SCAP
SOCIEDADE DE CIÊNCIAS AGRÁRIAS DE PORTUGAL

Study on yield values of two irrigation systems in adult chestnut trees and comparison with non-irrigated chestnut orchard

Estudo de rentabilidade entre dois sistemas de rega em castanheiros adultos e comparação com soutos não regados

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http://dx.doi.org/10.19084/RCA17233

Received/recebido: 2017.09.09
Received in revised form/recebido em versão revista: 2017.09.22
Accepted/aceite: 2017.09.29

A B S T R A C T

Different types of irrigation systems can be used in chestnut orchards. To understand which one grants higher yield values treatments were applied in adult trees: drip system – TI; micro-sprinkler system – SI; non-irrigated system – NI. The study covers two years in the northeast of Portugal. Irrigation was triggered every time stem water potential was lower than -1.2 MPa. The study considers costs with the equipment, water and labour, and the income from the chestnuts' sale. Due to the hotter conditions of 2016 more water was supplied (93 mm) than in 2015 (47 mm). Little more water was furnished in SI (73 mm) than in TI (67 mm). Production was 27% higher in irrigated (48 kg/tree) than in NI trees (38 kg/tree) and in relation to the canopy's area (kg/m^2) the TI produced 18% and SI 29% more than NI. Annual costs were higher with irrigation (4654, 4549 and 1530 €/ha for SI, TI and NI, respectively) but the higher income (22126, 21984 and 16174 €/ha for TI, SI and NI respectively) made up for the investment. The profits from irrigated trees can be 22% or 37% higher than in non irrigated ones, for 1 ha or 5 ha, respectively.

Keywords: *Castanea sativa* Mill., water management, water potential, production, economic.

R E S U M O

Para avaliar qual dos dois sistemas de rega se revela mais eficiente em castanheiro, foram estudados três tratamentos: sistema de gota-a-gota – TI; sistema de micro-aspersão – SI; sistema não irrigado – NI. O estudo abrange dois anos no nordeste de Portugal. A rega foi ativada sempre que o potencial hídrico de ramo era inferior a -1,2 MPa. O estudo considera os custos com equipamentos, água e mão-de-obra e os proveitos da venda das castanhas. O ano 2016 foi mais quente tendo sido fornecida mais água (93 mm) do que em 2015 (47 mm). Foi fornecida um pouco mais em SI (73 mm) do que em TI (67 mm). A produção foi 27% superior nas árvores regadas (48 kg/árvore) do que em NI (38 kg/árvore) e em relação à área da copa (kg/m^2), TI produziu 18% mais do que o controlo NI, assim como o SI produziu mais 29%. Os custos anuais foram maiores em SI (4654 €/ha) e TI (4549 €/ha) do que em NI (1530 €/ha), tendo a maior receita compensado o investimento (22126 €/há TI, 21984 €/ha SI e 16174 €/ha NI). Os lucros das árvores regadas pode ser 22% ou 37% maior do que as não irrigadas, para 1 ha ou 5 ha, respetivamente.

Palavras-chave: *Castanea sativa* Mill., gestão da água, potencial de ramo, produção, balanço económico

INTRODUCTION

Over the past decades global chestnut production has slowly integrated new techniques of agricultural production transitioning from a forestry crop to a fruit crop. This is especially true in China, the world's largest chestnut producer (1.650.000 tons; FAO, 2012), in some orchards in France (Vernol, 2013) and Chile (Valderrama, 2016). However, this is not as common as it seems in Portugal, the third largest European chestnut producer with 27.337 tons in 35.436 hectares (INE, 2015). Nevertheless, Portuguese producers have been implementing some new techniques on chestnut orchards such as ink disease resistant rootstocks, hybrid varieties, irrigation, adequate fertilizations and high tree densities (Gomes-Laranjo *et al*., 2016). The definition of the better suited irrigation is a common discussion topic within the Portuguese chestnut sector. According to Pereira and Trout (1999) there are three main categories of irrigation systems: 1) surface/gravity irrigation systems – those that depend on gravity to spread the water across the surface of the land; 2) sprinkler systems – in which water is pressurized with a pump, distributed to areas of the fields through pipes or hoses, and sprayed across the soil surface with rotating nozzles or sprayers; and 3) micro irrigation/drip or trickle systems – these systems use regularly spaced emitters on or in the tubing to drip or spray water onto or into the soil. As far as we know there was only one trial conducted by Jayne (2005) that compares different types of irrigation system (drip, sprinkler and micro sprinkler) in a chestnut orchard. However, the choice of the type of irrigation system is not merely dependent on a singular crop but it must consider several factors such as water availability and its purity, soil permeability and its water storage capacity, topography, product value, labour costs, energy costs, capital and technology requirement (Pereira, 2004). According to INE (2015) in Portugal only 447 ha are actually irrigated and on the newest 835 ha planted within the year 2007-2013, 23% are irrigated (PRODER, 2014). In France it is frequent to irrigate chestnut orchards below 50 years of age (Vernol, 2013) and in Chile, the irrigation became common in the new chestnut plantations (Valderrama, 2016). The irrigation systems found in the different orchards of these countries vary from the drip system (with one or two pipes per tree row) to the micro-sprinkler system (with the pipe suspended above the tree trunk and the emitters facing downward). Both these irrigation systems operate at low pressure therefore they require less energy for water pumpage resulting in fewer costs when compared to other high pressure irrigation systems (Talens, 2009; MSU, 2017). According to some authors (Pereira, 2004; MSU, 2017) the drip system has the advantage that can be used in conditions unsuitable for other irrigation methods on steep and undulating slopes, in very sandy soils and in fields with widely varying soils. Drip irrigation places water precisely where it is needed and apply it with a high degree of uniformity, so it lessens water running off the lower end of the field and deep percolation water flowing down through the soil past the root zone where cannot be used by the crop. These features make drip irrigation potentially much more efficient than other irrigation methods which can translate to significant water savings. Drip irrigation can only achieve this level of high efficiency if the system is carefully designed and managed in order to prevent issues such as emitter clogging and differences in emitter flow rates stemming from pressure variations in the irrigation system or from differences in emitters and flow passages originating in the manufacturing process (Talens, 2009; MSU, 2017). The hanging micro-sprinkler system meets two of the chestnut growers' expectations: the weeds are better controlled with proper equipment rather than using herbicides and the largest wet area increases the probability to enhance mushroom production which represents a supplementary income to the producer (Marques, 2007; Martins *et al*., 2011).

