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Radicchio Cultivation under Different Sprinkler Irrigation Systems

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Abstract

Gun sprinklers were commonly used in Italy to irrigate Radicchio. Although this high-pressure irrigation system allows large areas to be irrigated in a short time, it has some major disadvantages. Disadvantages include the impact of the drops on the soil and crop can be very strong, the high volume of water used tends to increase water use and runoff and water distribution uniformity is low. A 3-year experiment was conducted in North-East Italy in order to evaluate the possibility of using a mini-sprinkler irrigation system with low-volume application rates. The use of mini-sprinkler resulted in a higher distribution uniformity, higher Christiansen uniformity coefficient and a higher water use efficiency. Energy cost was also lower when the mini-sprinkler system was used for irrigation as compared to the irrigation gun system. Radicchio head weight and marketable yield were higher when plants were irrigated with the mini-sprinkler as compared to those irrigated with the irrigation gun. Therefore, the use of mini-sprinklers resulted in not only a reduction in water use and energy cost but also an increase in radicchio production.

Keywords: chicory, irrigation uniformity, irrigation gun, mini-sprinkler, energy, water use efficiency

1 Introduction

Radicchio (Cichorium intybus L., rubifolium group) is a common red-and-white-leafed green eaten fresh or as a component in cooked dishes. There are various types or groups of radicchio with the groupings generally referring to plant growth habit and head shape and form. The “Rosso di Chioggia” types are the most common grown in Italy followed by “Rosso di Verona”, “Rosso di Treviso” and “Variegato di Castelfranco”. With 100,000 tons produced annually on 9000 hectares, the Veneto is the largest radicchio-producing region in Italy and accounts for approximately 58% of cultivated land and 42% of the annual Italian radicchio production [12]. Although it has been considered a traditional Italian fresh leafy green, radicchio is now commonly being grown throughout Europe, Japan, the United States, Guatemala, Mexico and South America [8].

Sprinkler irrigation practices have been shown to have a significant impact on both quantity (rate of growth and biomass produced) and quality of field-grown radicchio [2, 4, 16, 17]. The most commonly used irrigation systems in Italy for radicchio production are large irrigation guns with 28 – 32 mm diameter nozzles supplied by pumps coupled to the power take-off (PTO) of a tractor and operating at 4 to 8 bar of pressure at the nozzle. These irrigation guns can supply water to large areas at a time, but they produce large droplets with high kinetic energy that impact the soil and cause the formation of a surface crust (especially in silty and clay soils) that can impair the growth of newly transplanted radicchio plants and reduce the number of harvestable heads [5]. This soil crust also acts as an impermeable layer that reduces oxygen availability to the plant roots, reduces the infiltration of irrigation water into the soil and increases surface runoff [3, 18]. When irrigating with the irrigation guns, it is common to apply high volumes of water with long irrigation intervals, so that large variations in soil moisture occur (from dry to saturated) causing stress to the crop [15, 20]. Finally, the field layout of irrigation gun systems fails to insure uniform water distribution and the application rate tends to exceed the infiltration capacity of the soil so that significant surface runoff is common in the final phases of irrigation.

In contrast to large gun irrigation systems, portable mini-sprinkler irrigation systems have directed no-impact sprinklers mounted on metal rods (stands) with a quick connector to a lateral polyethylene or layflat type supply pipe. These systems apply low volumes of water using pressures of 2.5 to 4 bar. They typically have a short throw radius of 6 – 12 m and flow rates of 150 to 700 L/hr. The water can be directed to specific areas of the field to insure uniform water distribution and to minimize runoff. The installation and operation of these types of systems allow for more uniform irrigation, a reduction in runoff, application of smaller droplet sizes, and shorter more frequent irrigation cycles which have proven to be beneficial for horticultural crops such as lettuce, carrots, onions and potatoes. Therefore, the objective of this research was to compare irrigation water use efficiency [19], energy cost and radicchio crop production and quality under irrigation gun and a portable mini-sprinkler irrigation system.

