Jerusalem Artichoke (*Helianthus tuberosus* L.) and Chicory (*Cichorium intybus* L.): Potential Crops for Inulin Production in the Mediterranean Area

G. De Mastro, G. Manolio and V. Marzi
Dipartimento di Scienze delle Produzioni Vegetali
Università degli Studi di Bari
Via Amendola 165/a Bari, Italy

Keywords: irrigation, harvest time, roots, tubers, growth, carbohydrates, biomass

Abstract

Chicory and Jerusalem artichoke are among the best crops for inulin production. Inulin and other polyfructosides are mainly used for the production of high-fructose syrups, foods and for the production of ethanol and in the non-food industry. This work reports on field trials conducted over a 2-yr period (1999-2000) on chicory and Jerusalem artichoke in south Italy at Policoro (40° 13' N, 16° 45' E, 15 m a.s.l.), a typical Mediterranean area. The aim of the study was to determine the biomass and carbohydrates' dynamics of both species, and define the most suitable growing techniques for the highest inulin production. The main agronomic factors (irrigation and harvest time) were investigated. Crop yields were influenced by the growing techniques tested, and promising results were achieved especially in terms of inulin quality.

INTRODUCTION

Among alternative crops, inulin crops are being extensively investigated (Smith et al., 1997, Meijer and Mathijssen, 1993) for industrial and food use, and also for nutri-ceutical applications **(**Chubey and Dorrell, 1977, Spiegel et al., 1994**)**. In Jerusalem artichoke and Chicory root, fructans (linear polymers of fructose) represent the largest part of the biomass, but potential productivity and quality of the crops (sugars concentration) show a large variability with genotype, location and technique (Denoroy, 1996).

In central and western European countries roots of chicory (*Cichorium intybus* L.) are widely used, on industrial scale, as raw material for the extraction of inulin and fructose, its hydrolysis product (Fuchs, 1987). High root yields, high inulin contents and long inulin chains are preferred (Baert, 1996). These countries represent marginal areas for the cultivation of Jerusalem artichoke (*Helianthus tuberosus* L.) because of the short season, the relatively low temperatures and light available for the crop, but promising indications come from limited studies carried on in Southern Europe (Barloy and Fernandez, 1988, De Mastro, 1988, De Mastro, 1995). For these crops, growing tech-niques suitable for the highest inulin production and quality need to be well defined in the Mediterranean region, particularly with regard to southern Italy.

The aim of this work was to study biomass and carbohydrate dynamics of the plants as influenced by irrigation level and harvest time, with a view to determine the yield potential of these alternative crops under Mediterranean conditions.

MATERIALS AND METHODS

The research was carried out in the 1999-2000 two-year period at the "E. Pantanelli" experimental farm of the Agricultural Faculty of Bari in the area of Policoro, on a clay-loam soil. For each species, a single variety was used, "*Bergues*" for chicory and "*Violetto di Rennes*" for Jerusalem artichoke, with different harvest times and two irrigation levels. For chicory, four dates of harvest were applied in the first year, and three in the second, whereas for Jerusalem artichoke two times per year were applied, respectively for the harvest of stalks and tubers and for tubers only. The crop irrigation management involved a full (100%) and partial (25%) re-establishment of ET_M.

Proc. XXVI IHC – Future for Medicinal and Aromatic Plants
Eds. L.E. Craker et al.
Acta Hort. 629, ISHS 2004
Publication supported by Can. Int. Dev. Agency (CIDA)

The field design used a split-plot design, replicated four times, the irrigation levels were in the main plot and the harvest times (dates) in the subplot. Overall size of sub-plots was 40 m^2, of which 20 m^2 was harvested.

Sowings were performed on 12th April 1999 and 30th March 2000, spacings were 50 and 70 cm between the rows, and 13 – 25 cm in the rows, with a plant population of 15 and 5.7 plants per m^2 respectively for chicory and Jerusalem artichoke. In regard to fertility, 75 units of nitrogen, 120 of phosphorous were applied before sowing and 75 additional units of nitrogen were applied before the first inter-row cultivation at the beginning of May.

At each harvest; as a side-dress application; 12-15 representative plants were monitored for growth per species per plot, starting from the end of June till the end of the growing season, for a total number of 10 samplings. At each sampling the following parameters were determined: the fresh weight and the dry matter percentage of roots, tubers and stalks, the leaf area and the sugar content. Dry matter content was determined using standard methods (after drying at 105° for 24 h). Sugar content of tubers and roots was determined using Carl Zeiss refraction meter. Samples of tuber and root juice for carbohydrate analysis were obtained from sliced tubers and roots, boiled at 1.5 bar pressure for 60 min. The juice was cleaned using an ion exchanger to remove substances, that could interfere with the analysis. At each harvest the following characteristics were determined: tuber, root, and stalk yield, dry matter and sugar contents. Statistical analysis was carried out by the SAS programme.

