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Characterization of Growth and Quality Parameters in Escarole (*Cichorium endivia* L.) with different Covering Techniques

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Summary

Intensive horticulture is a traditional agricultural system in Southern Spain, with crop rotations that are often surface irrigated and heavily fertilized. The Granada Vega has been classified according to European Union regulation as a vulnerable zone to nitrate contamination. Farmers must comply with mandatory agricultural practices aimed to reduce groundwater and surface water pollution with nitrate. The goals of this study were to propose and evaluate alternatives to traditional crop management practices to minimize nitrate leaching. An escarole crop under three different crop management systems (plastic mulch, plastic mulch combined with floating cover and control at open air) was studied in 2005 and 2006. Commercial yield, crop evapotranspiration, biomass production, leaf area, nitrate concentration in leaves and in drainage water were monitored. Protected escaroles (mulched and mulched with floating cover) reached their commercial fresh weight before the control did. Commercial yield of open air crops was highly dependent on weather conditions. The results of this study suggest that mulching in escarole may have a positive effect on reducing nitrate leaching. Also, the amount of N fertilizer applied to the protected treatments following the N_{min} method was found to be excessive and can be adjusted in order to reduce nitrate leaching without affecting yield. Covering the crops did not seem to increase nitrate content in leaves. Adding a floating cover to the mulched crop would be advantageous only under unfavorable weather conditions. In that case, it could increase marketable yield and shorten the crop cycle.

Key words. evapotranspiration – floating cover – leachates – nitrates – mulching

Introduction

The Granada Vega in southern Spain has been farmed for centuries and it still is an important agricultural area in the Eastern Andalusia region. Traditional crops include cereals (barley, wheat, corn), horticultural crops (asparagus, garlic, potato) and tobacco, most of them surface irrigated and heavily fertilized. This agricultural area has been classified according to European Union regulation as "vulnerable zone to nitrate contamination from agricultural use and exploitation", following the directives on protective measures against aquifer contamination by fertilizers (C.E.C. 1991). This directive contains mandatory measures relating to agricultural practices in order to reduce groundwater and surface water pollution by high nitrate contents. Furthermore, groundwater contamination from nitrate leaching receives special attention by the European Union legislation (E.C. 2000), establishing a framework for the protection and sustainable use for all European waters by 2015.

In leafy vegetables, an additional disadvantage of excessive fertilization is the increase of nitrates in the edible plant organs, which may pose a health threat if the daily ingestion of nitrates for a prolonged period is above 4 mg kg^{-1} body weight (Boink and Speijers 2001). Thus, there is a need of research for alternative management practices that would reduce nitrogen losses while maintaining crop yield in these vulnerable areas.

The use of both, plastic mulching and fertigation in horticultural crops is increasing, mainly as a result of its agronomic and environmental benefits (Robledo and Martin 1981; Benoit 1994; Farias-Larios and Orozco-Santos 1997). Some of the reported beneficial effects of plastic mulches are an increase in crop yield, modification of the soil thermal regime, reduced weed competition and conservation of soil moisture (Tarara 2000). Also, a decrease in nitrate leaching through the reduction of drainage (Benoit 1994; Romic et al. 2003) and nitrate concentration in the drainage water (Romic et al. 2003) has been reported.

An alternative to mulching could be the use of floating covers (polypropylene fabric), which can be laid over the crop without any supporting frame. The use and advantages of these covers have been documented as an inexpensive mean to improve the crop micro-environmental conditions (Gimenez et al. 2002; Hernandez et al. 2004). One possible disadvantage of using floating covers is the reduction of the solar radiation incident in the canopy, which might increase the nitrate concentration in leafy vegetables (Lillo 1994). Reported values for transmission of solar radiation under polypropylene fabric range from 70 to 80 % (Chen et al. 1988; Suarez-Rey et al. 2008).

The objectives of the present study were: i) to analyze the effects of different covers on crop growth, develop-

ment and yield of escarole; ii) to evaluate the accumulation of nitrates in escarole leaves under these conditions, and iii) to asses the effect of nitrate leaching when using the crop covers.

