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Tuber yield and leaf mineral composition of Jerusalem artichoke (*Helianthus tuberosus* L.) grown under different cropping practices

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Abstract

Jerusalem artichoke is commonly grown for its edible tubers, livestock feed and as an ornamental. The possibility of growing Jerusalem artichoke for energetic purposes has aroused scientific interest in this species. Despite several studies that have already been done in the last few decades, many aspects of the cropping practice are still relatively unknown. During the growing seasons of 2004-2006 field trials were carried out in NE Portugal. In the experimental period different cropping conditions were imposed, regarding planting density, N fertilization and propagation method. The crop was irrigated in 2004 and 2005 and grown in rain-fed conditions in 2006. The planting densities were 7 plants m^{-2} in 2004, 2, 3 and 4 plants m^{-2} in 2005 and 2 and 4 plants m^{-2} in 2006. Botanical-seed was used in 2005 and seed-tubers in all the three years. In 2005, 0 and 100 kg N ha^{-1} was combined in a factorial design with the planting densities. The maximum tuber dry matter yield was 18.4 Mg ha^{-1} (65.6 Mg ha^{-1}, fresh weight basis) and it was recorded in 2005 in the plots where 100 kg N ha^{-1}, 2 plants m^{-2} and seed-tubers were combined. The best planting density was 2 plants m^{-2} in irrigated (2005) and rain-fed (2006) conditions. Nitrogen significantly increased tuber yield in 2005 only when seed-tubers were used. Averaged across N fertilization rates and planting densities mean tuber dry matter yields were 12.8 and 6.9 Mg ha^{-1} for seed-tuber and botanical-seed, respectively. Leaf mineral composition was little affected by cropping practices. The 'Bragança' clone showed high tuber yield potential, although the mean weight of the individual tubers was low which could make mechanization of the harvest difficult. The poor results achieved with botanical-seed argue against its use as an alternative to the seed-tubers.

Additional key words: botanical-seed, leaf mineral composition, nitrogen fertilisation, planting density, seed-tuber.

Resumen

Producción de tubérculos y composición mineral en hojas de pataca (*Helianthus tuberosus* L.) utilizando diferentes prácticas de cultivo

La pataca se cultiva por sus tubérculos comestibles, también se utiliza como forraje y como planta ornamental. La perspectiva de que se pueda cultivar con fines energéticos ha incrementado el interés por esta especie. En los años 2004-2006 se han efectuado experimentos de campo en el NE Portugal, mediante ensayos de diferentes condiciones de cultivo, en cuanto a densidad de plantación, fertilización nitrogenada y métodos de propagación. La plantación se regó en 2004 y en 2005 y se cultivó en secano en 2006. Las densidades de plantación fueron de 7 plantas m^{-2} en 2004, 2, 3 y 4 plantas m^{-2} en 2005 y 2 y 4 plantas m^{-2} en 2006. Se utilizaron propágulos vegetativos en los tres años de ensayo y semilla botánica en 2005. Respecto al N se utilizaron dos tratamientos (0 y 100 kg N ha^{-1}) combinados de forma factorial con las densidades de plantación. La máxima producción de materia seca en tubérculos fue de 18,4 Mg ha^{-1} (65,6 Mg ha^{-1}, en peso fresco) y se obtuvo en las parcelas en las que se combinaron 100 kg N ha^{-1}, 2 plantas m^{-2} y propágulos vegetativos. La mejor densidad de plantación fue de 2 plantas m^{-2}, tanto en regadío como en secano. La aplicación de nitrógeno aumentó significativamente la producción, pero sólo cuando se utilizaron propágulos vegetativos. Con propágulos vegetativos y semilla botánica se obtuvieron producciones medias de materia seca de 12,8 y 6,9 Mg ha^{-1}, respectivamente. La composición mineral de las hojas se vio poco afectada por la técnica de cultivo. El clon 'Bragança' ha mostrado elevado potencial de producción, aunque el peso medio de los tubérculos individuales haya sido bajo, lo que puede dificultar la mecanización de la cosecha. Los bajos resultados obtenidos a partir de semilla botánica disuaden su uso en alternativa a los propágulos vegetativos.

Palabras clave adicionales: composición mineral de las hojas, densidad de plantación, fertilización nitrogenada, semilla botánica, tubérculo-semilla.