RESULTS

Dynamics of Biomass and Carbohydrates

The growth of the two species tested was influenced both by the seasonal pattern in the two-year period (Table 1) and the different irrigation management (Figs. 1, 2). The particular rainfall pattern recorded during the first year induced a high accumulation of dry matter in both species, and concealed any differences that could have been observed between treatments; no notable differences were observed among treatments within species. The 2000 season pattern was dry in the spring-summer period and resulted in differences and reduced yields per unit area as compared to the previous year, notably in the treatment with the partial re-establishment of ET_M.

The comparison between the two species revealed an initially faster inulin accumulation for chicory, followed by a phase of lower growth towards the end of the season. In 2000, however, re-growth of vegetation occurred; in the most irrigated treatment, it caused a net consumption of dry matter, and brought again the dry matter level to that of the water-stressed treatment.

In contrast, there was a sharp rise in growth in Jerusalem artichoke from the second half of August, at the same time as the start of tuber formation. Such a rise was particularly evident in the first year, and concerned in particular the plants under non-limiting water conditions. The dry matter yield was sharply higher in Jerusalem artichoke which, unlike chicory, responded positively to the higher supply of irrigation water.

The different trend in the growth of the two species was confirmed by the dynamics of carbohydrate accumulation, which reflects the same trend of dry matter. Differences were found in chicory (Fig. 3)only between the wet and dry treatments during the second year through the re-growth that took place during October in wet plots. Jerusalem artichoke showed a higher sugar accumulation, notably in 1999, and marked increases related to the better water supply (Fig. 4).

Regardless of the differences observed between the years and the two irrigated treatments, sugar accumulation in chicory increased since the early growth stages, whereas with Jerusalem artichoke, such sugar accumulation began at the initiation of tuber formation (Spitters et al., 1987) coinciding with flowering.

Biomass and Sugar Yield

The years and the different irrigation levels affected not only the tuber, stalk and root yield, but also the sugar yield response. On average, the year 1999, as noted for growth, was characterized by a rainfall pattern favouring the maximum yield especially in chicory, in which the observed mean root yield was 51.2 t ha^{-1}, about 10.0 t ha^{-1} higher than in 2000 (Fig. 5). Regardless of the years, in general, a non-limiting water condition of the crop resulted in a better yield behaviours for all cases. On average, in the most irrigated treatment, both crops showed a 18% yield increase over non-irrigated treatments (Figs. 5, 6).

In terms of root fresh weight, in 1999 the non-irrigated and irrigated treatments did not show any difference, whereas in 2000 the irrigated treatment produced, on average, 34.2% higher yields than the non-irrigated roots. Fresh tuber yield per unit area was higher in irrigated treatments as compared to non-irrigated. This was especially evident the second year through an increase of 28.1 % . Dry matter content of tubers and roots was affected by year; on average, for both crops the dry matter percentage was higher in 1999 in the treatments of partial restoration of ET_M with values of 25.0 % and 25.7 %, respectively for Jerusalem artichoke and chicory (Table 2) Fresh stalk yield per unit area (Table 3) was affected both by the year and the different crop irrigation management; actually the observed yield in the wet treatment was 43.1 t ha^{-1} in the first year and 36.1 t ha^{-1} in the second year (Table 3). The stalk dry matter percentage was sharply higher in the first year, but did not change with the level of ET_M re-establishment. In both years, and for each irrigated treatment, the delay in the time for harvesting led to, on average, an increase in the quantity of harvested tubers and roots. This was especially the case for Jerusalem artichoke, in which the early harvest time was led to a crop of "stalks + tubers", considering the incomplete translocation of assimilates from the stalk to the tubers that were still growing. Tuber yield results at the first harvest time did not fully express the actual crop potential, as the stalks contain a good amount of sugars.

The delayed harvest of chicory resulted in an increase in the amount of harvested roots, but that could induce a reduction in quality due to a lower sugar accumulation subsequent to the re-growth process, with detrimental consequences on the storage substances of roots. The sugar yield per hectare was influenced by the year and irrigation effects in both species (Figs. 7, 8). In particular the chicory produced, on average, 8.19 t ha^{-1} of sugar in the first year, and 6.57 in the second. It is noteworthy that the effect of the different crop irrigation management was different in the two years. In the first year a higher biomass production in the most irrigated treatments did not result in a higher sugar yield because of a lower percent content than that recorded in dry treatments, where the higher concentration compensated for the lower root yield.