Materials and Methods

The study was conducted at the Centre for Agricultural Research (IFAPA Camino de Purchil, Junta de Andalucía, Granada, Spain) (37 º 10 ' N; 3 º 40 ' W; 640 m altitude) during the fall seasons of 2005 and 2006. The climate is Mediterranean continental temperate with warm summers and cool winters, low relative humidity and 2935 hours of sunlight per year (I.N.M. 2007). The soil of the experimental area is classified as Typic Xerofluvent (Soil Survey Staff 1992) with an estimated bulk density of 1400 kg m^{-3}. This soil is characteristic of low river terraces, very permeable, highly calcareous, and has moderate organic matter in the lower layers. Well water was used for irrigation with the following characteristics determined *in situ*: sodium adsorption ratio (SAR) value of 0.4 (meq $L^{-1})^{0.5}$, pH of 8, electrical conductivity (EC) of 0.72 dS m^{-1}, and nitrate concentration of 37 mg L^{-1}. The water was classified of medium salinity and low sodic hazard. Climatic data were daily recorded from a weather station located at the research centre. The station provides meteorological data which can be downloaded from a website (www.juntadeandalucia.es), such as air temperature and relative humidity, rainfall, solar radiation, wind speed and direction, and reference evapotranspiration (ETo) estimated by the Penman Monteith equation (Allen et al. 1998).

Four weeks old escarole plantlets (*Cichorium endivia* L. 'Mesbella') were transplanted in October 3, 2005 and October 4, 2006, in nine 4 x 12 m plots. Plant density was 8.3 plants m^{-2} with lines 30 cm apart. The plots were drip irrigated with polyethylene (PE) laterals 60 cm apart, and inline emitters every 33-cm within the lateral. Average emitter flow rate was 2 L h^{-1}, with an emission uniformity of 93 %. There were three treatments: control-open air (OA), plastic mulch (PM; black polyethylene film, 25 µm thick), and plastic mulch plus floating cover (PM-FC; spunbonded non-woven polypropylene fabric of 17 g m^{-2}, Agryl-P17, Sodoca, France). The floating cover was placed at planting and maintained until harvest in 2005. In 2006, it was removed 20 days before harvest because high air temperatures were about to cause deformed heads under the covers. Weeds were controlled in the OA plots with mechanical methods (hand hoeing and tillage). All plots were fertigated using water-soluble fertilizers injected into the irrigation system. Nitrogen concentration in the irrigation water was periodically adjusted during the entire crop cycle to ensure that all treatments received the scheduled fertilizer.

Changes in soil moisture content in the root zone were obtained from Time Domain Reflectometer data (TDR MP-917, E.S.I. Environmental Sensors Inc., Victoria, Canada). TDR measurements were made every 1–2 days in three free-drainage lysimeters (2.4 m wide x 3.0 m long x 0.8 m depth in the deepest side), one per treatment, located next to the study area and managed in the same way than the experimental plots. The lysimeters were lined with a butyl sheet 0.6 mm thick and its bottom was slightly sloped towards a drainage outlet 0.80 m deep. The available water was 48 mm (16 % by volume) for the upper 30 cm of the soil, where most of the root growth was expected to occur. Irrigation was performed when there was a 30 % depletion of soil available water in the root zone. Lysimeters had perforated PE drainage pipes 0.80 m deep. Drainage from lysimeters was periodically collected, and analyzed for nitrate concentration with a portable Ion Selective Electrode (ISE 290Aplus, Thermo Orion, Beverly, MA). Crop evapotranspiration (ET_c) was estimated using a soil moisture balance equation:

$$ET_C = (\text{Precipitation} + \text{Irrigation}) - (\text{Changes in soil moisture} + \text{Drainage} + \text{Runoff}) \quad (1)$$

Runoff was not observed during the irrigation period, and therefore it was not considered in the balance.

Microclimate parameters were registered in one plot per treatment every 5 min saving average values every 30 min, with a datalogger (CR10X, Campbell Sci., UK). Sensors for photosynthetically active radiation (PAR) (SKP215 quantum sensor, Skye Instruments, UK), global radiation (SP1110 pyranometer sensor, Skye Instruments, UK) and air temperature and humidity (HMP45C temperature and humidity probe, Vaisala, Finland) were placed 0.30 m above the ground. The thermal integral for each treatment was calculated considering a basal temperature of 0 °C (France and Thornley 1984). In addition, one soil temperature probe per treatment (model 107T, Campbell Sci., UK) was placed 0.10 m deep. In 2006, soil temperature data from 46 to 57 days after transplanting (DAT) were lost due to some technical problems.