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Introduction

Jerusalem artichoke is a native plant of the North American plains cultivated for different purposes in many countries. Jerusalem artichoke accumulates high levels of fructans in their stems and tubers. Fructans and the fructose resulting from fructans hydrolysis can be used in human diet or in medical and industrial applications (Schittenhelm, 1999; Monti *et al*., 2005). Jerusalem artichoke is considered one of the primary sources for inulin in higher plants (Saengthongpinit and Sajjaanantakul, 2005). Its protein has high food value due to the presence of almost all essential amino acids but also due to their good balance (Rakhimov *et al*., 2003). Another potential use of this species is as a forage crop. Jerusalem artichoke is considered a suitable livestock feed (Seiler and Campbell, 2004). In the last decades Jerusalem artichoke has been considered as a biomass crop for ethanol because it commonly produces high levels of carbohydrates (Denoroy, 1996). The production of biogas from biomass is also economically viable under certain conditions (Gunnarson *et al*., 1985). The possibility of growing Jerusalem artichoke for energy has aroused the scientific interest in this crop.

Portugal imports the main raw materials usually used in other countries to produce bio-ethanol, such as maize and small grains. Portugal also imports sugar derived from cane or sugar beet. Considering that Jerusalem artichoke is a hardy crop that may be cultivated at low cost with simple input techniques and, eventually, without irrigation (Monti *et al*., 2005), it is imperative to test its potential as an alternative crop for marginal lands that has been cultivated in the past with poor returns. Jerusalem artichoke seems to be also little affected by weed infestation. The high weed competitiveness of this species is attributable to the rapid growth and enormous final plant size, eliminating most of the weeds by shade (Schittenhelm, 1999).

Despite the actual interest in Jerusalem artichoke, studies that evaluate field performances of this crop are still scarce. The objective of this study is to gather information on cropping practices such as planting density, nitrogen fertilisation and irrigation, by using a high productive clone of the Jerusalem artichoke usually cultivated as an ornamental plant in the gardens of the Bragança region in NE Portugal. Leaf mineral composition of Jerusalem artichoke plants is also provided. As far as we know, there is no available information on this species in the literature, including the reference manual «Plant Analysis Handbook» by Mills and Jones (1996). Thus, it is an important target to gather information on leaf mineral composition that will help in the fertiliser recommendations in the future for this particular species.

Material and Methods

The field trial took place on Sta. Apolónia experimental farm located in Bragança, NE Portugal (41°48'N, 6°44'W), during the summer seasons of 2004, 2005 and 2006. The regional clone 'Bragança' of Jerusalem artichoke (*Helianthus tuberosus* L.) was used in the experiments. The soil is an eutric Cambisol, sandy loam textured, with 10 g kg^{-1} of organic matter and pH (H_2O) 5.8. Extractable soil P and K (ammonium lactate and acetic acid) levels in the plots used in this 3-yr trial were in the range of 35 to 45 mg kg^{-1} for P and 85 to 100 mg kg^{-1} for K. Local climate is Mediterranean type, warm and dry during the summer season. Weekly precipitations and mean weekly temperatures are shown in Figure 1. Maize (*Zea mays* L.) grown for silage was always the preceding crop to the Jerusalem artichoke in the three years of the experiments.

A preliminary experiment was carried out in 2004. The main objectives were to obtain enough botanical-seed for the next year and to get some information on the basic cropping practices. Whole tubers within the weight range of 20 to 25 g each were used in the experiments. In 2004, 7 tubers m^{-2} were hand-planted in 7 rows of 15 m long and 70 cm row-spaced. Planting was carried out on 22 March. Each one of the three internal rows was used as a replication for tuber yield evaluation and crop nutritional status analysis. Nitrogen, phosphorus and potassium were applied in the rates of 100, 20 and 40 kg ha^{-1}, respectively, based on the results of pre-plant soil analysis and taking into account the nutritional needs of sunflower (*Helianthus annuus* L.). The crop was sprinkler irrigated during the season. The crop was irrigated simultaneously with maize grown in a neighbouring field. Depth and interval irrigation application were estimated for maize according to the FAO methods (Allen *et al*., 1998). Total water supplied in 2004 accounted for 430 mm. Weeds were chemically controlled using glyphosate, following the protection of the Jerusalem artichoke plants with inverted pots, when plants had two pairs of true leaves. *Sclerotinia sclerotiorum* was controlled by using iprodione at flower initiation. The crop was hand harvested in early