2 Materials and methods

This research was conducted on a commercial farm near the Venice lagoon (North-East Italy; 45°14’11” N, 12°11’0” E). Meteorological data were recorded by the nearest regional weather station and are reported in Figure 1.

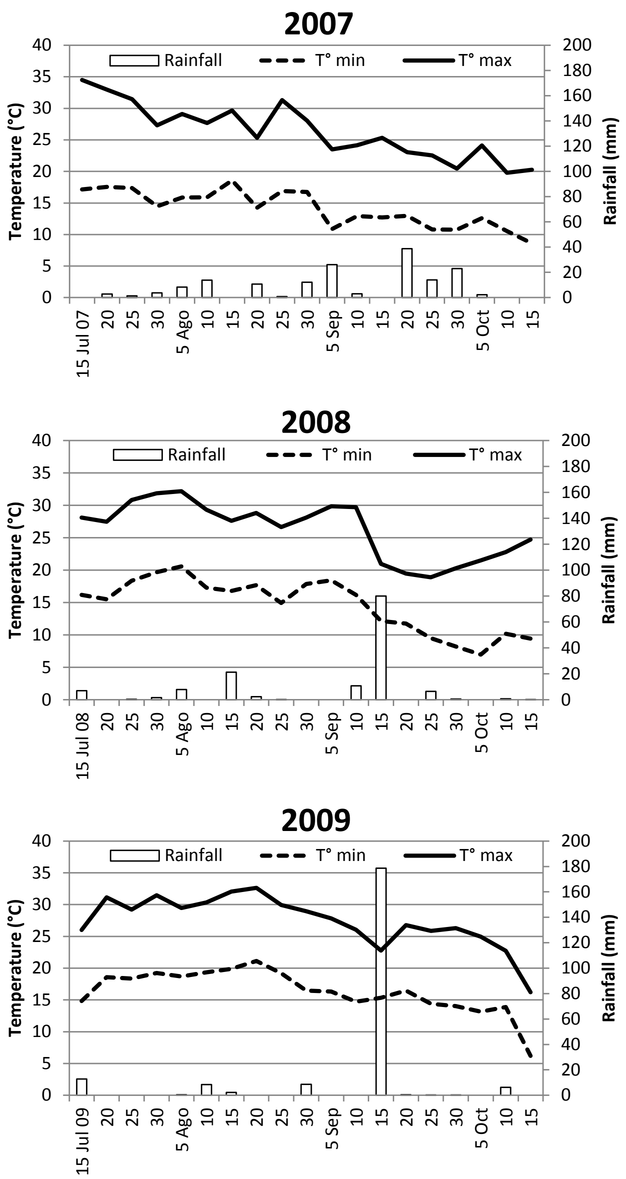

Fig. 1 – Five-day averages of maximum and minimum temperature and five-day cumulative rainfall recorded during the three years of experiment

The soil type was a Typic fluvaquents coarse-silty, mixed, calcareous, mesic (USDA Soil Taxonomy classification) and a Calcari-Epigleyic Fluvisols (World Reference Base for Soil Resources classification) [1]. The soil texture was a silty-loam with an organic matter content of 1.68%, the total available water capacity was 172 mm/m and the saturated hydraulic conductivity was 8 mm·h^{-1}. The available water capacity of the top 0.30 m where plant roots were distributed was 51.6 mm.

The trials were conducted during the 2007-2009 production seasons. Two contiguous plots were set up (Figure 2).