The main intention of this work is to evaluate the costs and benefits of two different irrigation systems installed on an adult chestnut orchard and in the end to assess their usefulness to chestnut production based on a study of profitability. This study relies on data obtained from experimental research of two years about water management in an orchard of adult chestnuts trees that can be consulted for more details in Mota *et al*. (2017).

MATERIAL AND METHODOS

Site description

The trial was conducted during 2015 and 2016, in Sortes, a small town belonging to the Bragança Council, located in the northeast of Portugal (41°39'28.16"N; 6°50'37.09"W) at 862 m above sea level. It was carried in a commercial chestnut orchard planted in 1993. The total study area is1.5 ha surrounded by border trees and guard trees within sample trees. The rootstocks are seedlings from *Castanea sativa* Mill. and they are grafted at 2 m height with 'Judia' variety scions. Trees are spaced 5 meters by 10 meters, with a plant density of 200 plants per hectare. Since the first years of plantation the soil is kept with seeded legumes (annual reseeding and perennial) and grass-plot (annual and perennial) that are cut for straw-bale in June. The soil, to the depth of 30 cm, has a medium texture, pH of 5.5, 3.1% of organic matter, low values of phosphorous (39 mg $P_2O_5.kg^{-1}$) and a medium level of potassium (101 mg $K_2O.kg^{-1}$) measured by Égner-Riehm method (Egnér *et al*., 1960).

Treatments

Two types of irrigation systems were used on the chestnut orchard: a drip system (TI) (Figure 1, left) and a micro sprinkler system (SI) (Figure 1, right) and a control treatment with no irrigation (NI). The irrigation was triggered when the midday stem water potential (Ψw_{md}) was bellow -1.2 MPa. The irrigation system features are shown in Table 1. Each one of these treatments corresponds to 0.5 ha (about 100 trees).

Figure 1 - Left: Drip system, two pipes per row of chestnut trees. Right: micro-sprinkler system with suspended pipe and inverted emitters.

Table 1 - Irrigation system features and hydraulic data for drip and micro sprinkler systems given by the irrigation system provider (Magos Irrigation System)

Irrigation System Features		
	Micro Sprinkler system	Drip system
Planting area	0.5 ha	0.5 ha
Plant spacing	10 m x 5 m	10 m x 5 m
Irrigation emitters	JDW Rondo	JDW Hydro PC
Emitters spacing	10 m x 5 m	10 m x 1 m
Emitters debit	51 L/h	3,6 L/h
No. of emitters by tree	1	5
No. of lines by tree row	1	2
Hydraulic data		
Daily water needs for planting area	8 m^3/day	8 m^3/day
Irrigation rate	1,02 mm/h	0,72 mm/h
Flow rate by sector	6 m^3/h	4 m^3/h
Flow rate by hectare	11 m^3/h	8 m^3/h

Both irrigation systems shared the main intake structure which includes a submersible water pump and a compression system equipped with a threaded wedge valve, a disc filter (John Deere Water 7000), a water counter (Arad Multijet) and a 500-litre hydro pneumatic flask and accessories. The main intake structure also includes an irrigation controller (Progrés Agronic 2500) and the fertigation system. The fertigation system is composed by two 500-litre deposits for fertilizer and one injection pump (Doseuro A175N-47-19, 226 L/h 8 kg). Water comes from borehole. This water bore was made 30 years ago and its cost is not considered on this study.

Data collection.