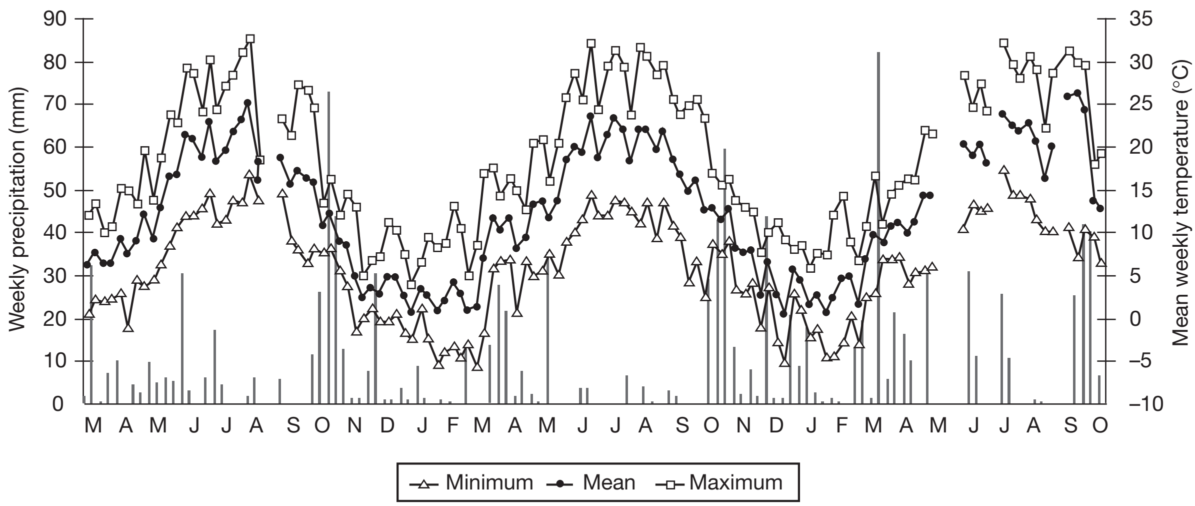

Figure 1. Weekly precipitation (in bars) and mean weekly temperatures (minimum, mean and maximum) recorded during the three growing seasons of 2004, 2005 and 2006.

October. The crop was considered as mature when the aerial parts were totally dry. Samples of 50 randomly selected tubers per plot were washed to obtain the mean fresh weight of the individual tubers. Samples of 300 to 400 g of tubers were oven-dried at 70°C to obtain the tuber dry matter percentage. Tuber dry matter yield per hectare was estimated by considering the useful area of each plot, total tuber fresh weight per plot and tuber dry matter percentage.

The plants of the 2004 trial showed strong aerial branching, thin stems and suffered from lodging at the flowering stage. Thus, in order to promote better crop development lower planting densities were used for the 2005 experiments. In 2005, seed-tubers and botanical-seed were used in separate experiments as means of crop propagation. The seed-tubers were included in a factorial design with three planting densities (2, 3 and 4 plants m^{-2}) and two N rates (0 and 100 kg N ha^{-1}). With botanical-seed the factorial design included only two planting densities (2 and 4 plants m^{-2}) and two N rates (0 and 100 kg N ha^{-1}). Each experimental unit included 30 useful plants, excluding perimeter plants and was replicated three times. The botanical seed was sown in micro-pots with a mixture of soil and peat on February 16, and kept in a greenhouse during the germination phase. On 16 March the young plants produced in the greenhouse as well as the seed-tubers were planted in the field, according to the experimental design. Irrigation water amounted to 460 mm in this year. All the other aspects of crop management were similar to that described for the 2004 experiment.

The field trial of 2006 was conducted in rain-fed conditions. Two planting densities (2 and 4 seed-tubers m^{-2}) were established in a completely randomized design. The experimental set up also included three replications and 30 useful plants per experimental unit. Nitrogen, P and K were applied in the rates of 50, 15 and 30 kg ha^{-1}, respectively. The seed-tubers were planted on 16 March. No chemical treatments were needed for *Sclerotinia* in the 2006 experiment and the weeds were controlled by hand-hoeing.

During the growing season the greenness of the leaves was recorded from 50 days after planting (DAP) until flowering by using the SPAD-502 chlorophyll meter. SPAD readings are usually used as an N nutritional index (Waskom *et al*., 1996; Rodrigues *et al*., 2005). The SPAD readings were made on young leaves with fully expanded blades in the upper part of the main stem of the plants. Leaf N, P, K, Ca, Mg, B, Fe, Cu, Zn and Mn concentrations were also determined during the season until flowering by sampling leaves in a similar position in the canopy as referred for SPAD readings. The leaf samples were oven-dried at 70°C and ground. Tissue analyses were performed by Kjeldahl (N), colorimetry (B and P), flame emission spectrometry (K) and atomic absorption spectrometry (Ca, Mg, Fe, Cu, Zn and Mn) methods (Walinga *et al*., 1989).