Under the environmental conditions of the first year, the higher capacity of sugar accumulation of less irrigated plants enabled a better yield response per hectare. In the second year, instead, the small differences in the percent content of root sugars kept unchanged the crop superiority of the well-irrigated chicory.

The year effect on the sugar yield was also noticeable in Jerusalem artichoke, with 10.82 t ha^{-1} and 7.48 t ha^{-1}, respectively in the first and second years. In the second year, instead, the higher rainfall of the late season limited and levelled the sugar concentration in tubers, thus keeping the superiority of the fully-irrigated crop unchanged as a result of the increased tuber yield. In the stalk the production per unit area of total sugars was higher, in 1999, by 46.4 %, whereas irrigated plots produced, on average, 0.71 t ha^{-1} more than the dry ones.

The delayed harvest induced, on average, an increase in the sugar yield, although this trend was more evident in water-stressed treatments. The increase in sugar yield at the second harvest time was obviously related to the carbohydrates' flux from stalks to tubers at the late crop stages.

CONCLUSIONS

Under the typical hot and dry conditions of the Mediterranean region, Jerusalem artichoke and chicory show a high yield potential due to favourable thermal and photosynthetic conditions, which allow relatively growth rates (Barloy et al., 1989). Both species appear to be sensitive to water availability, so that adequate moisture by rainfall or irrigation is a pre-condition in obtaining acceptable yields.

It should be specified, however, that if, on t one hand, the higher water supply always induced an increase in root and tuber yield; on the other hand, in the years characterised by wet spring seasons, an increased water supply negatively affected sugar yield, due to the lower accumulation capacity in storage organs.

The optimal time for harvesting occurs for chicory between late October and early November, whereas for Jerusalem artichoke a delay (late November – early December) would enable the total translocation of sugars to the tubers, unless you consider the crop for stalks+tubers thus advancing harvest to mid-October.

In general the yield potential, both in terms of biomass and sugars, was always higher in Jerusalem artichoke, possibly due to the different pattern of growth and accumulation of storage substances. The agro-technique of this crop seems more complex than that of chicory; and more similar to that of sugar-beet, which is indigenous to the Mediterranean environment.

Further adjustments in the cropping techniques and in the definition of the quality features of the carbohydrates produced by these species might lead to an overall evaluation of the potential of these two crops in the Mediterranean environment, in relation to the new possible uses of inulin.

ACKNOWLEDGEMENT

The research was supported by the Italian Ministry of University Scientific and Technological Research (MURST) within the framework of the research project “Crops for inulin production: modelling of the environmental effects and cropping strategies”.

Literature Cited

Baert, J.R.A. 1996. The effect of sowing and harvest date and cultivar on inulin yield and composition of chicory (*Cichorium intybus* L.) roots. Industrial Crops and Products. 6:195-199.

Barloy, J. and Fernandez, J. 1988. Synthesis on Jerusalem artichoke projects. Second Workshop EEC on Jerusalem artichoke. Rennes, 6-8 December.

Barloy, J., Curt, M.D., Martinez, M. and De Mastro, G. 1989. Comparaison de l’élaboration du rendement de deux cultivars de topinambur selon un gradient latitudinal. Proc. of 5th European Conference Biomass for Energy and Industry, Lisbon, 9-13 October.

Chubey, B.B. and Dorrell D. G., 1977. Chicory, another potential fructose crop. Canadian Inst. Food Sci. and Techn. J. 10, 123-131.

De Mastro, G. 1988. Productivity of eight Jerusalem artichoke cultivars in Southern Italy. Proceedings of 2nd Workshop on Jerusalem Artichoke. Rennes, 6-8 December 1988.

De Mastro, G. 1995. Influenza dell’irrigazione e dell’epoca di raccolta sulla produttività di 8 cloni di topinambur (*Helianthus tuberosus* L.). Scienza e Tecnica Agraria, 35 (1-3), 37-49.

Denoroy, P. 1996. The crop physiology of *Helianthus tuberosus* L.: a model orientated view. Biomass and Bioenergy, vol II. 1:11-32.

Fuchs, A. 1987. Potentials non-food utilisations of fructose and inulin. Starch, 39 (10), 335-343.

Meijer, W.J.M., Mathijssen, E.W.J.M. and Borm, G.E.L. 1993. Crop characteristics and inulin production of Jerusalem artichoke and chicory. In: A. Fuchs (Ed.), Inulin and inulin-containing crops. Studies in Plant Science, 3.