Plant, soil and climatic data: For the purpose of water management, from June to October of 2015 and 2016, the Ψw_{md} was monitored every 7-10 days in ten trees per treatment (n = 30). Ψw_{md} was measured using a pressure chamber (Model "pump-up" PMS Instrument® Corvallis, Oregon, USA) according to the methodology recommended by the manufacturer and adapted by Fulton *et al.* (2014).

One leaf per tree was covered by an aluminium foil and plastic bag for at least 40 minutes before excision. The Ψw_{md} readings were made between 12:00-h and 13:30-h. The soil water content (θ) was monitored every 7-10 days with a capacitive probe (Diviner 2000, Sentek Technologies) from July to October. Access tubes were installed about one meter from the tree's trunk, one tube per tree, in six trees per treatment (n = 18). The probe registers the soil water values every 10 cm until 80 cm depth. To give an overview of the climatic conditions of 2015 and 2016, general meteorological data were gathered from the agro-meteorological bulletins given by the Portuguese Institute of the Sea and Atmosphere on its website (www.ipma.pt) which uses data from a meteorological station located 20 km away from the study site. Growing degree-days (GDD, ºD) was calculated according to Cesaraccio *et al.* (2001): ΣTemperature (ºD) = $(T_{med} - T_0) * n$: where "T_{med}" is the average temperature of each month, "T_0" the base temperature, which was considered 6 ºC for chestnuts (Gomes-Laranjo *et al.*, 2008) and "n" the total days of each month.

on the calibre and on the period of harvesting; being higher in the early and late seasons. The harvest of 'Judia' in the Trás-os-Montes region occurs during the mid-season.

Figure 2 - Delimited area of harvesting below the trees canopy by a red stripe tape for determination of chestnut production per tree.

Chestnut production and price

Chestnut's orchard yield. An area of harvest beneath the canopy of each tree (n=30) was delimited using stripe tape (Figure 2). The chestnuts that dropped within the delimited area were caught and weighted on the field with a manual scale. Chestnut production per tree is given in kilograms of fresh weight (FW). The chestnut orchard yield is given in ton FW/hectare. The production per meters squared of the tree's canopy (kg FW/m^2) was also calculated.

Chestnuts' calibre. Thirty urchins were collected from each treatment in 2015 and 2016. The healthy chestnuts (n = 185 in 2015; n = 211 in 2016) were used to determine the calibre (fruits per kilogram). The chestnuts were weighted (fresh weight) in a digital scale.

Chestnuts' market price. The average value of the chestnut market price was consulted in the website of the governmental database – GPP-SIMA (System of Agricultural Market Information), http://www.gpp.pt/sima.html. In Portugal, the chestnut is marketed in bags of 50 kg. The price is dependent

Economic, natural and labour resources

Economic resources. The economic resource refers to the investment made in the acquisition and installation of the irrigation system as well as the equipment for monitoring trees (pressure chamber) and soil (capacitance probe). It also includes the maintenance and the electric costs for the pump of the irrigation system. The maintenance cost equates to 3% of the total investment.

Water resources. The water resource refers to the water volume (W, in m^3) used during the year for irrigation and its cost. The average water cost was calculated taking as reference the price of 0.06 €/m^3, given after an informal survey on different entities' data.

Labour resources. The labour resource considers the time spent on monitoring the soil and tree parameters needed for irrigation decision as well as the time spent on chestnut harvesting. This last parameter depends on chestnut's production, variety and weather conditions. According to the chestnut orchards owners' registries, in general, a person can harvest about 25 kg/h (200 kg/day) originating harvest's cost of 0.20 €/kg. Two minutes per tree are needed to monitor the Ψw_{md}, including covering the leaf with aluminium foil and plastic bag but excluding the forty minutes needed before the readings. Ten trees were monitored per treatment, once a week, so this cost was of 1.7 € per week per treatment. The other types of labour such as pruning, fertilization, hay cut or phytosanitary interventions were not accounted for.

Study on yield values

The data gathered from chestnut production and from the economic, water and labour resources found in the experimental trial was used to evaluate the yield values achieved on the chestnut orchard. The data is extrapolated for one and for five hectares in orchards with similar conditions to the studied one such as plant's density and chestnut's production per tree. The main intake structure, pressure chamber and capacitance probe are investments considered separately for each irrigation system type.

Statistical analysis

Results of soil water content, Ψw_{md}, tree production and chestnut calibre were analysed using the StatView 4.0 (Abacus Concept) software and comparisons were made with Fisher test ($p < 0.05$).

RESULTS

Plant and climatic data and irrigation events

The average values of monthly maximal (T_{max}) and minimal (T_{min}) air temperature, and monthly relative air humidity (HR) as well as the monthly cumulative precipitation (PP) along the months of 2015 and 2016 are shown in Figure 3. The rainy period typically goes from September to May. In 2016 the period between June and October was drier (total PP of 211 mm) when compared to 2015 (total PP of 310 mm) and it had higher T_{max} in August, September and October (32°C, 28°C and 21°C respectively). The total degree-day from May to October was of 2,348 °C in 2015 and 2,504 °C in 2016.

