орошение части корневой зоны давало здоровые корни большего веса, однако орошение также усиливало вредоносный эффект, при наличии *M. ethiopica* в орошаемой почве. Показано, что *Meloidogyne ethiopica* снижает способность растений к сохранению здоровой корневой системы при недостатке влаги.