Paolini, R., Del Puglia, S., Abbate, V., Copani, V., Danuso, F., De Mastro, G., Losavio, N., Marzi, V., Molfetta, P., Pignatelli, V., Venezia, G. and Vonella, A.V. 1996. Produt-

tività del topinambur (*Helianthus tuberosus* L.) in relazione a fattori agronomici diversi. Agricoltura Ricerca, anno XVIII, 163, 126-144 (maggio/giugno 1996).
Smith, N.O., Maclean I., Miller F.A. and Carruthers, S.P. 1997. Crops for industry and energy in Europe. OOPEC, Luxembourg.
Spiegel, J.E., Rose, R., Karabell, P., Frankos, V.H. and Schmitt, D.F. 1994. Safety and benefits of fructooligosaccharides as food ingredients. Food Technol., 48: 85-89.
Spitters, C.J.T. 1990. Modelling the seasonal dynamics of shoot and tuber growth of *Helianthus tuberosus* L. In: A. Fuchs (ed.). Third seminar on Inulin. National Council for Agricultural Research, The Hague, The Netherlands, 1-8 pp.

Tables

Table 1. Meteorological trend of the two year period.

Month	Precipitation (mm)			Temperature (C°)		
	1999	2000	40 - yr avg.	1999	2000	40 - yr avg.
April	32.3	31.8	34.0	13.2	14.9	13.4
May	2.1	44.6	29.9	18.7	19.4	18.0
June	44.2	2.5	18.0	22.7	23.5	22.1
July	78.1	6.4	15.9	24.4	24.7	25.0
August	13.2	0.0	21.9	25.2	25.9	25.0
September	12.2	110.0	39.3	21.9	21.6	21.9
October	20.6	192.3	64.8	18.0	17.4	17.5
Total/mean	202.7	387.6	223.7	20.6	21.0	20.4
Deviation from 40 yr avg.	-21.0	163.9	-	0.2	0.6	-

Table 2. Dry matter content (%) of chicory roots and Jerusalem artichoke tubers as influenced by irrigation, in two years.

Irrigation management	*Chicory (% DM)*			*Jerusalem artichoke (% DM)*		
	1999	2000	Mean	1999	2000	Mean
Wet	23.9	22.5	23.3	23.5	20.1	21.8
Dry	25.7	22.6	24.4	25.0	20.6	22.8
Mean	24.8	22.5	23.8	24.3	20.3	22.3

(Wet=100% of ET_M; Dry=25% of ET_M)

Table 3. Jerusalem artichoke stalks yield and corresponding dry matter content (%) and sugar content (t ha^{-1}), as influenced by water regime and year.

Irrigation management	*Stalks (t ha^{-1})*			*Dry matter (%)*			*Sugars (t ha^{-1})*		
	1999	**2000**	**Mean**	**1999**	**2000**	**Mean**	**1999**	**2000**	**Mean**
Wet	43.1	36.1	39.6	36.0	27.8	31.9	5.42	3.57	4.50a
Dry	36.4	32.4	34.4	34.6	26.4	30.5	4.43	3.14	3.79b
Mean	39.8a	34.2b	37.0	35.3	27.1	31.2	4.92a	3.36b	4.14

(Wet=100% of ET_M; Dry=25% of ET_M)