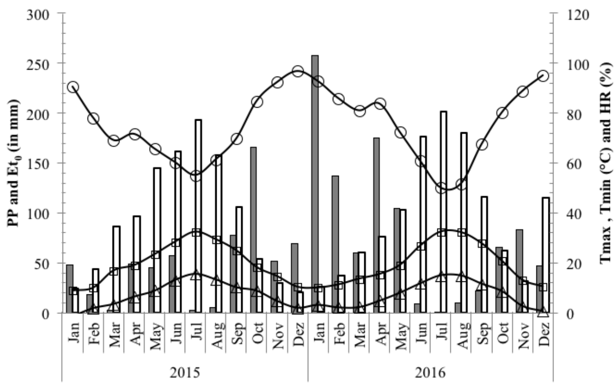

Figure 3 - Mean monthly maximal (□, T_{max}) and minimal (Δ, T_{min}) temperature (in °C), mean monthly relative air humidity (HR, ○, in %), total monthly precipitation (PP, grey bars, in mm) and total evapotranspiration of reference (ET_0, white bars, in mm) for 2015 and 2016 (source: Portuguese Institute of the Sea and Atmosphere, www.ipma.pt).

The monthly mean of Ψw_{md} (± se) in 2015 was -1.08 ± 0.06 MPa for TI and FI and -1.15 ± 0.09 MPa for NI. The monthly mean Ψw_{md} in 2016 was -1.14 ± 0.09 MPa (TI), -1.15 ± 0.06 MPa (SI) and -1.34 ± 0.08 MPa (NI) (Figure 4). Concerning the annual mean soil water content for the 10-40 cm depth it was higher in 2015 (14% in NI; 17% in TI; 15% in SI) than in 2016 (12% in NI; 16% in TI; 13% in SI).

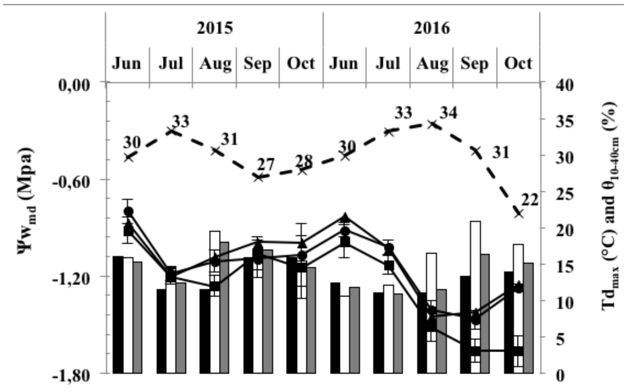

Figura 4 - Figure 4 – Monthly mean of midday stem water potential (Ψwmd, in MPa) for non-irrigated (NI, ■), drip irrigated (TI, ●) and micro-sprinkler irrigated (SI, ▲) treatment with vertical bars as standard error (se). Monthly mean soil water content on the average 10 to 40 cm soil depth (θ10—40cm, in %) for NI (black bars), TI (white bars) and SI (grey bars). Monthly mean maximum air temperature on the measurement days (Tdmax, in °C) is represented by dashed line.

In 2016, because of the drier and hotter conditions, the Ψw_{md} was generally lower than in 2015 which led to different irrigation events and total water volume allocated in each year (Table 2). For both years, the irrigation period started in the third week of July (end of flowering) but it finished later in 2016 (in the end of September). The water supplied in 2015 was 53% and 49% lower than in 2016 for TI and SI, respectively.

Table 2 - Irrigation period, number of irrigation events and total water volume supplied to drip system (TI) and micro sprinkler system (SI) in 2015 and 2016

Year	Treatment	Irrigation Period	Nº of irrigation events	Total Water Volume (mm)
2015	TI	Jul 23rd - Sep 11th	9	46.1
	SI	Jul 26th - Sep 11th	9	47.9
2016	TI	Jul 20th - Sep 30rd	19	87.1
	SI	Jul 20th - Sep 30rd	19	97.9

Chestnut production and market price

In 2015 the harvest occurred from October 22th until November 11th while in 2016 it started one week later (October 28th until November 25th). The chestnut production per tree was about 27%, 16% and 33% higher in 2015 than in 2016 for TI, SI and NI respectively (Table 3). The chestnut orchard yield on TI was 9.7 ton FW/ha, 9.6 ton FW/ha in SI and 7.7 ton FW/ha in NI. The production per canopy's area reduced from 2015 to 2016 about 21%, 10% and 31% for TI, SI and NI respectively. In both years, the NI trees had the lowest chestnut production (0.87 kg/m^2) while TI and SI had 1.0 and 1.1 kg/m^2, respectively, which represents 18% and 29% more production than NI. In spite of variation in nut production within treatments there was not a statistical difference.