Data analysis was carried out using JMP 6.0.0 software (SAS Institute Inc.). After ANOVA examination the means with significant differences ($\alpha < 0.05$) were separated by Tukey HSD or Student's t tests.

Results

The tuber dry matter (DM) yield in 2004, when 7 plants m^{-2} were used, reached the mean value of 8.8 Mg ha^{-1}. The main stems and the aerial ramifications appear thinner than those of the typical plants of this clone when cultivated as an ornamental in the gardens of the region. As a consequence, close to the flowering stage, most of the crop suffers from lodging. These are aspects that indicate that a very high crop density was used in 2004 trial, as was mentioned in material and methods.

In 2005, when seed-tubers were used, the application of 100 kg N ha^{-1} significantly increased tuber dry matter yield relatively to the treatment without N (Table 1). Averaged across tuber densities, the treatments of 0 and 100 kg N ha^{-1} showed mean tuber dry matter yields of 10.6 and 15.0 Mg ha^{-1}, respectively. Planting density significantly influenced tuber DM yield. The lower planting density gave the higher tuber yield and vice-versa. The planting density did not have a significant effect on fresh weight of individual tubers in the 2005 experiments. With seed-tubers, the use of 2, 3 and 4 plants m^{-2} produced mean fresh tuber weights of 29.2, 25.1 and 23.9 g $tuber^{-1}$, respectively (Table 1). The application of N led to a significant increase in the fresh weight of the tubers. Averaged across planting densities the use of seed-tubers yielded mean fresh tuber weights of 23.3 and 28.9 g $tuber^{-1}$ when 0 and 100 kg N ha^{-1} were respectively applied. Maximum fresh tuber weight was obtained when 2 plants m^{-2} and 100 kg N ha^{-1} were used.

In the experiment with botanical seed, planting density also significantly influenced tuber DM yield (Table 1). Averaged across N rates tuber DM yields were 9.9 and 6.9 Mg ha^{-1} when 2 and 4 plants m^{-2} were respectively used. Using botanical seeds there were no significant differences in tuber DM yield between the treatments with and without N application. Considering both planting densities together, the mean DM yields were 7.6 and 9.1 Mg ha^{-1} when 0 and 100 kg N ha^{-1} were applied (Table 1). Mean fresh tuber weights of 25.1 and 23.8 g $tuber^{-1}$ were recorded in botanical seed experiment in the plots corresponding to 2 and 4 plants m^{-2}, being those values not statistically different. Nitrogen rate significantly influenced the mean fresh tuber weights when botanical seed was used. The mean values were 20.7 and 28.2 g $tuber^{-1}$ when 0 and 100 kg N ha^{-1} were applied, respectively.

The experiments with botanical seeds and seed-tubers occurred in similar agro-ecological conditions notwithstanding in separated experimental designs. If the results of the botanical seed and seed-tuber plots are compared huge differences in tuber DM yields can be observed. Averaged across N fertilization and planting density mean tuber yields were 12.8 and 6.9 Mg ha^{-1} for seed-tuber and botanical-seed, respectively. The lower mean tuber DM yield was recorded in the plots

Table 1. Tuber dry matter yield and tuber fresh weight as a function of propagation method, planting density and nitrogen rate

Year	Propagation method		Tuber DM yield ($Mg\ ha^{-1}$)	Tuber fresh weight ($g\ tuber^{-1}$)
2005	Seed-tuber	Planting density (plants m^{-2})		
		2	14.9[1] A	29.2[1] A
		3	12.9 AB	25.1 A
		4	10.6 A	23.9 A
		Nitrogen rate (kg ha^{-1})		
		0	10.6[2] B	23.3[2] B
		100	15.0 A	28.9 A
	Botanical seed	Planting density (plants m^{-2})		
		2	9.9[2] A	25.1[2] A
		4	6.9 B	23.8 A
		Nitrogen rate (kg ha^{-1})		
		0	7.6[2] A	20.7[2] B
		100	9.1 A	28.2 A
2006	Seed-tuber	Planting density (plants m^{-2})		
		2	7.4[2] A	24.4[2] A
		4	7.1 A	24.1 A

Means not connected by same letter are significantly different ($\alpha = 0.05$) by [1]Tukey HSD or [2]Student's t tests.

corresponding to 4 plants m^{-2}, botanical seed and no nitrogen applied. With the combination of those factors only 6.2 Mg ha^{-1} of tuber DM yield was recorded. The combination of 2 plants m^{-2} with 100 kg N ha^{-1} and seed-tubers as propagation method gave the highest mean DM yield (18.4 Mg ha^{-1}). The mean fresh weights of tubers were not much dissimilar if the plots of seed-tubers and true-seed were compared. Averaged across planting density and N rates, mean fresh tuber weights were 26.5 and 24.5 g tuber^{-1} when seed-tubers and botanical seed were respectively used.

