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The influence of drip or furrow irrigation on yield and quality of Burley tobacco under saline conditions

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Abstract

Irrigation methods are critical to alleviate salinity problems in Mediterranean areas, where saline waters are frequently used to irrigate crops. Field experiments were conducted on Burley tobacco (*Nicotiana tabacum* L.) cv. C104 in Southern Italy for two years to compare drip versus furrow irrigation, in which waters of increasing salinity were used. Two irrigation methods (drip and furrow) and six irrigation treatments [rainfed control (RC), and fully-irrigated with water having an electrical conductivity (EC_w) of 0.5 (normal water, NW), 2.5 (saline water, SW_1), 5 (SW_2), 10 (SW_3), and 15 dS m^{-1} (SW_4)] were factorially combined. Irrigation water use efficiency (IWUE, kg ha^{-1} mm^{-1}), soil salt accumulation and soil moisture were measured for each treatment combination. Over the growing season the electrical conductivity of soil (EC_e) across the 0.6 m soil's top profile increased with increasing salinity of the irrigation water but more in drip- than furrow-irrigated plots [0.177 and 0.105 dS m^{-1} EC_e (dS m^{-1} EC_w)$^{-1}$, respectively, averaged over years]. Salinity of the irrigation water did not affect yield of cured leaves in the SW_2 - SW_4 range. Nevertheless, in the same range quality of cured product was generally depressed due to increases in leaf Cl^- and decreases of filling power (cm^3 g^{-1}) of cut tobacco. Overall, furrow irrigation significantly produced greater yield, mean cured leaves weight and IWUE as compared with drip irrigation (1.7 *vs.* 1.5 Mg ha^{-1}, 5.8 *vs.* 5.2 g, 5.9 *vs.* 5.4 kg ha^{-1} mm^{-1}). The drip-irrigation proved to be superior over conventional furrow irrigation for tobacco cultivation under open-field conditions.

Keywords: Electrical conductivity, irrigation methods, irrigation water use efficiency, *Nicotiana tabacum* L., salt stress.

Abbreviations: Cl^-_ chloride; DM_ dry matter; EC_e_ electrical conductivity of the soil; EC_w_electrical conductivity of the irrigation water; FP_ filling power; IM_ irrigation methods; IT_ irrigation treatments; IWUE_ irrigation water use efficiency; LSD_ least significant difference; N_ nitrogen; NW_ normal water; RC_ rainfed control_ SD, soil depths; SW_ saline water; Y_ year.

Introduction

In many irrigated areas of the Mediterranean basin, growers are forced to use saline water to irrigate their crops due to an inadequate supply of fresh water related to the competition among agricultural, industrial, and urban consumers (Colla et al., 2006; 2010). In this respect, irrigation system can significantly impact the effect of irrigation water salinity on crop performance (Rouphael et al., 2006). It is well established that irrigation system is the most important factor that could mitigate the detrimental effect of salinity as it differently affects the maintenance of soil water potential, uniformity of water application (Homaee and Schmidhalter, 2008; Malash et al., 2008a; Lv et al., 2010), percentage of wetted soil (Lynch, 1995; Michelakis et al., 1996; Lehmann, 2003; Lv et al., 2010), as well as salt accumulation pattern (Homaee and Schmidhalter, 2008; Malash et al., 2008a). All of these aspects are relevant for salinity management and control (Homaee and Schmidhalter, 2008; Malash et al., 2008a; Lv et al., 2010).

Furrow irrigation is the most commonly used surface method for irrigation of row field crops worldwide. Under furrow irrigation, a large soil volume is generally wetted and adequate soil wetting is achieved through lateral infiltration of water (Allen et al., 1998). Nevertheless, in arid and semiarid areas drip irrigation is recommended as a more efficient alternative to furrows (Rajak et al., 2006; Vàzquez et al., 2006). Differently from furrow irrigation, drip irrigation applies water at very low rates and wets only a small volume of soil around drippers (Vàzquez et al., 2005). Consequently, both soil evaporation or crop transpiration under drip irrigation are lower as compared to furrow irrigation (Hanson and May, 2004; Erdem et al., 2006).

Since drip and furrow irrigations do not equally distribute water in the soil profile, they may differently influence root uptake of water and nutrients. In general, drip irrigation increases both water and nitrogen use efficiencies with respect to furrow irrigation (Vàzquez et al., 2005; Aujla, et al., 2007; Ibragimov et al., 2007; Hassanli et al., 2009). Nevertheless, the greater water uptake of plants irrigated by surface methods from the 0.5-1.0 m soil layer with respect to drip-irrigated plants (Constable and Hodgson, 1990; Lv et al., 2010) may reduce differences in both nitrogen and water efficiencies between the two irrigation methods. When farmers are forced to use saline water for irrigation, the crop performance may vary differently based on the irrigation system adopted. For instance, Malash et al. (2008a) reported that drip irrigation produced a 33% greater fruit yield per unit of water than furrow irrigation in field-grown tomato irrigated with waters at different levels of salinity. Similarly, Rajak et al. (2006) reported a more marked salt-induced reduction in yield of furrow-irrigated than drip-irrigated cotton plants.