The calibre (fruits per kilogram) was higher in 2016 for all treatments which mean that fruits were smaller in this year (Table 4). The calibre was always higher in NI (93 fruits/kg) than in TI (75 fruits/kg) or SI (70 fruits/kg). Statistical analysis revealed no difference on the calibre in 2015 but irrigated trees had significantly bigger fruits in 2016 than non irrigated ones.

Market prices of 50 kg bags of the 'Judia' variety sold during the harvest period of both years are given in Table 5. The chestnut harvest occurred

Table 4 - Chestnut calibre (number of fruits per kilogram of fresh weight) with respective standard error (± se) for drip (TI), micro sprinkler (SI) and non irrigated (NI) treatment in 2015 and 2016. Comparisons were done within treatments on the same year. The values with the same letter, per column, are not significantly different according to the Fisher test, 5%

Treat.	Calibre (Fruits per kilogram ± se)		Fruits/kg
	2015	2016	Average
NI	64.5 ± 4.23a	122.71 ± 8.54a	93.61
TI	61.4 ± 2.12a	88.99 ± 5.14b	75.20
SI	62.7 ± 3.75a	77.71 ± 8.54b	70.21
	%		%
NI	100%	100%	100%
TI	95%	73%	83%
SI	97%	63%	80%

Table 3 - Mean chestnut production per tree (kg of fresh weight/tree) and per square meter of canopy area (kg of fresh weight/m^2) with respective standard error (± se) for drip (TI), micro sprinkler (SI) and non-irrigated (NI) treatments in 2015 and 2016. Comparisons were made within treatments. The values with the same letter per column are not significantly different, according to the Fisher test, 5%

Treat.	Chestnut production (kg/tree ± se)			(kg/m^2 ± se)		
	2015	2016	Average	2015	2016	Average
NI	43.7 ± 5.7a	32.8 ± 7.9a	38.3 ± 4.7a	0.98 ± 0.2a	0.75 ± 0.1a	0.87 ± 0.2a
TI	54.1 ± 3.0a	42.6 ± 8.5a	48.4 ± 4.0a	1.11 ± 0.1a	0.92 ± 0.2a	1.02 ± 0.1a
SI	51.6 ± 6.8a	44.3 ± 10.3a	47.9 ± 6.2a	1.15 ± 0.1a	1.05 ± 0.3a	1.10 ± 0.1a
	%			%		
NI	100	100	100	100	100	100
TI	124	130	127	113	123	118
SI	118	135	127	117	140	129

during the mid-season of Trás-os-Montes region then the called 'frequent price' is the one considered for 'Judia'. The frequent price slightly increased in 2016 (2.2 €/kg) compared with 2015 (2.0 €/kg).

Table 5 - Chestnut market price to the producers in 2015 and 2016. Minimum price (Min), maximum price (Max) and the most frequent price (Frequent). Source: GPP-SIMA, http://www.gpp.pt/index.php/sima/precos-de-produtos-agricolas, accessed at May 2017

	2015			2016			Average		
Price (€)	Min	Max	Frequent	Min	Max	Frequent	Min	Max	Frequent
	1.6	2.4	2.0	1.6	2.7	2.2	1.6	2.6	2.1

Economic, natural and labour resources

Table 6 shows the economic resources used in the trial of 2015 and 2016, in 0.5 ha. The costs of the investment in irrigation systems in 2015 includes the material and installation of the main intake structure (5,429.92 €), the fertigation equipment (1,813.72 €) and the distribution system for TI (2,282.90 €) and SI (2,659.47 €). The main intake structure and fertigation system were, in practice, common costs for both TI and SI systems but they are considered separately. The SI is slightly more expensive not only due to the materials but because installing the emitters on the pipe and extending the pipe over the trees requires more time and labour. In 2016, the economic resources were the annual maintenance costs which are considered to be 3% of the investment. Regarding water resources, more water was used in 2016 than in 2015 for both treatments and costs varied from 14 € to 29 € in half a hectare. The cost to harvesting in these two years was 967 €, 959 € and 765 € per 0.5 ha for TI, SI and NI respectively (Table 6).

Study on yield potential

From the data gathered over these two years is now possible to show the yield potential of the investment on irrigation system in 1 ha of an adult and healthy chestnut orchard with 200 trees of the 'Judia' variety (Table 7). The total investment in the drip system is of 16,521 €/ha and 17,274 €/ha for the micro-sprinkler system, including pumping system, water hole, compression system, fertigation system, irrigation controller, distribution system and monitoring equipment. The amortization of these investments is calculated over eight years and the annual maintenance cost is considered to be 3% of it (Table 7). The total annual

Table 6 - Units and costs of the economic, water and labour resources in each 0.5 ha of drip system (TI), sprinkler system (SI) and non irrigated system (NI) in 2015 and 2016, in an adult chestnut's orchard with 200 trees per hectare