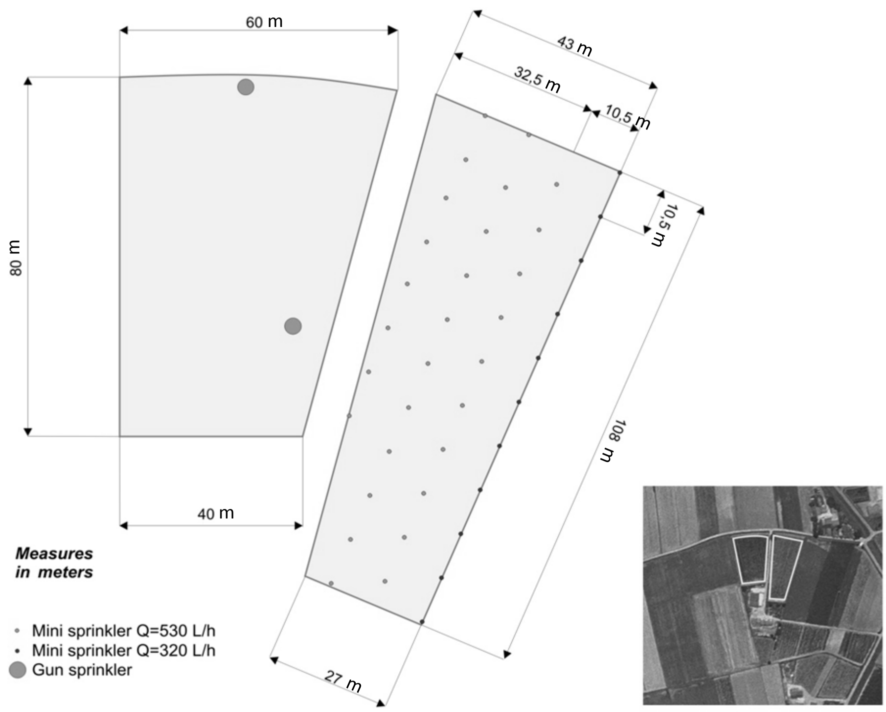

Fig. 2 - Sprinkler layouts of the two irrigation systems and orthophoto of the experimental area

In the first plot, a 3780 m^2 system was installed with low-volume mini sprinklers on a stand (model Super10 NaanDanJain Ltd.) placed in a triangular layout about 10 m apart. Sprinklers with 530 L·h^{-1} nominal flow rate at 3.5 bar were mounted in the central lines and sprinklers with 320 L·h^{-1} nominal flow rate equipped with a 180-degree deflector (road protector) were used in the lateral lines to avoid wetting outside the field. The nominal flow rate of the latter sprinklers was not exactly halved compared to those in the central lines due to the water volume lost (not distributed to the crop) near the sprinkler caused by the impact of the water jet on the deflector. Therefore, this required such increase in the flow rate in order to achieve a uniform distribution similar to the central sprinklers. The system was powered by a 4 kW electric pump that pumped water from the nearby irrigation district canal. The water was filtered through a 120 mesh screen to avoid any system clogging [9].

In the second plot, a 4100 m^2 system was set up that irrigated the crop using a high throw radius (about 40 m) 30 mm nozzle irrigation gun with a 22 $L \cdot s^{-1}$ nominal flow rate at 5 bar pressure at the nozzle. The irrigation gun was mounted on a fixed tripod operating in two different positions to cover the entire production area. The power supply was provided by a centrifugal pump coupled to the power-take-off (PTO) of a 59 kW tractor that drew water from the same irrigation district canal as described for the first plot.

Seedlings of “Rosso di Treviso Precoce” radicchio were transplanted into the field plots during the third week of July with a plant spacing of 0.28 m in the row and 0.40 m between rows (8 - 9 $plants \cdot m^{-2}$). Both plots had previously been planted with asparagus, and during the experiment, a radicchio followed by wheat crop rotation was followed. For both plots and years, ammonium nitrate (title 26% N) was applied during pre-planting tillage at a rate of 100 kg of $N \cdot ha^{-1}$. No phosphorus or potassium were applied as the content of these mineral elements in the soils was high. Irrigation scheduling was based on monitoring the soil water content with a Delta-T Devices soil moisture profile probe placed at depths of 0.10, 0.20, and 0.30 m. Irrigations were performed at about 40% depletion of total available water capacity (~20 mm).