Figures

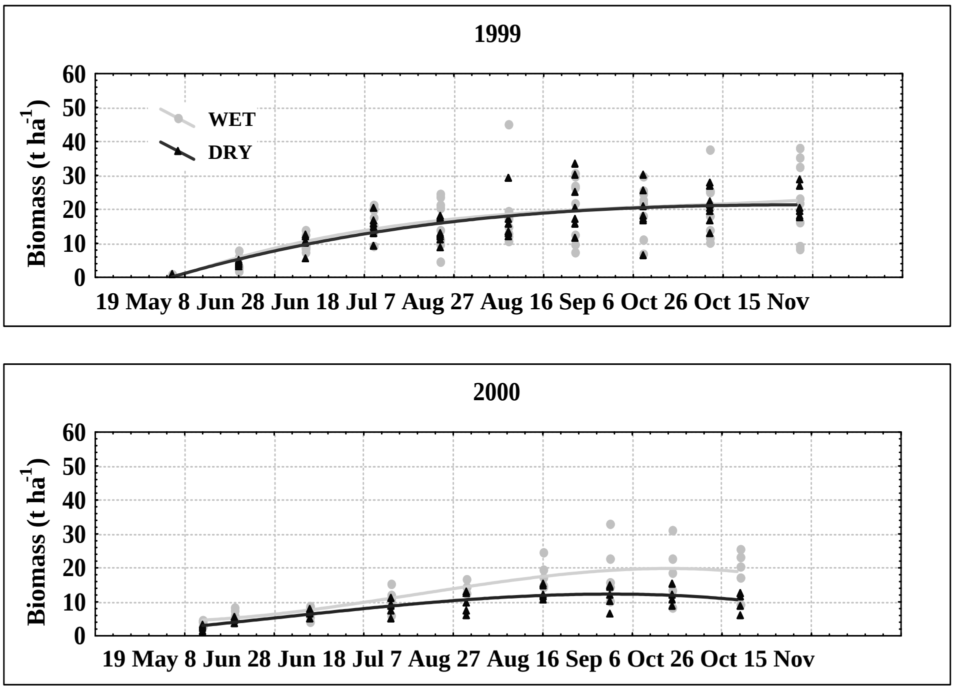

Fig. 1. Chicory accumulation in dry matter, as influenced by ET_M restoring level (average of two years). (Wet=100% of ET_M; Dry=25% of ET_M)

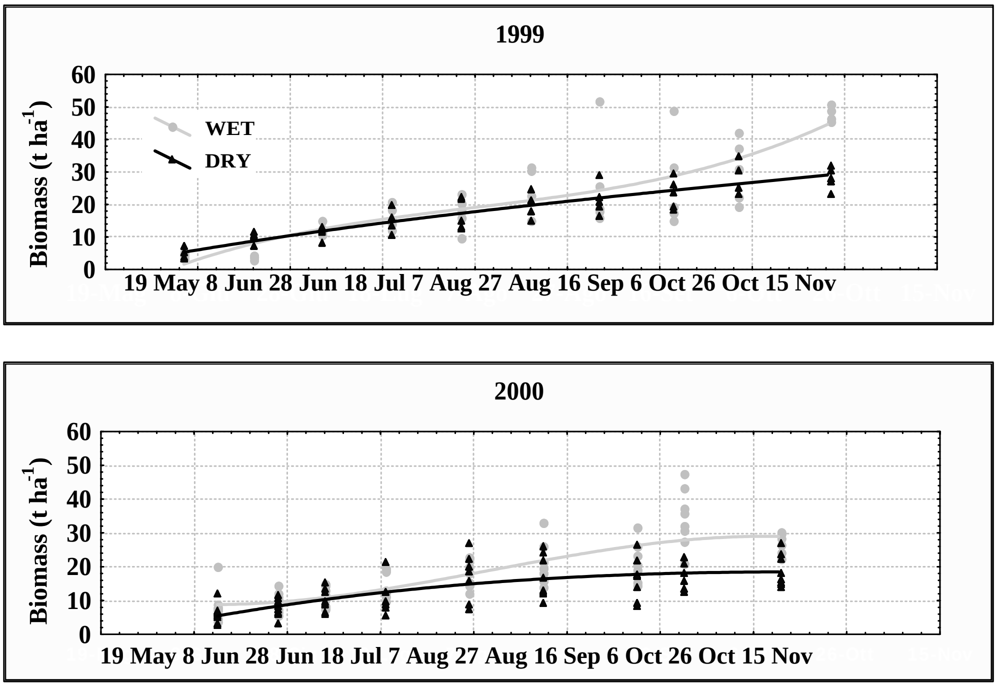

Fig. 2. Jerusalem artichoke accumulation in dry matter, as influenced by ET_M restoring level (average of two years). (Wet=100% of ET_M; Dry=25% of ET_M)