Treatment/description		2015		2016	
		Total units	Total costs	Total units	Total costs
Economic resources					
TI	Irrigation system	1 un	9,526.5 €	1 un	285.8 €
SI		1 un	9,903.1 €	1 un	297.1 €
NI		0 un	- €	0 un	- €
TI	Monitoring Equipment	1 un	2,000.0 €	1 un	60.0 €
SI		1 un	2,000.0 €	1 un	60.0 €
DI		0 un	-	0 un	
Water resources					
TI	Water consumption	230.4 m³	13.8 €	435.6 m³	26.1 €
SI		239.7 m³	14.4 €	489.6 m³	29.4 €
NI		0 m³	- €	0 m³	- €
Labour resources					
TI	Monitoring	6 weeks	10.2 €	9 weeks	15.3 €
SI		6 weeks	10.2 €	9 weeks	15.3 €
NI		0 weeks	- €	0 weeks	- €
TI	Harvesting	5.41 ton	1,082.0 €	4.26 ton	852.0 €
SI		5.16 ton	1,032.0 €	4.43 ton	886.0 €
NI		4.37 ton	874.0 €	3.28 ton	656.0 €

volume of water furnished varies depending on the year's weather conditions (defined as hotter or mild year when GDD > 2400°D or below GDD < 2400°D, respectively) and stem water potential. So, considering 2015 and 2016, it can range from 460 – 870 m^3/ha in TI and from 480 to 979 m^3/ha in SI system with annual costs varying from 28 to 52 €/ha and 29 to 59 €/ha for TI and SI, respectively. The chestnut production can range from 6.6 to 8.7 ton FW/ha in NI, 8.5 to 10.8 ton FW/ha in TI and 8.9 to 10.3 ton FW/ha in SI. According to Martins *et al.* (2011) calibres above 90 could depreciate 0.20 € per kilogram within the same period of harvest. For 2015, all calibres of the different treatments were below 90 (Table 4) so the market price considered was 2.2 €/kg. However, in 2016, the market price for NI was of 2.0 €/kg while for TI and SI it was 2.4 €/kg. In general, the profits generated due to the benefits of the irrigation system can increase up to 42% in the hotter years, in comparison to non-irrigated systems during the amortization period and certainly they increase after it.

Table 8 shows the cost of the investment in detail for each irrigation system on five hectares. The investment on irrigation can be up to 23,756 € in 5 ha (SI) and 19,990 € in 5 ha for TI.

The investment is naturally higher than for one hectare but some components have similar costs such as the fertigation system, water hole and the irrigation controller. As a consequence the profits will be up to 59% higher than in NI, in the hotter years (Table 9).

Table 7 - Annual costs during the amortization period (€/ha), annual income (€/ha) and profits (€/ha) generated in one hectare of an adult chestnut orchard with tree density of 200 plants per hectare with drip system (TI), micro-sprinkler system (SI) and in non irrigated system (NI), considering a hotter (hot- growing degree days > 2400°D) and less hotter (mild - growing degree-days < 2400°D) year

System	Annual costs (€/ha)								Yield (€/ha)								
	Amortization	Maintenance	Water resources			Labour resources			Annual income			Profits			Profits (%)		
			hot		mild	hot		mild	hot		mild	hot		mild	hot		mild
NI	0	0	0	to	0	1,312	to	1,748	13,120	to	19,228	11,808	to	17,480	100	to	100
TI	2,065	496	28	to	52	1,704	to	2,164	20,448	to	23,804	16,156	to	19,027	137	to	109
SI	2,159	518	29	to	59	1,772	to	2,064	21,264	to	22,704	16,786	to	17,904	142	to	102

Table 8 - Investment costs (in euros, €) of different components of drip (TI) and micro-sprinkler (SI) irrigation systems on five hectares, including the equipment for monitoring leaf water potential and soil water content

System	Water hole and pump (13 m^3/h)	Compression system	Valves colector	Fertirrigation system	Controller	Main pipes	Secondary pipes and emitters	Equipment monitoring	Total investment
TI	7,200	3,522	466	1,632	1,028	1,169	2,973	2,000	19,990
SI	7,200	3,522	466	1,632	1,028	1,169	6,739	2,000	23,756

Table 9 - Table 9 - Annual costs during the amortization period and income for five hectares of a chestnut orchard more than 20 years old and with a tree density of 200 plants per hectare with drip system (TI) and micro-sprinkler system (SI) and in non irrigated system (NI), considering a hotter (hot- growing degree days > 2400°D) and less hotter (mild - growing degree-days < 2400°D) year

System	Annual costs (€/5ha)								Yield (€/5ha)								
	Amortization	Maintenaince	Water resources			Labour resources			Annual income			Profits			Profits (%)		
			hot		mild	hot		mild	hot		mild	hot		mild	hot		mild
NI	0	0	0	to	0	6,560	to	8,740	65,600	to	96,140	59,040	to	87,400	100	to	100
TI	2,499	600	138	to	261	8,520	to	10,820	102,240	to	119,020	90,483	to	104,840	153	to	120
SI	2,969	713	144	to	294	8,860	to	10,320	106,320	to	113,520	93,634	to	99,224	159	to	114