Application rate and uniformity of water distribution were determined. The field measurements of water distribution uniformity were performed in both experimental plots using full-grid collector arrays (ISO Standard 15886-3, 2004). For the mini-sprinklers, the test was performed using rain collectors placed on the ground to form a grid 10 m x 10 m with a layout 1 m apart replicated in three different sites of the plot. In the second plot, the grid covered almost the whole area irrigated by the irrigation gun (collectors 5 m apart). The irrigation times were chosen based on the application rate of the two systems with 2 hours for mini-sprinklers and 30 minutes (15 minutes for each position) for the irrigation gun system. The different irrigation times were set in relation to the greater flow rate of the irrigation gun and also considering the significant runoff that occurred due to the slow water infiltration rate that was 8 $mm \cdot h^{-1}$ in some areas. Instead, for mini-sprinklers the reduced flow rates were taken into account.

The precipitation depths measured at the various collecting points were recorded and the distribution uniformity of low quarter (DU_{lq}) and the Christiansen Uniformity coefficient (CU) were determined [6, 13]. The uniformity of distribution was considered good when the DU_{lq} value was greater than 0.7 and CU was greater than 80% [7]. The irrigation volumes used were calculated for each season and both systems. The values were estimated considering the nominal flow rate at operating pressure of the mini-sprinklers and the irrigation gun, the duration of each irrigation, the area of the plots and the number of irrigations per season. The water use efficiency (WUE) values were calculated and expressed as the ratio between crop yield ($kg \cdot ha^{-1}$) and irrigation water volumes ($m^3 \cdot ha^{-1}$).

At the end of each season (first half of October), plant samples were taken to estimate the crop yield. Five plots for each treatment were identified along the central part of each field before harvesting. Each plot covered an area of 2.4 m^2, so as to ideally include 21 plants (7 plants per row in 3 rows). Crop yield was evaluated in terms of quantity expressed as number of heads harvested, weight of individual marketable heads, marketable yield. Quality was evaluated according to the Specifications in the “Radicchio Rosso di Treviso” PGI (Protected Geographical Indication; Regulation EC 1263/96) which involved subdividing the heads between first quality (≥ 150 g) and second quality (< 150 g). Before weighing, the plants were cleaned as is usual for the market by removing the outer leaves and cutting a portion of the taproot. All statistical calculations were made using analysis of variance. In the case of a significant F-values, the means were compared by Tukey’s HSD test.

The energy cost was estimated by calculating the total energy consumed during the irrigation season by the two systems [10, 13]. For the mini-sprinkler, the total consumption (kWh) of the electric pump was multiplied by the cost of 1 kWh (0.175 euro kWh^{-1}). For the irrigation gun, the mechanical power (MP in kW) required by the pump was transformed into liters of diesel fuel consumed using the formula MP x D x NO, where D is the fuel consumption (0.27 kg kWh^{-1}) and NO are the hours of use, and then multiplied by the cost of agricultural diesel (1 euro L^{-1}). The values were proportional to a unit surface area of 1 hectare.

3 Results and discussion

There were 8 irrigations in 2007, 11 irrigations in 2008 and 10 irrigations in 2009. In all years, the applied water volumes were significantly lower for the mini-sprinkler system than for the irrigation gun system (Table 1).

Table 1. Volume of irrigation water applied to a radicchio crop for each of three growing seasons using mini-sprinklers and an irrigation gun

	Irrigation volumes per year (mm)^z		
Irrigation system	**2007**	**2008**	**2009**
Mini-sprinkler	88	125	110
Irrigation gun	203	278	253

^{z} Total volume of irrigation water applied per year for each irrigation system.