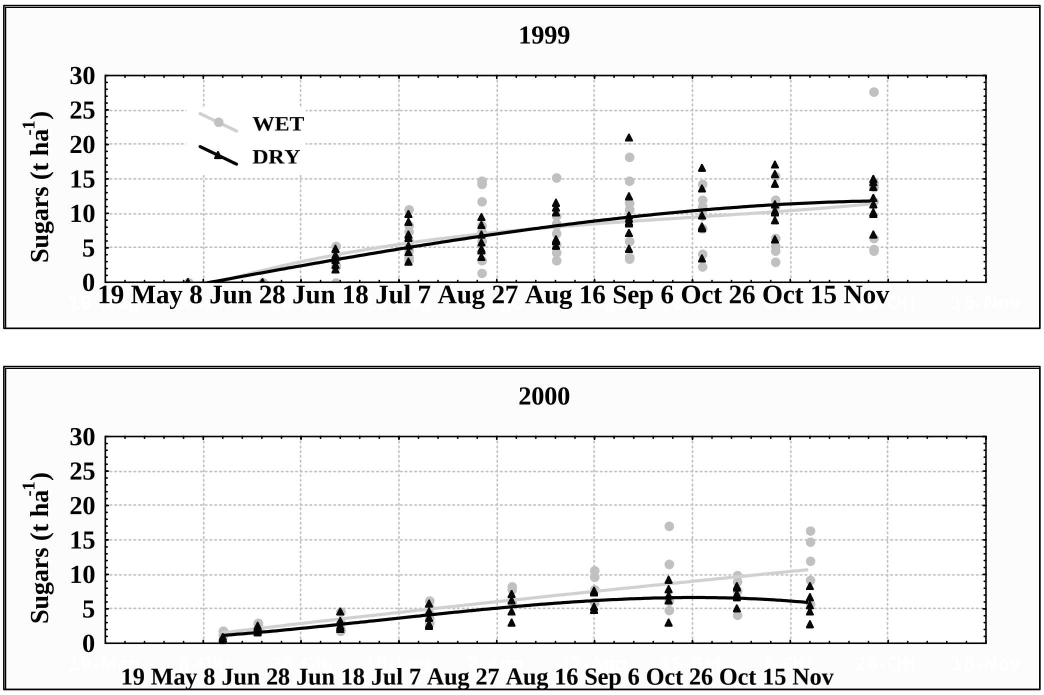

Fig. 3. Chicory accumulation in sugars, as influenced by ET_M restoring level (average of two years). (Wet=100% of ET_M; Dry=25% of ET_M)

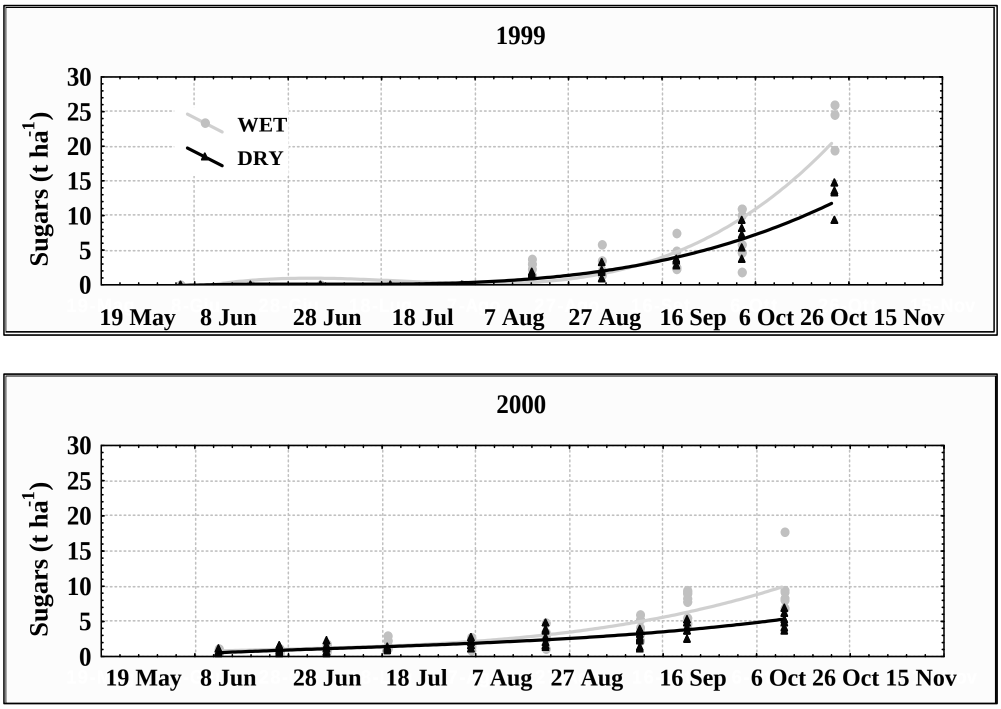

Fig. 4. Jerusalem artichoke accumulation in sugars, as influenced by ET_M restoring level (average of two years). (Wet=100% of ET_M; Dry=25% of ET_M)