Tobacco (*Nicotiana tabacum* L.) is a widely cultivated crop in Southern Italy, where there are incipient seasonal problems of soil salinity due to irrigation with saline waters (Sifola, 2002). In these areas, Burley tobacco is traditionally furrow-irrigated. Nevertheless, there has recently been a growing interest to drip irrigate this crop since, in spite of greater installation and materials costs, it is less labour intensive and may contribute to save much water than furrow irrigation due to its potential greater efficiency of water distribution.

The effects of salinity on yield and quality of drip-irrigated Burley tobacco was previously reported (Sifola and Postiglione, 2002). In this study, the authors demonstrated that tobacco could be classified as moderately tolerant or moderately sensitive to salinity, based on the EC_e, at which yield was reduced by 50% (EC_{e50}) or 10% (EC_{e10}), respectively, although threshold values were very low (0.56 and 0.96 dS m^{-1}, in the first and second year of experiment). Salinity can decrease the plant dry matter at harvest (-35 and -18% in the two years) as well as both photosynthetic rates and stomatal conductance, but increases dry matter partitioning to leaves. Further four years experiment on drip-irrigated tobacco showed that even though there was no effect of salinity on yield and yield components, quality traits were generally depressed, due to high leaf Cl^- concentration. The cigarettes obtained from saline treatments showed an unsatisfactory burning capacity on the whole during the smoking test (Sifola, 2005). To the best of our knowledge, no published data are available on the effect of irrigation methods under saline conditions, on yield and quality of tobacco despite the importance of its cultivation in areas, where soil salinity due to irrigation is becoming a growing concern.

Based on the above considerations, the aim of this study was to evaluate the effect of salinity of the irrigation waters on drip and furrow-irrigated tobacco crop Burley type over two consecutive years. The crop performance was evaluated in terms of yield, quality of cured products and irrigation water use efficiency.

Results

Relationship between soil and water electrical conductivities

The electrical conductivity of the irrigation water (EC_w) corrected for the dilution effect of rainfall ranged between 0.5 and 12.8 dS m^{-1} in 2000 and between 0.5 and 14.4 dS m^{-1} in 2001 (Fig. 2), whereas the time-weighted electrical conductivity of the soil (EC_e) ranged between 2.7 and 6.6 dS m^{-1} (drip), 2.2 and 6.3 dS m^{-1} (furrow) in 2000 and between 2.9 and 7.1 dS m^{-1} (drip), 3.1 and 5.2 dS m^{-1} (furrow) in 2001. The average EC_e during the growing season, across the 0.6 m top profile, increased with increasing EC_w. Regression equations between EC_e and EC_w were significant for both treatments (Fig. 2). The slope of the regression equation was significantly higher in drip- than furrow irrigated plots only in the second year of the study (i.e 2001). The EC_e measured at 0.9 m soil depth was significantly lower than that measured at either 0.3 or 0.6 m at the beginning and at the end of the growing season, but no difference in EC_e across soil depths was measured in the middle of the growing season (data not shown). When averaged over irrigation methods, the EC_e/EC_w at the root zone through the season decreased with increasing salinity and were lower than 1 at SW_3 and SW_4 treatments in 2000 and at SW_2, SW_3 and SW_4 treatments in 2001.

Changes in soil moisture

Soil moisture was significantly higher in 2000 than 2001 although differences disappeared at the end of the growing season (Table 3).

The rainfed control (RC) treatment showed significant less soil moisture than other irrigation treatments at the 2nd, 3rd and 4th sampling dates (Table 3). In general, the soil moisture significantly increased with depths in 2000 but not in 2001 (Fig. 3a, b) and under drip but not under furrow irrigation (Fig. 3c), with significant differences at 0.6-0.9 m depth (Fig. 3). In the middle part of the growing season, the soil moisture was significantly greater under drip than furrow irrigation in 2000 but not in 2001 (data not shown). In the first year, at the end of the growing season, less soil moisture was recorded in drip-irrigated than furrow-irrigated plots under all saline conditions (SW_1 to SW_4). Nevertheless, there was no difference in soil moisture between irrigation methods due to salinity of the irrigation water at plant maturity in 2001 (data not shown).

Yield of cured leaf and irrigation water use efficiency

The RC exhibited the lowest yield and yield components in comparison to the other treatments (data not shown). Moreover, yield, yield components and IWUE were affected differently by irrigation methods in the two years of the experiment. For instance, yield, cured leaf mean weight, number of marketable cured leaves per plant and IWUE were significantly higher under furrow than drip irrigation in 2000. However, in the second year, no significant differences among irrigation methods were recorded on yield, yield components and IWUE (Fig. 4). Interestingly, irrigation methods did not affect the performance of tobacco to salinity in terms of yield, yield components (cured leaf mean weight, number of marketable cured leaves per plant) and IWUE. Overall, furrow irrigation determined significantly greater yield, mean cured leaves weight and IWUE as compared with drip irrigation (1.7 *vs.* 1.5 Mg ha^{-1}, 5.8 *vs.* 5.2 g, 5.9 *vs.* 5.4 kg ha^{-1} mm^{-1}).