In 2006, in rain-fed conditions, the effect on tuber DM yield of the different planting densities was not statistically significant. Jerusalem artichoke gave tuber DM yields of 7.4 and 7.1 Mg ha^{-1} in the treatments of 2 and 4 plants m^{-2}, respectively (Table 1). Mean fresh weights of individual tubers were 24.4 and 24.1 g in the plots where 2 and 4 seed-tubers m^{-2} were planted (Table 1). In 2006, in rain-fed conditions, the mean tuber DM yield on the treatment of 2 plants m^{-2} was only 40.2% relative to the same treatment of the trial of 2005 carried out in irrigated conditions. This result seems to stress the importance of irrigation, despite the fact that the experimental design does not permit a proper comparison of different water regimes.

In a general way the size of the tubers was very low. The tubers also showed marked extensive secondary growth or chain-like tubers. These aspects limit the use of this clone for commercial purposes if a mechanical harvesting system was required.

Leaf mineral composition of Jerusalem artichoke is shown in Table 2. In order to avoid overload, Table 2 reports only data taken from the most productive treatments of each year. Thus, the 2005 data were taken from plots where seed-tubers, 2 plants m^{-2} and 100 kg N ha^{-1} were used; whereas the 2006 data were taken from the plots of 2 plants m^{-2}. Data from the other treatments were only considered for statistical analysis.

The application of 100 kg N ha^{-1} in the trial of 2005 did not produce significant differences in leaf mineral composition including leaf N concentration in comparison with the treatment without N application. The development of the plants was markedly delayed when botanical seed was used. However, if the results of leaf analysis were compared, taking into account similar phenological stages, the differences in leaf mineral composition were minimal.

Planting density had not a significant effect on leaf concentration of P, K, Ca, Mg and B. However, planting density significantly influenced leaf N concentration in the 2005 trial on the sampling date of August 8th (Fig. 2). Averaged across N rate, mean leaf N concentrations reached the values of 37.8, 37.6 and 34.7 g kg^{-1}, respectively for the plots of 2, 3 and 4 plants m^{2}. The extremely dense canopies of crop in the plots of 4 plants m^{-2} seem to produce a dilution effect in tissue N concentration. In the other sampling dates and in the 2006 trial, the differences in leaf N concentration among planting densities were not statistically significant.

Leaf N concentration decreased slightly over the growing season (Table 2). Leaf N concentration varied from ≈ 40 g kg^{-1} at 4-5 leaf pair's stage to ≈ 30 g kg^{-1} at flower initiation. Leaf boron concentration followed an opposite pattern than N. As the growing season pro-

Table 2. Leaf mineral composition as a function of sampling date (DAP, days after planting). Data of 2005 was obtained from plots cultivated with seed-tubers and where 2 plants m^{-2} and 100 kg N ha^{-1} were used. Data of 2006 was obtained from plots with 2 plants m^{-2}

Year	Sampling date	DAP[1]	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})	B (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})
2004	Jun, 8	78	35.4 (2.5)[2]	1.9 (0.6)	41.8 (10.4)	15.6 (7.1)	4.8 (1.1)	43.1 (5.2)				
	Jun, 30	100	36.6 (0.9)	2.0 (0.3)	42.5 (6.2)	29.4 (4.5)	6.5 (0.7)	45.8 (2.0)				
	Sep, 2	164	31.3 (1.9)	1.7 (0.3)	39.2 (5.1)	31.1 (3.2)	6.6 (0.2)	58.6 (5.3)				
2005	Jun, 13	89	40.8 (1.8)	2.1 (0.5)	50.7 (8.3)	26.5 (4.7)	5.5 (0.5)	40.9 (2.0)				
	Jul, 8	114	36.8 (2.9)	1.8 (0.3)	47.8 (4.6)	27.4 (2.9)	6.5 (0.8)	43.6 (1.1)				
	Sep, 1	169	34.7 (0.9)	2.0 (0.4)	34.8 (9.7)	30.4 (4.4)	6.5 (0.9)	60.2 (9.1)				
2006	May, 23	68	31.6 (1.9)	1.8 (0.5)	41.3 (14.9)	21.3 (2.6)	3.0 (1.6)	53.1 (1.1)	138.3 (18.6)	11.0 (5.2)	60.7 (3.1)	32.7 (11.0)
	Jun, 26	72	30.8 (1.2)	2.2 (0.5)	49.1 (12.6)	19.0 (1.9)	6.0 (0.8)	67.7 (3.3)	165.3 (27.2)	20.0 (3.6)	65.3 (6.7)	47.7 (4.2)
	Sep, 4	162	30.1 (1.3)	2.0 (0.3)	32.5 (2.5)	25.7 (6.7)	6.1 (1.1)	80.0 (5.7)	135.3 (3.8)	20.0 (2.6)	67.0 (8.2)	52.0 (12.1)