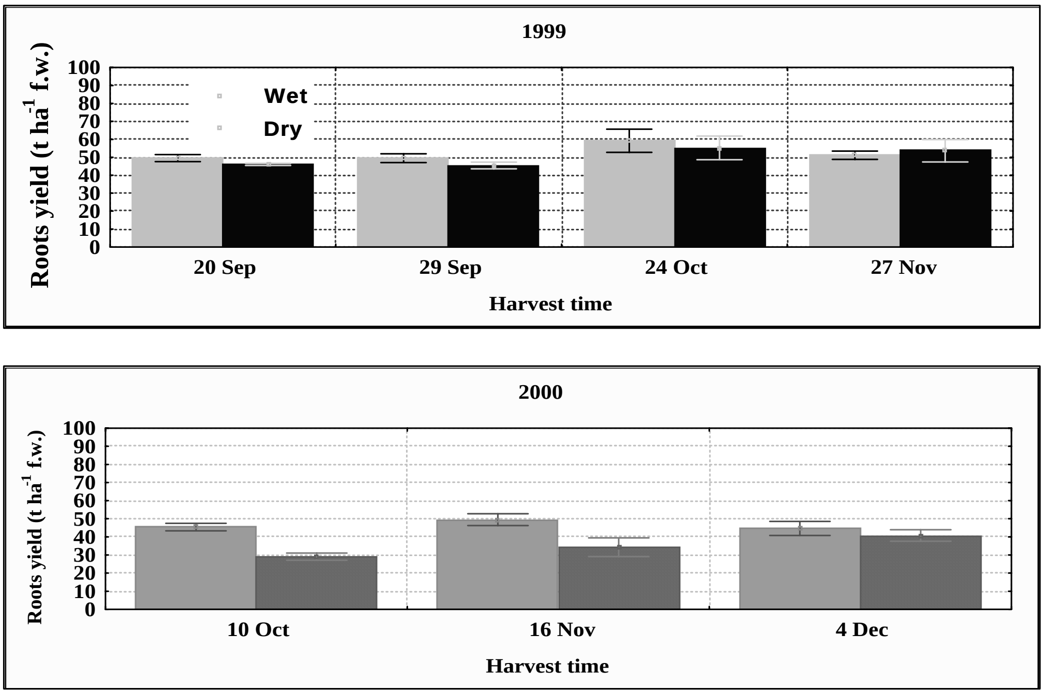

Fig. 5. Yield of Chicory roots, as influenced by year and harvest date. (Wet=100% of ET_M; Dry=25% of ET_M)

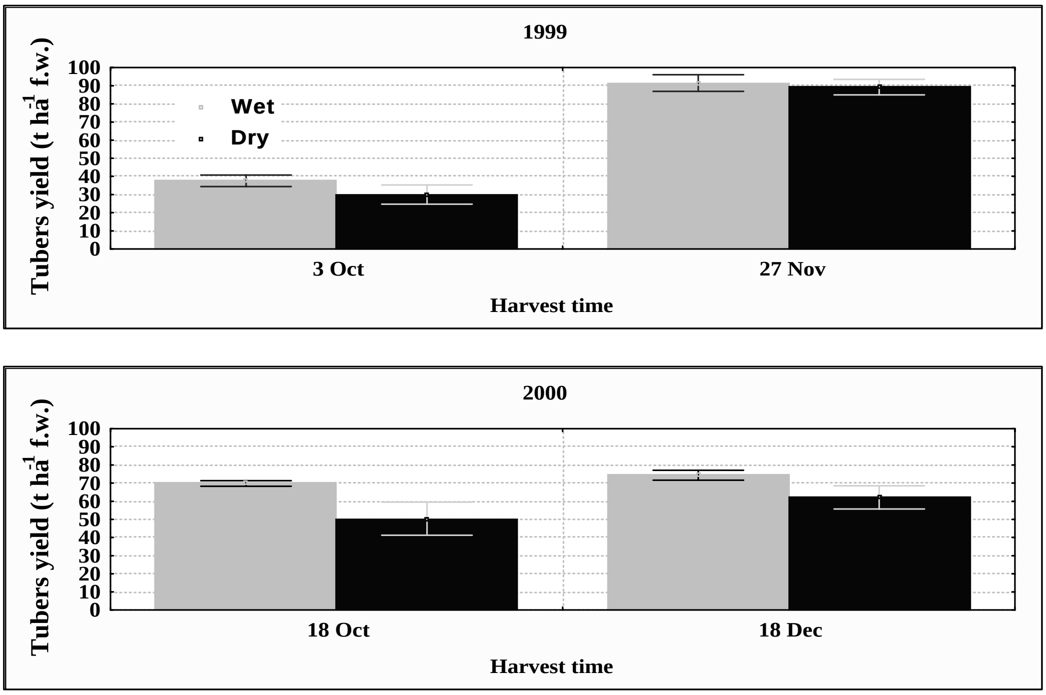

Fig. 6. Yield of Jerusalem artichoke tubers, as influenced by year and harvest date.
(Wet=100% of ET_M; Dry=25% of ET_M)