Cured leaves quality parameters

For the quality traits, there was no effect of year, irrigation method and irrigation treatment on nitrogen concentration of cured leaves (Table 4). The alkaloids concentration was significantly less in 2000 than in 2001. Surprisingly, it was significantly higher under furrow than drip irrigation and as for salinity it increased significantly with saline waters at SW_2 treatment without any further increase up to the SW_4 level (Table 4). Moreover, the filling power was significantly greater in 2000 than in 2001. Differently from alkaloids, it was not influenced by irrigation methods (5.8 and 6.0 cm^3 g^{-1}, in drip and furrow irrigation, respectively) and with respect to normal water (NW) treatment, it decreased with increasing salinity at SW_2 level (6.6 *vs.* 5.7 cm^3 g^{-1}). Similarly, to alkaloids concentration, there was no further significant change due to salinity up to the SW_4 treatment (Table 4). Plants grown under RC conditions had alkaloids concentration significantly greater than those grown under NW treatment but similar to SW_2, SW_3 and SW_4 treatment (Table 4). On the other hand, the filling power of RC-treated plots was significantly less than that of the NW treatment (Table 4). In 2000, the chloride concentration of cured leaves of drip-irrigated plants was higher than in furrow-irrigated plants, but oppositely was occurred in the 2nd year of the study (Fig. 5a). In particular, Cl^- did not vary significantly between years under drip irrigation, whereas it was significantly greater in 2001 than 2000 under furrow irrigation (Fig. 5a).

Table 1. Physical and chemical properties of soils (mean over 0-0.6 m soil layer) of drip and furrow irrigation experiments in 2000 and 2001.

	2000		2001	
	Drip	Furrow	Drip	Furrow
Sand (%)	45.3	44.8	54.6	48.9
Silt (%)	22.2	21.5	17.6	18.8
Clay (%)	32.8	33.7	27.8	32.3
Lime (%)	0.6	1.4	4.1	1.4
pH	6.9	6.7	7.9	7.7
Organic matter (%)	0.830	0.863	0.555	0.567
N (Kjeldahl) (%)	0.112	0.096	0.069	0.057
NO_3-N (ppm)	4.2	5.8	8.8	11.8
NH_4-N (ppm)	11.8	7.0	12.8	8.3
EC_e (dS m^{-1})	1.24	0.91	1.55	1.19
Field Capacity (0.03 MPa, % dry weight)	30.4	29.4	29.9	29.8
Wilting Point (1.5 MPa, % dry weight)	18.4	17.4	18.0	18.4

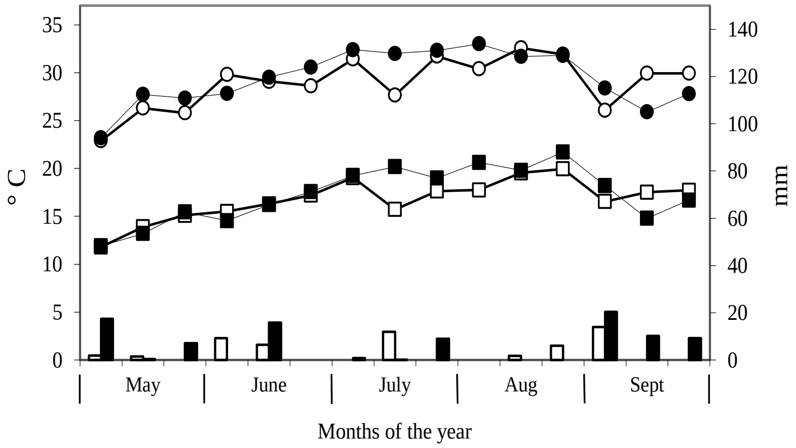

Fig 1. Rainfall (bars), minimum (square) and maximum (circle) air temperature during the trial period (ten-day basis). Open and closed bars and symbols represent 2000 and 2001 data, respectively.

In addition, the Cl^- concentration of cured leaves of SW_1 treatment increased significantly with respect to NW plants and then remained constant up to the SW_4 level in 2000. However, in 2001, it increased significantly up to the SW_3 treatment without any further increase at the highest level of salinity in irrigation water (Fig. 5b). Similarly to the yield and yield components, irrigation methods did not affect the response to salinity of tobacco crop in terms of cured leaves quality (Table 4).