DISCUSSION

Water management based on the Ψw_{md} of the chestnut tree is very dynamic because it implies frequent readings of the tree water status which in turn reveals a particular response to specific weather and soil conditions (Shackel *et al.*, 2000) resulting in not-fixed irrigation events. In this case, irrigation events occurred every time the Ψw_{md} was lower than -1.2 MPa which, according to Mota *et al.* (2014) in a previous study on the same orchard, the Ψw_{md} at -1.2 MPa reflects a higher photosynthetic rate and good soil moisture. Under the hotter temperatures and long dry period in 2016 chestnut trees revealed a great need of water and more irrigation events were programmed. Independently of the irrigation system, the Ψw_{md} was identical between irrigated trees and consequently the same number of irrigation events occurred although water consumption was higher in SI. Based on this fact alone, the drip system looks like a better option because with less water than the micro sprinkler system, the production was identical. Still, the mean annual water amount used in this study (666 m^3/ha in drip and 729 m^3/ha in micro-sprinkler) was much lower than the water used in chestnut trees on a study carried out by Jayne (2005). In Jayne (2005) the micro sprinkler system on the full (100% ET_0) and deficit (50% ET_0) modality used 2,570 and 2,020 m^3/ha, respectively, while the drip system used 940 and 1,420 m^3/ha on the deficit and full modality, respectively. Naturally these differences are related with the irrigation strategy followed by the author together with the different ages and density of trees, tree variety, regional climatic conditions and soil type. For instance, in Martins *et al.* (2011) the irrigation schedule followed on chestnut trees from 2006 to 2008 was based on the predawn leaf water potential and irrigation was triggered when it was lower than -0.6 MPa. As a result, the water volume was lower (mean of 767 m^3/ha) than those used in Jayne (2005) and it was within the values found in our study. Therefore, the irrigation strategy based on Ψw_{md} rather than in ET_0 suggests a better use and savings of water. Actually, Lampinen *et al.* (2001) and Shackel *et al.* (2000) also refer water savings in prune trees when irrigation scheduling is based on Ψw_{md}. The use of Ψw_{md} for irrigation scheduling has the inconvenient of the time required for bagged leaves to reach equilibrium with the stem as well as the interval of readings (1300 to 1500HR) which restricts the hectares that can be monitored by one person with a pressure chamber (Fulton *et al.*, 2001). However, the same author found out that in prune, almond and walnut trees the shaded leaves in the interior of the canopy rapidly align with stem water potential (minimum of 10 minutes) once transpiration is stopped with a reflective impermeable bag. Thus, it is relevant to test the same procedure on chestnut trees to save time and reduce costs with the monitoring.

According to INE (2016) the total national chestnut production decreased from 2015 to 2016 and fruit size was smaller. The chestnut production decreasing was noticeable in this study in all treatments but irrigated trees had less variation than the control, and the micro-sprinkler trees revealed more stability from 2015 to 2016. The high temperatures in 2016 may explain the decrease of the production. For instance, in July (T_{max} = 32°C) when flowering occurred, there were several days with temperatures above 30°C which may have constrained pollination and the photosynthesis rate which is maximal when temperatures are between 24 to 27°C (Gomes-Laranjo *et al.*, 2008). It remains unknown if there was a possible effect of the micro-sprinkler on the decreasing of the air temperature below the tree canopy that may have helped the chestnut production. The productivity calculated in our study was in terms of fresh weight and above 7 ton FW/ha. Considering an average dry matter (DM) of the Portuguese varieties is of around 45 to 50% (Ferreira-Cardoso, 2007; Portela *et al.*, 2007) our results are in accordance with Martins *et al.* (2010, 2011) who reported production values between 19 to 27 kg of DM per tree, equivalent to a fresh-weight 2 to 3 ton FW/ha. This yield and ours are clearly far away from the national yield reported by INE (2015) which is around 0.8 ton/ha. However it must be keep in mind that the statistics for national chestnut productivity includes also areas with low productivity (new plantations or very old trees), areas with high tree's mortality without replacement, areas with high incidence of diseases (ink and blight) which lowers production (Marcelino *et al.*, 2000) and areas where bad soil preparation or maintenance constraints chestnut trees' production (Raimundo, 2003). On the other hand, national statistics exclude the chestnuts that are traded in the parallel market which is underestimated as well as the ones for auto consume by the producers (Gomes-Laranjo *et al*., 2016). For these reasons, we consider that the yield found in this study is close to the realistic situation of the Portuguese 'Judia' variety production in healthy and adult chestnut orchards although the trees' density is uncommonly high. Dinis *et al*. (2011) found different calibres in 'Judia' variety depending on the temperature sum and bigger fruits (46 to 66 chestnuts/kg) were found when degree-days (from May to October) ranged from 2000 to 2200 °D. In our study, with higher degree days (> 2400 °D) , chestnuts were bigger in irrigated treatments (73 chestnuts/kg) and the calibres were within the values found by Pimentel-Pereira *et al.* (2007) for 'Judia' variety (71 to 79 chestnuts/kg). In the portuguese market, which is mainly for fresh consumption, the differences in price due to the calibre are not very clear but the industrial market privileges big chestnuts with calibres between 50 to 90 chestnuts/kg (Breisch, 1993; Ferreira-Cardoso, 2007). The calibre is influenced by edapho-climatic conditions (Ferreira-Cardoso, 2007; Dinis *et al*., 2011) and the watering, whatever the irrigation system, helps to achieve bigger chestnuts as shown in Martins *et al.* (2011) and in our results. Curiously, Jayne (2005) found bigger chestnuts in the non irrigated trees and in trees irrigated with the drip system at 50%$ET_{0.}$ This may be explained by the reduced number of fruits per tree which allow them to increase their size due to more assimilation but this was not verified in our study.