The short throw radius of mini-sprinklers allowed easily to irrigate inside the cultivated area as much as possible, while the longer throw of the irrigation guns inevitably resulted in irrigation outside of the field boundaries to ensure sufficient wetting of the whole cultivated area. The longer the throw radius, the more likely was irrigation water to be applied outside of the production area. This is a diffuse problem in Italy where the plots cultivated with radicchio have often small size and irregular shape. Additionally, with the variation in the amounts applied per area (see below), more surface runoff occurred with the irrigation gun and this water was lost to outside of the production area. The volume of water applied per area ranged from 2.9 $mm \cdot h^{-1}$ to 7.7 $mm \cdot h^{-1}$ when the mini-sprinkler was used for irrigation (Table 2). However, ranging from 3.0 $mm \cdot h^{-1}$ to 72.0 $mm \cdot h^{-1}$, the variation in the range of the volume of water applied per area was higher for the irrigation gun system than the mini-sprinkler systems.

Table 2. In-field measured application rates and calculated distribution uniformity and Christiansen uniformity coefficients using mini-sprinklers and an irrigation gun to irrigate radicchio[z]

Irrigation system	**Application rate range ($mm \cdot h^{-1}$)**			**DUlq**	**CU (%)**
	Minimum	**Average**	**Maximum**		
Mini-sprinkler	2.9	4.3	7.7	0.76a	82.8a
Irrigation gun	3.0	35.4	72.0	0.43b	63.3b

[z] Data pooled across 2007, 2008 and 2009 production seasons.

Values without letters in common are significantly different at $P \leq 0.05$ according to Tukey HSD Test.

The very high application rates when using the irrigation gun resulted in application rates that exceed infiltration rates for this soil (8 $mm \cdot h^{-1}$) and resulted in surface runoff of water from the plots when using the irrigation gun system. The more uniform application of water using the mini-sprinklers also resulted in higher DUlq and CU values for the mini-sprinkler irrigation system than for the irrigation gun system.

Radicchio head weight, marketable production, percent of transplants developing marketable heads and WUE did not differ across the research years (Table 3). However, when pooled across years, all of these parameters were higher for radicchio irrigated using the mini-sprinkler system than for those irrigated with the irrigation gun (Table 3). Radicchio irrigated using mini-sprinklers had 9% higher head weight than radicchio irrigated using the irrigation gun system. In terms of market product classes there were no significant differences for the number of heads of first and second choice (data not shown). Second choice heads were on average 3 - 4% of total harvested heads in both irrigation systems. For the marketable production a significant increase of more than 4 tons (+19 %) was obtained when the crop was irrigated with the mini-sprinklers as compared to the irrigation gun (Table 3). The percentage of plants harvested in relation to those transplanted was higher for the mini-sprinkler treatment than for the irrigation gun.

Table 3. Crop production parameters and water use efficiency for field-grown radicchio irrigated using mini-sprinklers and an irrigation gun[z]

Irrigation system	Head weight (g)	Marketable yield ($t \cdot ha^{-1}$)	Transplants producing marketable heads (%)	WUE ($kg \cdot m^{-3}$ of applied water)
Mini-sprinkler	303 a	22.8 a	89.1 a	21.5 a
Irrigation gun	276 b	18.4 b	75.9 b	7.5 b
Significance	*	**	**	**
Years				
2007	269	18.5	76.7	16.1
2008	302	21.2	80.0	12.6
2009	297	22.1	89.5	15.0
Significance	NS	NS	NS	NS

[NS, *, **] Nonsignificant or significant at $P \leq 0.05$ and 0.01, respectively.

[z] Values within a column followed different letters were significantly different at $P \leq 0.05$ according to Tukey HSD Test.

The WUE expressed as the ratio between crop yield ($kg \cdot ha^{-1}$) and irrigation volumes ($m^3 \cdot ha^{-1}$), was a parameter that demonstrated how effectively the water resources were utilized in the production of the radicchio crop. As with radicchio growth and harvest variables, the WUE was not significantly different across years. However, the WUE was 286% higher when the crop was grown using the mini-sprinkler since as compared to the irrigation gun system. Therefore, use of the mini-sprinkler system not only resulted in generally higher production of radicchio but more efficient use of water resources in doing so.
The mini-sprinkler system allowed energy cost to be significantly reduced compared to the traditional system with the irrigation gun. This reduction was higher, the larger the number of irrigations performed during the season. In order to better compare the two irrigation systems, a further calculation was made considering the energy consumption of an electric pump with enough power to ensure the proper operation of the irrigation gun (at least 30 kW). In such a case the energy cost was double that of the mini-sprinkler (Figure 3).