Discussion

In the current experiment, furrow irrigation caused increases in the time-weighted EC_e in the root zone at 0-0.6 m depth less than drip irrigation. Moreover, furrow-irrigated tobacco showed a greater efficiency in water use and yield than drip-irrigated plants in 2000 in contrast with previous studies in field-grown eggplant (Aujla et al., 2007), cotton (Rajack et al., 2006; Ibragimov et al., 2007), tomato (Malash et al., 2008a) and maize (Hassanli et al., 2009) plants. In the second year differences between irrigation methods disappeared (Fig. 3) probably due to the abundant precipitations occurring in 2001 from transplanting to flowering (50 mm, well distributed during the period May-July), which presumably vanished potential differences in the amount of wetted soil between the two methods during the rapid growth and elongation period, which are crucial for tobacco yield (Tso, 1990). Similarly, Constable and Hodgson (1990) and Hodgson et al. (1990) reported that differences in yield and quality between furrow and drip-irrigated cotton plants became negligible, when the growing season was rainy.

In general, tobacco plants irrigated with saline water (SW_1 to SW_4 treatments) had a slightly higher, although not significant, efficiency in water use than the NW control (+11% SW_4 *vs.* NW treatment), in agreement with results reported for other field-grown crops like cotton (Ibragimov et al., 2007) and tomato (Malash et al., 2008b). It should also be noted that in the present experiment salinity did not affect yield of cured leaves in the SW_2 - SW_4 range. The actual time-weighted EC_e on row did not exceed 6.6 (drip) and 6.3 dS m^{-1} (furrow) in 2000 and 7.1 (drip) and 5.2 dS m^{-1} (furrow) in 2001. In particular, the EC_e/EC_w ratios at the root zone, always below 1 at medium-high levels of salinity treatments, indicated that salts did not over-accumulate within the 0-0.6 m soil profile, regardless to irrigation methods. As a result, leaching appeared adequate under those saline conditions as also shown in previous studies conducted on drip-irrigated Burley tobacco in the same area (Sifola and Postiglione, 2002; Sifola, 2005). It has been reported that localized irrigation systems partially make wet the potential root zone. Thus, they strongly affect the level of water availability and the rate of water absorption by the plants (Michelakis et al., 1996). In the current study, the soil moisture of furrow-irrigated plots in both years was generally less than that of drip-irrigated ones in the mid-season, indicating a greater water uptake of furrow-irrigated plants (Table 4).

Table 2. Monthly distribution of the number of irrigations, irrigation volumes and rainfall in the two years of study. The irrigation volume supplied at transplanting (22 mm) was not included.

	Number of irrigations		Irrigation volumes (mm)				Rainfall	
	2000	2001	2000		2001		2000	2001
			Drip	Furrow	Drip	Furrow		
May	-	-	-	-	-	-	-	25
June	-	1	-	-	20	20	16	16
July	5	5	129	126	170	180	12	10
August	6	3	164	164	101	101	8	0
September	-	-	-	-	-	-	14	-

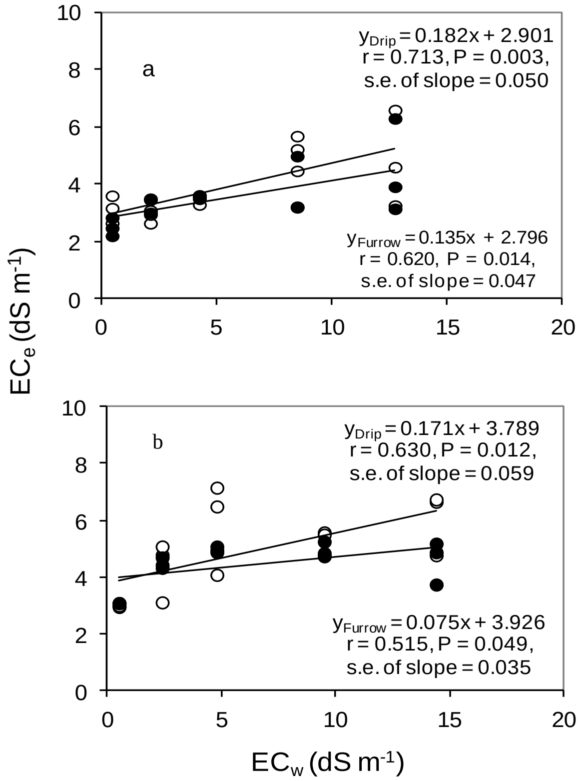

Fig 2. The relationship between electrical conductivity of the irrigation water (EC_w), corrected for the dilution effect of rainfall, and mean weighted electrical conductivity of the soil (EC_e) in 2000 (a) and 2001 (b). Legend: drip irrigation (open symbols); furrow irrigation (closed symbols); s.e., standard error.