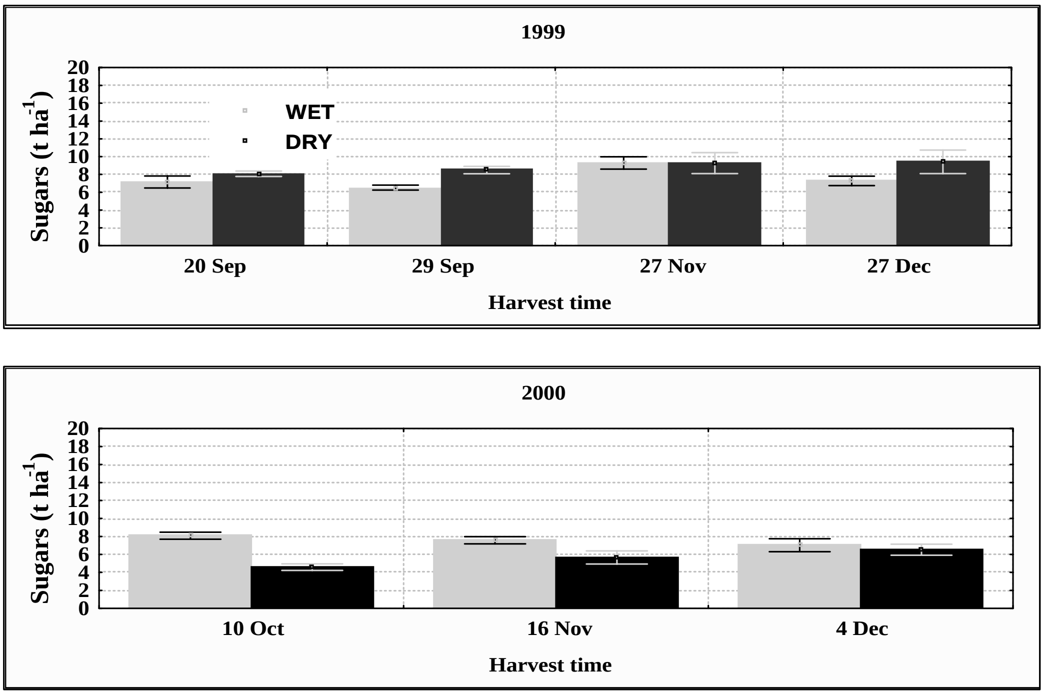

Fig. 7. Chicory sugars yield, as influenced by year and harvest date.
(Wet=100% of ET_M; Dry=25% of ET_M)

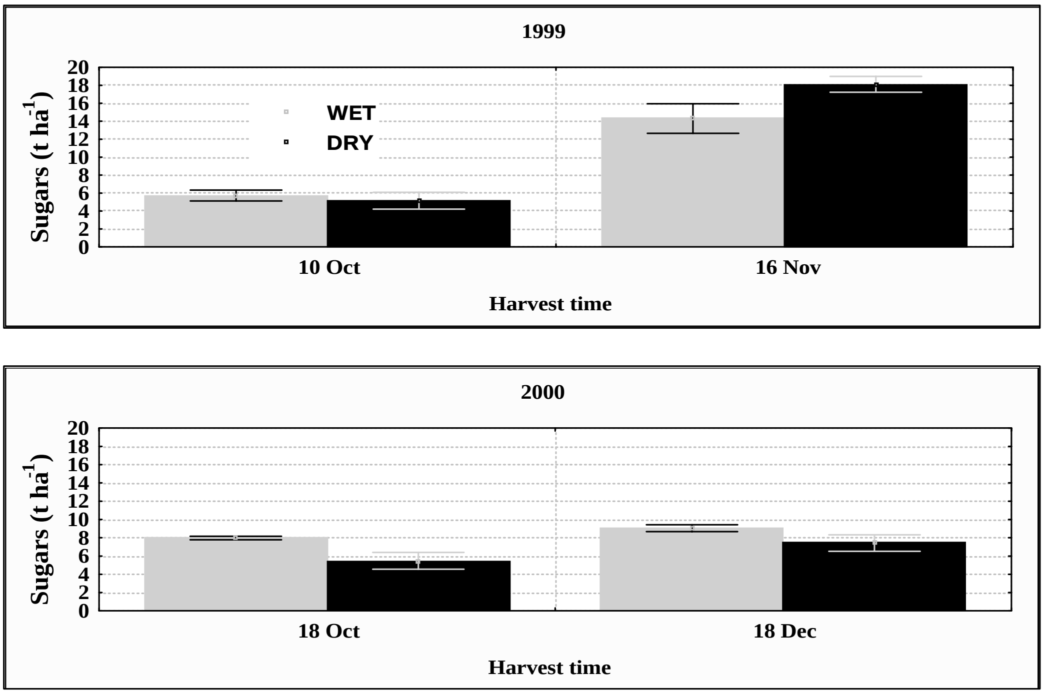

Fig. 8. Jerusalem artichoke sugars yield, as influenced by year and harvest date.
(Wet=100% of ET_M; Dry=25% of ET_M)