4 Conclusions

In this 3-year trial, we demonstrated that the mini-sprinkler system allowed for the production of radicchio using less water. The water applied using a mini-sprinkler system was applied to the crop more uniformly with more precision (inside of the production area) and less runoff than with an irrigation gun. In addition to a reduction in water use and energy cost when using mini-sprinklers, radicchio crop yield and head weight were higher when the crop was irrigated using the mini-sprinkler system as compared to the irrigation gun. Therefore, growers would benefit from shifting to mini-sprinklers by both reducing water use and energy cost and having higher marketable yields.

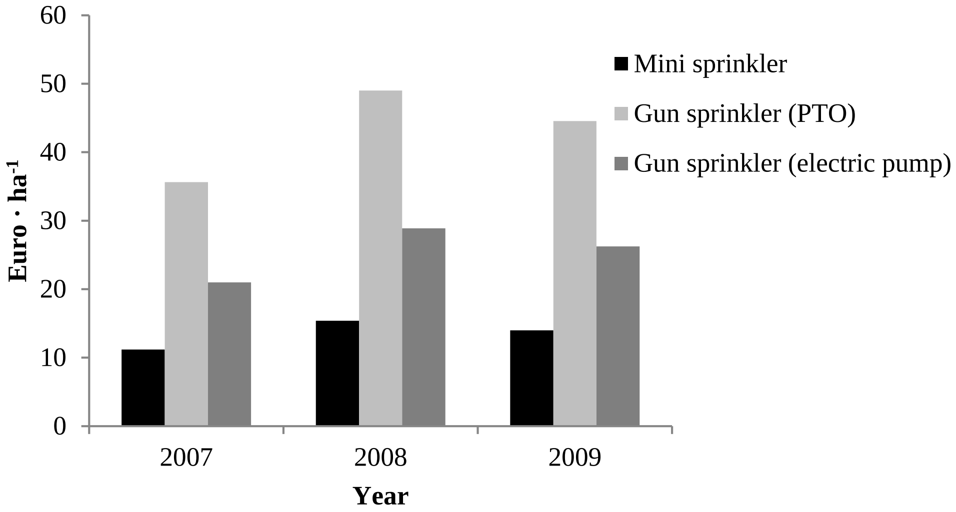

Fig. 3 - Comparison between energy costs of mini sprinkler system and gun sprinkler system operating with (PTO) pump coupled to the PTO of 59 kW tractor and (electric) 30 kW electric pump

References

[1] ARPAV, *Carta dei suoli del Bacino scolante in Laguna di Venezia*, Regione Veneto, Italy, 2004.

[2] M.T. Asghari, J. Daneshian, H.A. Farahani, Studying of planting density influence on dry matter accumulation changes in chicory (Cichorium intybus L.) under irrigation deficit stress regimes, *American-Eurasian Journal of Sustainainable Agriculture*, **3** (2009), 371-374.

[3] N.K. Awadhwal, G.E. Thierstein, Soil crust impact on crop establishment: a review, *Soil and Tillage Research*, **5** (1985), 289-302. http://dx.doi.org/10.1016/0167-1987(85)90021-2

[4] J. Babik, S. Kaniszewski, and J. Dysko, Effect of cultivation methods and drip irrigation on the yield of roots and the quality of chicons of witloof chicory, *Vegetable Crops Research Bulletin*, **70** (2009), 183-191. http://dx.doi.org/10.2478/v10032-009-0018-7

[5] L. Bortolini, M. Andriolli, E. Ramponi, B. Zanchetta, Una nuova tecnica per

l’irrigazione del radicchio, *L’Informatore Agrario,* **23** (2005), 31-34.