In particular, at the second sampling date (the end of rapid growth-leaf ripeness in both years) differences in water uptake between methods increased with increasing soil depth (Fig. 5 c). There was a greater water uptake from the deepest soil layer (0.6-0.9 m) of root systems under furrow- than drip-irrigated conditions. Several studies also showed that when the volume of soil, potentially explored by the root system, was as large as possible, absorbing roots had a greater ability to uptake water and nutrients (Constable and Hodgson, 1990; Hodgson et al., 1990). In addition, Hodgson et al. (1990) showed that roots of furrow-irrigated cotton were properly deeper than those of drip-irrigated one. Therefore, the higher water uptake by the soil of furrow- than drip-irrigated plants could be responsible for the best IWUE of furrow-irrigated than drip-irrigated plants in the conditions of the present experiment. Finally, as expected, saline irrigation decreased quality of cured leaves since the chloride content was increased and the filling power was decreased (Sifola, 2005).

Materials and methods

Experimental site and climatic data

An experiment was conducted over two consecutive years, in 2000 and 2001, at the experimental farm of the University of Naples, South Italy (40° 37’ N; 14° 58’ E). Table 1. Shows the physical and chemical properties of the soil. Average daily maximum temperatures were greater than 30 °C in early and late July and in August during the 2000 growing season, whereas in 2001 the highest air temperature were recorded from late June through late August. Rainfall amount was 53 mm (June-September) and 26 mm (June-August), in 2000 and 2001, respectively, well-distributed during the growing seasons except for August 2001, which was completely dry (Fig. 1).

Table 3. The effects of soil depths, years, irrigation methods and irrigation treatments on soil moisture (% dry weight) during cropping.

2000 2001	3 July 26 June	21 August 20 July	4 September 7 August	22 September 7 September
Soil depths				
0 - 0.3 m	20.9	18.9 a	19.8 a	17.7 a
0.3 - 0.6 m	21.3	18.8 a	20.0 a	17.9 a
0.6 – 0.9 m	24.3	23.3 b	23.0 b	20.2 b
Year				
2000	25.6 B	23.9 B	22.5 B	18.8
2001	18.7 A	16.8 A	19.3 A	18.4
Irrigation Method				
Drip	21.9	23.1 B	22.1 B	17.9 a
Furrow	22.5	17.6 A	19.7 A	19.3 b
Irrigation Treatment				
RC	18.7	17.1 A	15.9 A	15.8 A
NW	22.5	24.9 C	23.5 C	19.2 BC
SW_1	24.4	19.7 B	21.3 B	19.6 C
SW_2	21.3	19.8 B	20.2 B	18.5 B
SW_3	22.5	19.5 B	22.9 C	18.9 B
SW_4	23.7	21.0 BC	21.7 BC	19.7 C
ANOVA				
Soil depth (SD)	NS	*	*	*
Year (Y)	**	**	**	NS
SD × Y	NS	**	**	NS
Irrigation Method (IM)	NS	**	**	*
SD × IM	NS	*	NS	NS
Y × IM	NS	*	NS	**
SD × Y × IM	NS	NS	NS	NS
Irrigation Treatment (IT)	NS	**	**	**
SD × IT	NS	NS	NS	NS
Y × IT	NS	NS	**	NS
IM × IT	NS	NS	NS	**
SD × Y × IT	NS	NS	NS	NS
Y × IM × IT	NS	NS	NS	*
SD × Y × IM × IT	NS	NS	NS	NS

Means with a common letter within columns are not significantly different according to LSD at $p \leq 0.05$ or 0.01 (capital letters). NS, *, ** are non-significant or significant at $p \leq 0.05$ or 0.01, respectively. RC, Rainfed Control; NW, fully-irrigated with normal water of 0.5 dS m^{-1} EC_w; SW_1, fully-irrigated with saline water of 2.5 dS m^{-1} EC_w; SW_2, fully-irrigated with saline water of 5.0 dS m^{-1} EC_w; SW_3, fully-irrigated with saline water of 10.0 dS m^{-1} EC_w; SW_4, fully-irrigated with saline water of 15.0 dS m^{-1} EC_w.

Plant material, crop management, and irrigation treatments

Seedlings of Burley tobacco (*Nicotiana tabacum* L.) cv. C104 were transplanted on 13 June 2000 (Year 1) and on 10 May 2001 (Year 2), with 1m row spacing and 0.5 m spacing between plants, giving a plant density of 2 plants m^{-2}. In both years, the crop was fertilized at transplanting with 150 kg ha^{-1} P_2O_5 and 120 kg ha^{-1} K_2O. One hundred and twenty kg ha^{-1} of nitrogen (N) were distributed in two applications: 50% at transplanting (ammonium sulphate, 21% N) and 50% at side-dressing (ammonium nitrate, 26% N). On 20th August 2000 and on 22 July 2001 plants were topped and after topping, 5% solution of m-decanol (Off-shoot-T85, Dow Agrosciences) was applied to control suckering. Treatments were defined by a factorial combination of two irrigation methods (drip-irrigation or furrow irrigation) and six irrigation treatments: a rainfed control (RC), irrigated only twice (25 mm total seasonal volume) at transplanting to ensure seedling establishment, a fully-irrigated with normal water (NW) of 0.5 dS m-1 electrical conductivity (ECw), fully-irrigated with saline water of 2.5 dS m-1 (SW1), 5 dS m-1 (SW2), 10 dS m-1 (SW3) and 15 dS m-1 (SW4). Saline solutions were obtained by adding commercial salt containing Na^+ 23.8%, K^+ 14.8%, Ca^{2+} 0.102%, Mg^{2+} 0.1%, Cl^- 51.2% and $SO4^{2-}$ 0.28% to irrigation water to obtain the ECw levels of 2.5, 5, 10 and 15 dS m^{-1} (Sifola and Postiglione, 2002).