[1] 50 DAP ≈ 4-5 pairs of leaves; 100 DAP ≈ 8-10 pairs of leaves; 150 DAP ≈ flower initiation. [2] In parentheses mean standard deviation.

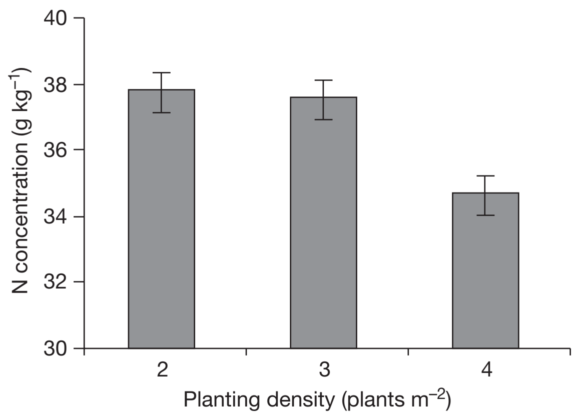

Figure 2. Leaf N concentration in August 8th, 2005 as a function of planting density. Vertical bars are the mean confidence limits ($\alpha < 0.05$).

gressed leaf boron concentration increased (Table 2). The lower values were recorded at 4-5 leaf pair's stage ($\approx$40 mg kg^{-1}) and the higher values ($\approx$80 mg kg^{-1}) at flower initiation.

SPAD readings were not significantly influenced by fertiliser-N application and planting density. The chlorophyll SPAD values increased during the growing season in each one of three years of experiments (Fig. 3). Younger plants seem to have thinner leaves than older ones, which results in lower SPAD values early in the season. At 60 DAP, SPAD values were close to 35 units, whereas at flower initiation SPAD readings reached values close to 47 units.

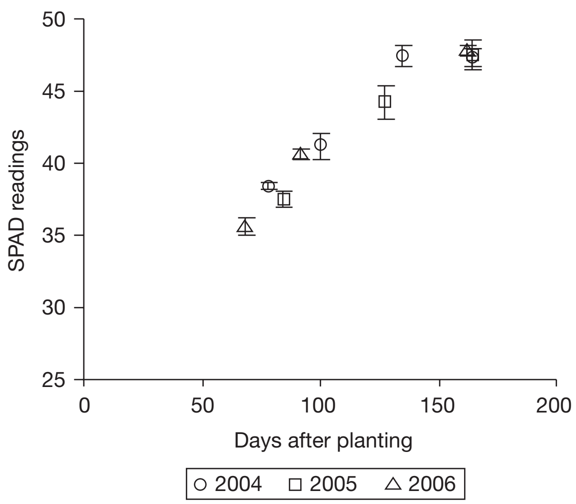

Figure 3. Variation of chlorophyll SPAD readings during the growing season. Data of 2005 was taken from the plots of seed-tubers and where 2 plants m^{-2} and 100 kg N ha^{-1} were used. Data of 2006 was taken from the plots of 2 plants m^{-2}. Vertical bars are the mean confidence limits ($\alpha < 0.05$).

Discussion

The 'Bragança' clone appears to be very productive since tuber DM yield of 18.4 Mg ha^{-1} (65.6 Mg ha^{-1}, fresh weight basis) was recorded in the most productive treatment of 2005. This could be considered a high value considering other results reported in the literature. Schittenhelm (1999) recorded tuber DM yield of 11.5 Mg ha^{-1} in an irrigated trial, with weed control and optimal nitrogen rates applied. Paolini *et al*. (1998) found tuber yields up to 7.9 Mg ha^{-1} in an experiment with several different types of weed control. Conde *et al*. (1991) mentioned 80 Mg ha^{-1} of fresh tubers for cv. 'Nahodka' grown in Italy and when the plants did not suffer any water shortage. Based on recent literature, Denoroy (1996) quoted tuber fresh weight for Jerusalem artichoke ranging from 30 to 70 Mg ha^{-1}.