Finally, the most important is to evaluate either if the investment on the irrigation system is profitable or not on an adult orchard already in production. In summary, irrigated trees produce 27% more chestnuts than none irrigated trees increasing the annual income from 16,174 €/ha to 22,055 €/ha. This additional income pays the costs with amortization, water, maintenance and labour and still generates a profit of more than 17,000 € ha which easily increases after the amortization period. Non-irrigated trees are also a viable solution but with lower profits (14,644 €/ha). In Martins *et al.* (2011) a brief income estimate is presented for irrigated and non-irrigated chestnut trees both with seeded pastures which are more like to our irrigated treatments and NI modality, respectively. According to the author, the chestnut production generates 2,775 €/ha and 4,198 €/ha (70 trees/ha), for none irrigated and irrigated trees respectively. These outputs can even increase up to 3,851 to 5,835 €/ha if the forage and commercial mushrooms are marketed (Martins *et al.,* 2011). In the expected increase in productivity due to fertigation and tree maturity, which will naturally increase the income in all treatments together with the forage and mushrooms production, were not taken into account. Still, the income estimated by our study is higher than in Martins *et al.* (2011) either due to tree's density or due to the higher market price in 2015 and 2016. The price considered by Martins *et al.* (2011) was of 1 to 1.2 €/kg and becomes clear the high valorisation that the chestnuts' have been over the last decade.

The gain obtained with irrigation in one hectare can relatively be higher if the irrigation system is expanded to more area because the investment in the main intake structure is virtually the same for one or more hectares due to common equipment. This was clear when comparing the profits from one with five irrigated hectares. The profits can increase 22% up to 37% more in one and in five hectares, respectively, when comparing to the non-irrigation system. There is an evident economy of scale when more hectares are irrigated because costs per unit go down (Duffy, 2009; Rasmussen, 2013). The drip system appears to be a better option because, for similar income, it uses less water which is important when the water is scarce. However, specific crop practices can constrain the decisions of which irrigation system is preferable. For instance, the drip system with pipes resting on the soil constraints the use of a brush cutter to control weeds or can be dragged by cattle feet. The weed controls on drip systems could be overcome by the use of herbicides but these are harmful for the soil biotic life and prejudicial to the chestnut production as previous studies have shown (Raimundo, 2003). In alternative, the suspended irrigation system overcomes these constraints. Also, the size of the wetted area can be a key point if mushroom production is to be considered. The mushrooms appear naturally in chestnut orchards (Marques, 2007) and their production and diversity is enhanced by irrigation (Martins *et al*., 2011). In drip systems the wetted area is smaller than with the sprinkler system (Pereira, 2004) and this last one may be interesting if the intention is to irrigate chestnuts trees and at same time to improve mushrooms production. However, micro-sprinkler system can easily wet the chestnut trunk which is not desirable if there is a presence of *Cyphonectria parasitica* since it developed well in humid conditions (Magalhães *et al*., 2016). Future studies about mushroom production and its additional income for chestnut orchards under two different irrigation systems should be conducted. Also, studies about irrigation on young trees should be conducted aiming the reduction of plant mortality on the first few years as well as to anticipate the beginning of nut production. Additionally, the subsurface irrigated system can be an interesting option for new plantations because of water savings (Payero *et al*., 2005) and the restrictions on the crop practices would be overcome. However, it must be highlighted, that whatever the irrigation system, its performance is dependent of the project design, proper installation and maintenance, and proper water management (Pereira, 2004; Payero *et al*., 2005).

CONCLUSION

Bellow the current market prices, the investment on irrigation in adult chestnut trees is safe in rainfed adult and healthy chestnut orchards with similar features as the ones studied. However, more than the costs with the investment, the mushroom's production and crop practices may be decisive in the moment of choose the type of irrigation, as soon as there is water availability guaranteed.

ACKNOWLEDGEMENT

This work was supported by Hubel Verde SA, Geosil, CITAB-Universidade de Trás-os-Montes e Alto Douro and by Fundação para a Ciência e Tecnologia, through the PhD scholarship Ref: SFRH/BDE/52061/2012.

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