Fully-irrigated treatments (both drip- and furrow-irrigated) received an amount of water equal to crop evapotranspiration (ETc), applied when water depletion in the soil profile exceeded 40% of available water, as previously reported (Sifola and Postiglione, 2002). Monthly distribution of the number of irrigations, irrigation volumes and rainfall are reported in Table 2. Drip-irrigated plots received about the same amount of water of furrow-irrigated ones (Table 2) because, due to the short length of furrows (12 and 15 m in 2000 and 2001, respectively), we assumed that the efficiency of water distribution was equal to 100% in both methods. The irrigation treatments started on 6 and 7 July 2000 and on 27 and 29 June 2001, for drip-irrigation and furrow irrigation, respectively.

Soil electrical conductivity and moisture

In both years, four soil samples per plot were taken on row in both irrigation methods, at three depths (0-0.3 m; 0.3-0.6 m; 0.6-0.9 m) from the beginning of irrigation treatments through commercial harvest, in order to determine both soil

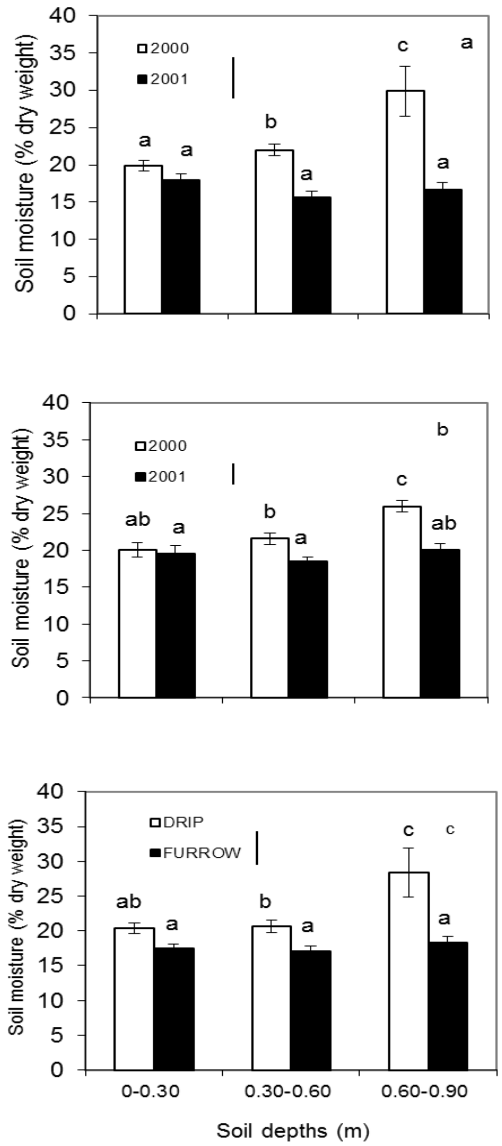

Fig 3. The effect of interactions for Soil depth × Year at the second (a) and third sampling date (b) and Soil depth × Irrigation method at the second sampling date (c) on soil moisture. Data are means ± standard errors. Bars and different letters indicate least significant differences at P ≤ 0.05 (c) and 0.01 (a, b).

electrical conductivity (EC_e) and moisture. Soil sampling dates were: 3 July, 21 August, 4 and 22 September in 2000 and 26 June, 20 July, 7 August and 7 September in 2001. Soil samples were taken one day before irrigation. Average EC_e values over the season were calculated as the mean weighed electrical conductivity (dS m^{-1} at 25 °C) of the soil in the 0-0.6 m top soil depth, which includes 80-90% of tobacco roots (Jones et al., 1960), taking into account the dilution effect of rainfall (Sifola and Postiglione, 2002). Soil moisture was also determined by oven drying at 105 °C to constant weight.

Leaf curing, yield and irrigation water use efficiency

Thirty days after topping (10 September in 2000 and 23 August in 2001) 68 and 84 plants were harvested from the central part of each plot in 2000 and 2001, respectively. Plants were air cured as previously reported (Sifola and Postiglione, 2002).