[6] C.M. Burt, A.J. Clemmens, T.S. Strelkoff, K.H. Solomon, R.D. Bliesner, L.A. Hardy, T.A. Howell, D.E. Eisenhauer, Irrigation performance measures: efficiency and uniformity, *Journal of Irrigation and Drainage Engineering*, **123** (1997), 423-442. http://dx.doi.org/10.1061/(asce)0733-9437(1997)123:6(423)

[7] C.M. Burt, A.J. Clemmens, R. Bliesner, J.L. Merriam, L. Hardy, *Selection of Irrigation Methods for Agriculture*, On-Farm Irrigation Committee of EWRI. American Society of Civil Engineers, USA, 2000. http://dx.doi.org/10.1061/9780784404621

[8] M.F. Filippini, J.B. Cavagnaro, C. Nicoletto, F. Pimpini, P. Sambo, Influence of fertilization on the growth of radicchio "Rosso di Chioggia" cultivated in two different environments, *Revista de la Facultad de Ciencias Agrarias*, **43** (2011), 111-131.

[9] D. Friso, L. Bortolini, Precoat filtration with body-feed and variable pressure. Part II: Experimental tests and optimization of filtration cycles, *Applied Mathematical Sciences*, **9** (2015), no. 148, 7367-7378. http://dx.doi.org/10.12988/ams.2015.510634

[10] R.D. Grisso, M.F. Kocher, D.H. Vaughan, Predicting tractor fuel consumption, *Applied Engineering in Agriculture*, **20** (2004), 553-561. http://dx.doi.org/10.13031/2013.17455

[11] ISO Standard15886-3. Agricultural irrigation equipment – Sprinklers - Part 3: Characterization of distribution and test methods. International Organization for Standardization. Geneva, Switzerland, 2004.

[12] R. Lazzarin, F. Tosini, D. Rolvaldo, Radicchio Rosso di Chioggia. In: Ortaggi da foglia, *II Divulgatore*, **1** (2004), 36-50.

[13] J. Keller, R.D. Bliesner, *Sprinkle and Trickle Irrigation*, Blackburn Press, New Jersey, USA, 2000.

[14] M. Kutz, (Ed.), *Mechanical Engineers' Handbook*, John Wiley & Sons. Inc., New York, USA, 1998.

[15] M. Martello, N. Dal Ferro, L. Bortolini, F. Morari, Effect of Incident Rainfall Redistribution by Maize Canopy on Soil Moisture at the Crop Row Scale, *Water*, **7** (2015), 2254-2271. http://dx.doi.org/10.3390/w7052254

[16] J.R. Patel, J.B. Patel, P.N. Upadhyay, V.P. Usadadia, The effect of various

agronomic practices on the yield of chicory (Cichorium intybus), *Journal of Agricultural Sciences*, **135** (2000), 271-278. http://dx.doi.org/10.1017/S0021859699008229

[17] F. Pimpini, G. Chillemi, R. Lazzarin, P. Parrini, M. Lucchin, *Il Radicchio Variegato di Castelfranco*, Aspetti tecnici ed economici di produzione e conservazione, Veneto Agricoltura, Regione Veneto, Italy, 2001.

[18] F.L. Santos, J.L. Reis, O.C. Martins, N.L. Castanheira, R.P. Serralheiro, Comparative assessment of infiltration, runoff and erosion of sprinkler irrigated soils, *Biosystems Engineering*, **86** (2003), 355-364. http://dx.doi.org/10.1016/S1537-5110(03)00135-1

[19] F. Tromboni, L. Bortolini, M. Martello, The use of water in the agricultural sector: a procedure for the assessment of large-scale irrigation efficiency with GIS, *Irrigation and Drainage*, **63** (2014), 440-450. http://dx.doi.org/10.1002/ird.1833

[20] P.J.M. Van Boheemen, P.J. Kusse, C. Maas, J.W. Wesseling, Effect of fresh water supply on agriculture in the southwest of the Netherlands, *Netherlands Journal of Agricultural Sciences*, **31** (1983), 269-278.

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