On the other hand, the mean weight of individual tubers is undesirably low. With the best cropping techniques the mean weight of tubers was 29.2 g tuber^{-1}. The tubers are small and show malformations and secondary growth, which would reduce the efficiency of mechanical harvesting. However, the clone seems to have great potential to be included in breeding programs to improve its agronomic performance.

For the main crops over the world there are planting densities well established by seed companies or agronomists. The farmer knows for a given species or cultivar which planting density produces the best harvest. For the Jerusalem artichoke however little is known about the best planting densities for the diverse available genetic material and growing conditions. Diverse planting densities have been used without any comparison in each experiment. Paolini *et al*. (1998) and Monti *et al*. (2005) used 7 plants m^{-2} in studies with cv. 'Violet de Rennes'. However, Meijer and Mathijssen (1996) used only 3.33 plants m^{-2} with the same cultivar. Baldini *et al*. (2004) used 3.6 plants m^{-2} with several clones and standard varieties including also 'Violet de Rennes'. Schittenhelm (1999) used a crop density of 4 plants m^{-2} with the cultivars 'TopStar' and 'Gigant'. Seiler and Campbell (2004) used 4 plants m^{-2} in studies with genetic material tested for forage. In the present study the best planting density for the clone 'Bragança' was 2 plants m^{-2} in irrigated and rain-fed conditions, when evaluated by tuber DM yield.

The plants of this clone showed a strong aerial structure, reaching 3 m high and with strong side branches. Since high planting densities reduce stem diameter more than stem height (Denoroy, 1996), the strong mutual shading which occurs particularly when water and N were not limiting factors promotes the early senescence of the lower parts of the canopy. Moreover, such dense crops are often prone to disease and lodging, and this decreases final yield (Meijer and Mathijssen, 1996). Thus, the use of low planting densities seems to be much more appropriate particularly when the cultivars show vigorous stem growth and strong aerial branching.

The response to the N applied seems to be tenuous, taking into account the exuberant vegetative development of the crop. A significant response to N rate was only achieved when the best growing conditions were present (low crop density, irrigation and seed-tubers as propagation material). Contrary to other crops, such as maize and potato (*Solanum tuberosum* L.), which respond to high N rates, Jerusalem artichoke seems to have low N requirements. In this aspect it seems similar to sunflower (*Helianthus annuus* L.), a crop with a high ability to take up soil available nutrients (Guerrero, 1999). Schittenhelm (1999) reported results of the application of 0, 60 and 120 kg N ha^{-1} in a 3-yr study. Nitrogen increased mean tuber yield although the differences between 60 and 120 kg N ha^{-1} were not statistically significant. Tuber DM yields ranged between 8.4 and 12.9 Mg ha^{-1} when 0 and 120 kg N ha^{-1} were applied.

The use of botanical seed delayed the crop development which led to a significant reduction in tuber yield. Botanical seed delayed the closure of the canopy reducing the potential growth through the decrease in interception of radiation in the early stages. The young plants that emerged from seed-tubers showed a most vigorous and homogeneous growth particularly in the first weeks probably because seed-tubers contain more energy than botanical seed. The plants that emerged from botanical-seed never reached the height and the level of branching attained by plants emerged from tubers.

The flowers of Jerusalem artichoke are often sterile and the viability of the achenes is low and very cultivar-dependent (Denoroy, 1996). The clone 'Bragança' showed a very high level of sterile flowers. To obtain enough seed for the 2005 experiment a lot of flowers were collected from the plots of the 2004 trial. However, achene viability was not low. The mean rate of seed emergence was 84%.

Jerusalem artichoke is considered a hardy plant against drought. Monti *et al*. (2005) consider that irrigation is not necessary to grow Jerusalem artichoke in the region of Bologna, Italy. Nevertheless many other studies have shown that irrigation is worthwhile when water is available. Schittenhelm (1999) considers that drought may strongly influence the DM production of Jerusalem artichoke. In German conditions, Schittenhelm (1999) reported that mild water stress affects the DM yield of Jerusalem artichoke more than chicory and sugarbeet. The result of the former species is attributed to its shallow root system. Without water limitation Conde *et al*. (1991) reported results of fresh tuber yield of 80 Mg ha^{-1} with the cv. 'Nahodka'. When the optimum water supply was reduced to 50%, Conde *et al*. (1991) observed that a certain acclimatisation to water stress occurred and the decreased yield was only 20%. The results reported now indicate that without irrigation, the yield could be severely reduced. The present experiments were carried out in a typical Mediterranean climate where little rainfall occurs in the summer period (Fig. 1). In these conditions water supply appears to be a serious growth limiting factor.