After harvest and curing period, yield of cured leaves at 19% standard moisture content and yield components (number and mean weight of cured leaves) were determined. In addition, the following quality traits were also measured: (i) the filling power (cm^3 g^{-1}) measured on cut tobacco using a densimeter DD60/A (Borgwaldt, Hamburg, Germany) (Sifola, 2005); (ii) alkaloids and chloride concentrations, determined on ground lamina of cured leaves from the middle part of plants by reaction with sulphanilic acid and cyanogen chloride and nitric acid and then adding mercuric thiocyanate, respectively (Sifola, 2005); and (iii) the nitrogen content by the Kjeldahl method (Bremner, 1965) after mineralization with H_2SO_4. The irrigation water use efficiency (IWUE~~,~~ kg ha^{-1} mm^{-1}) was calculated as the ratio between the yield of cured leaves (kg ha^{-1}) and the seasonal irrigation water (mm) applied.

Statistical analysis

In both years, irrigation methods were arranged in different field and irrigation treatments were completed randomized within each field in plots of 120 and 150 m^2 in 2000 and 2001, respectively, with three replications (blocks). Yield, yield components, IWUE and quality traits were subjected to analysis of variance (ANOVA) by SPSS 20 software package for Windows 2012 (www.ibm.com/software/analytics/spss), using a completely randomized block design, combined over years and locations (irrigation methods fields), and means separated by least significant difference (LSD) at P ≤ 0.05 and 0.01. The mean values of each year were tested for homogeneity of variance before data of both years were pooled together. Soil moisture was tested for significance by ANOVA within each date of measurement following a split-plot design, combined over years and locations (irrigation methods fields) with soil depth as the main plot and irrigation treatments as sub-plot (SPSS, 2012). The relationship between soil electrical conductivities (EC_e, dS m^{-1}) and electrical conductivities of irrigation waters (EC_w, dS m^{-1}) in drip- and furrow-irrigated plots was analyzed by linear regression. Slopes of regression equations were compared for significance using t-Student test.

Conclusions

To summarize, salinity of the irrigation water in the SW_2 - SW_4 range did not affect yield of cured leaves. In particular, in that range there was an increase in mean leaf weight which counteracted the decrease in number of marketable leaves per plant. Nevertheless, quality was generally depressed due to increases in leaf Cl^- and to decreases of filling power. Our results also demonstrated that, furrow irrigation could be adopted to irrigate tobacco since it decreased the EC_e at medium-high salinity levels and generally increased IWUE with respect to drip irrigation, presumably due to the greater amount of wetted soil which improved plant water uptake especially by the deep soil layers. Despite promising results reported in literature on other open-field crops, drip-irrigation has yet to prove superior to conventional furrow irrigation for growing tobacco under open field conditions. Our study did not provide evidence to suggest drip-irrigation was better over furrow irrigation. However, it should be taken into consideration that for economic reasons drip-irrigation could be adopted by tobacco growers since it is less labour-intensive and allows saving more water than furrow irrigation.

Table 4. The effects of years, irrigation methods and irrigation treatments on total alkaloids, chlorides, nitrogen (N) and filling power (FP) of cured leaves.

	Alkaloids (% d.m.)	Chloride (% d.m.)	N (% d.m.)	FP (cm^3 g^{-1})
Year				
2000	2.1 A	4.9 A	2.9	6.1 B
2001	2.8 B	5.7 B	2.9	5.7 A
Irrigation Method				
Drip	2.4 a	5.3	2.9	5.8
Furrow	2.5 b	5.3	2.9	6.0
Irrigation Treatment				
RC	2.6 b	4.7 AB	3.0	5.9 AB
NW	2.2 a	4.3 A	2.9	6.6 C
SW_1	2.3 a	5.5 BC	2.9	6.2 BC
SW_2	2.5 b	5.5 BC	2.9	5.7 AB
SW_3	2.6 b	6.0 C	2.9	5.7 AB
SW_4	2.4 ab	5.7 BC	2.9	5.5 A
ANOVA				
Year (Y)	**	**	NS	**
Irrigation Method (IM)	*	NS	NS	NS
Y × IM	NS	**	NS	NS
IrrigationTreatment (IT)	*	**	NS	**
Y × IT	NS	**	NS	NS
IM × IT	NS	NS	NS	NS
Y × IM × IT	NS	NS	NS	NS

Means with a common letter within columns are not significantly different according to LSD at $p \leq 0.05$ or 0.01 (capital letters). NS, *, ** are non-significant or significant at $p \leq 0.05$ or 0.01, respectively. RC, Rainfed Control; NW, fully-irrigated with normal water of 0.5 dS m^{-1} EC_w; SW_1, fully-irrigated with saline water of 2.5 dS m^{-1} EC_w; SW_2, fully-irrigated with saline water of 5.0 dS m^{-1} EC_w; SW_3, fully-irrigated with saline water of 10.0 dS m^{-1} EC_w; SW_4, fully-irrigated with saline water of 15.0 dS m^{-1} EC_w.

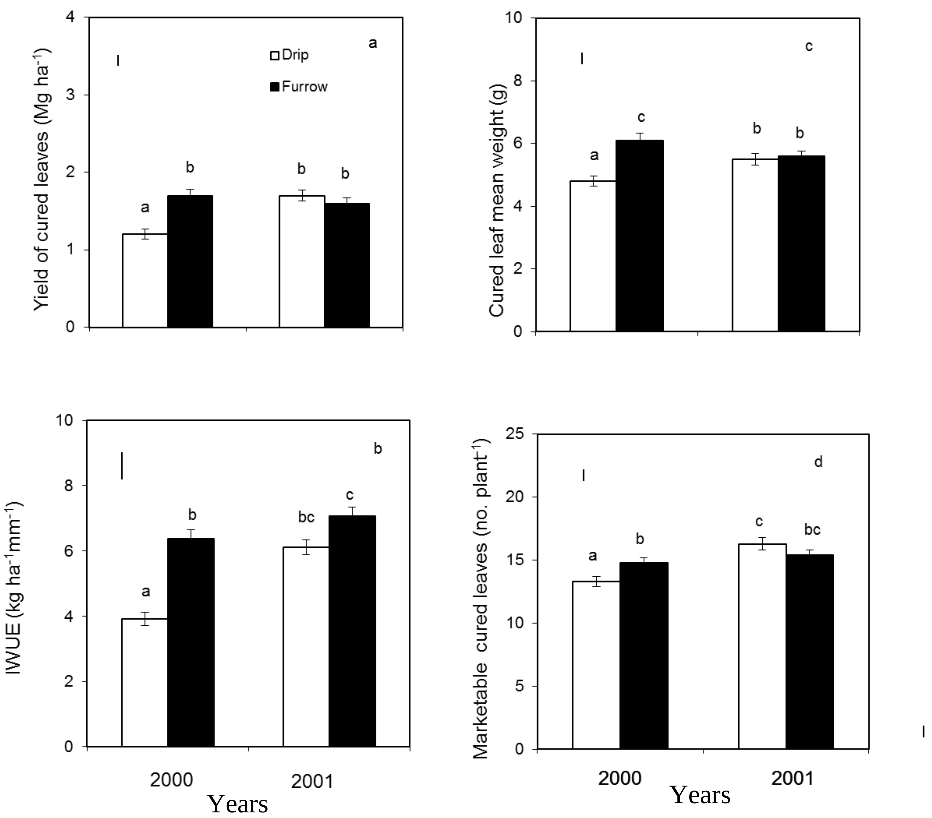

Fig 4. The effect of the interaction Year × Irrigation methods on yield of cured leaves (a), irrigation water use efficiency (IWUE) (b), mean leaf weight (c) and number of marketable cured leaves (d). Data are means ± standard errors. Bars and different letters indicate least significance differences of interaction at P < 0.01.

Madison, WI, pp. 1149–1178, Agron.Monograph 9 (Part 2).

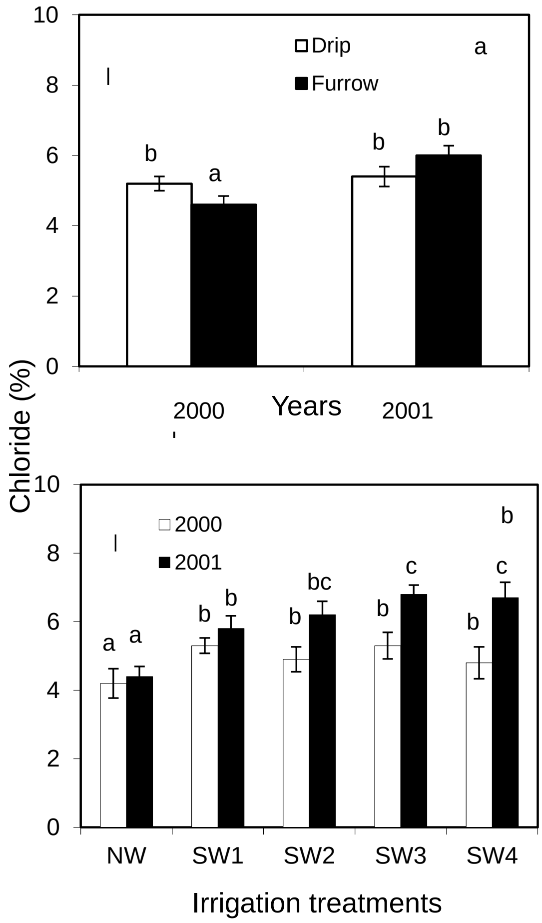

Fig 5. The effect of Irrigation methods (a) and of the five irrigation treatments (b) in the two years on chloride concentration of cured leaves. Data are means ± standard errors. Bars and different letters indicate least significant differences at P ≤ 0.01. Irrigation treatments: NW, 0.5 dS m^{-1} EC_w; SW_1, 2.5 dS m^{-1} EC_w; SW_2, 5.0 dS m^{-1} EC_w; SW_3, 10.0 dS m^{-1} EC_w; SW_4, 15.0 dS m^{-1} EC_w.

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