Cropping practices did not significantly influence leaf mineral composition for N, P, K, Ca, Mg, B, Fe, Cu, Zn and Mn, excluding the effect of planting density on leaf N concentration in the sampling of August 8th 2005. Few studies on Jerusalem artichoke have reported results of leaf analysis. Seiler and Campbell (2004) compared the within-population variation for several minerals. They found that the variation within-population is high for N, Ca and K and low, for instance, for Mg. However, the objective of Seiler and Campbell (2004) was not to report data on leaf mineral composition for diagnosing the plant nutritional status of the crop. Their aim was to evaluate the nutritional value of the above-ground biomass of the Jerusalem artichoke as a feedstock. Monti *et al*. (2005) reported leaf N concentrations ranging from 30 to 36 g kg^{-1}, with the cv. 'Violet de Rennes' grown in Bologna, Italy, under irrigated and rain-fed conditions. These are values very similar to the reported in the present study.

Although there were not differences in leaf mineral composition among treatments, some elements showed a dynamic pattern over time. Leaf N concentration, for instance, decreased during the growing season while leaf B concentration increased. The decrease in tissue N concentration with the ageing process is common among several plant species (Mills and Jones, 1996; Fageria *et al*., 1997; Rodrigues, 2004). Early in the season there is more available N in soil which can be taken up by plants. Over the season, the accumulation of products of photosynthesis occurs at higher rates than N uptake which leads to the decrease of tissue N concentration by dilution effect (Peeters and Van Bol, 1993). Regarding B, it is well known that its function is structural rather than metabolic, being associated with the cell wall synthesis and with the lignification process (Shelp, 1993; Power and Woods, 1997). Thus, the increase of boron in tissues during the ageing process is common to several species (Mills and Jones, 1996).

Based on the more productive plots, a preliminary set of data for leaf mineral composition of Jerusalem artichoke is reported. It would therefore be wise to assemble a comparative database of leaf mineral composition from studies conducted around the world to validate the present findings. One of the most complete books on the subject «Plant Analysis Handbook» published by Mills and Jones (1996) did not contain data for this particular species.

SPAD readings did not significantly vary between treatments. SPAD values increased over the season from 35 units at 4-5 leaf pair's stage to 47 units at flowering. Monti *et al*. (2005) reported similar SPAD values for this crop, ranging from 38 to 46 units for 'Violet de Rennes'. Studies with other crops had shown that the SPAD readings usually decreased during the season, following the pattern of other N nutritional indices, such are leaf N concentration or petiole nitrate concentration (Minotti *et al*., 1994; Rodrigues, 2004). The main reasons for that are the decrease in soil available N during the growing season and the dilution effect associated with crop growth and development. However, some warm season crops seem to respond to the light intensity increasing the thickness of the mesophyl (Yano and Terashima, 2004). Considering that the SPAD-meter measures the transmittance of light through the leaf, this could justify the increase in SPAD readings as the summer progresses.

Jerusalem artichoke regenerates from tubers which persist in the soil and appear as volunteers in the subsequent crops (Seiler and Campbell, 2004). When once planted, the difficulty seems to be to get the ground rid of them again. The small tubers not recovered at harvest raise a serious weed problem in the following seasons. For complete elimination of the infestation, Schittenhelm (1996) considers that volunteers must be controlled in the second and probably in third year following Jerusalem artichoke. In the experiments reported in this work, a winter cover crop was introduced shortly after the Jerusalem artichoke harvest. The winter crop was cut for silage at the end of May. Thereafter the soil is tilled and silage-maize is sown as summer crop. This sequence of crops is very competitive to perennial weeds. In the period of these field studies, volunteers of Jerusalem artichoke did not appear as a serious weed problem.

The results reported here highlight several important cropping parameters for the Jerusalem artichoke. This species seems to have low N requirements, despite its strong aerial structure and exuberant growth. The use of botanical-seed led to a significant tuber yield reduction relative to the seed-tuber. In future studies it will be interesting to test the performance of «true» seed planted at higher densities. Despite the fact that the experimental design of these trials does not permit a proper comparison of the different water regimes, it seems that, in Mediterranean conditions, irrigation greatly improves tuber yields. The 'Bragança' clone showed high tuber yield potential based on its 18.4 Mg DM ha^{-1} yield obtained under the best cropping conditions. However, the mean weight of the individual tubers was low, which could cause difficulties to the mechanization of the harvest.

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