Plant growth was monitored along the cropping cycles through the periodic assessment of fresh weight, dry weight and leaf area (LA) in six plants once every other week, eight times in 2005 and six times in 2006. Aboveground plant material was harvested and carefully washed in the lab with deionized water. Leaf area was measured using an area meter (Mk2, Delta-T Devices, Cambridge, England). Then the leaves were weighed and oven-dried at 65 °C to constant weight. Plant biomass per unit area, leaf area index (LAI) and specific leaf area (SLA) were calculated from these data and crop density. The dried plant material was ground and stored in sealed bags for later analyses.

Irrigation water was pumped from a nearby well and stored in a large tank where its NO_3^-concentration was recorded periodically. N and other nutrients were injected in the irrigation water, keeping a ratio $N\text{-}NO_3^-$ / $N\text{-}NH_4^+$ of 1. To calculate the amount of N to apply (N_{fert}), the N_{min} system (Scharpf 1991) was followed. The N_{min} (mineral N) system is based on the use of N_{min} target values (N_{target}) which have been obtained from data of many fertilizer experiments, considering N in the crop at harvest (N_{crop}), the necessary N_{min} residue in the soil at harvest ($N_{min-final}$), and the apparent net N mineralization (ANM), for maximum yield. A N_{target} value of 190 kg N ha^{-1} was indicated in escarole (Feller and Fink 2002).

N_{min} (initial and final) was determined in the upper 60 cm of the soil profile, at 0–15, 15–30 and 30–60 cm depth intervals. At the beginning of the 2005 experiment, soil samples were taken in 10 different points of the experimental area. A composite soil sample was obtained thoroughly mixing the 10 samples taken at the same

depth. In the 2006 experiment, one sample was taken in each replicate of each treatment at the same depth intervals. The samples were air dried and later 1:2 (mass based) soil to water extracts were obtained. Nitrate and ammonium concentration in the extracts were determined with ion selective electrodes (9307BN for nitrate and 9512BN for ammonium, Thermo Orion, Beverly, MA). Nutrient content of the 1:2 extract can be considered a good estimate of water extractable nutrients (SONNEVELD 1990).

N_{crop} was computed adding plant N determined by the Kjeldhal method and NO_3^--N measured with the ion selective electrode:

$$N_{crop} = (N\ Kjeldhal) + (NO_3^- - N) \quad (2)$$

Nitrate leaching ($N_{leached}$) for a given period was determined from the lysimeters' drainage volume and its NO_3^--N concentration.

Apparent net mineralization was calculated from a mass balance equation:

$$ANM = N_{min-initial} + N_{fert} - N_{crop} - N_{leached} - N_{min-final} \quad (3)$$

ANM is a term accounting for the balance between N inputs (mineralization) and outputs (volatilization, immobilization and denitrification).

N_{fert} was supplied entirely through the drip irrigation system and includes N present in the irrigation water and that supplied as fertilizer. As a first approximation, N_{fert} was calculated using the values given by FELLER and FINK (2002) for N_{crop}, $N_{min-final}$ ($N_{residue}$) and ANM, and $N_{min-initial}$ for our soil conditions, resulting in an estimated value of 53 kg N ha^{-1}. The total amount of N applied in 2005 was 70 kg N ha^{-1} in the OA treatment, and 59 kg N ha^{-1} in the PM and PM-FC treatments. The higher amount of N supplied to the OA treatment was a failed attempt to promote crop growth in this treatment, as will be shown later. The high nitrate content measured in leachates that year suggested the need to reduce fertilizer application the following season, although decreasing the N_{target} value. Thus, in the 2006 experiment, N_{fert} was lowered to 28 kg N ha^{-1} in all three treatments.

Nitrogen use efficiency (NUE) was calculated as the ratio between crop N uptake (N_{crop}) and N supply (N_s), being N_s the total amount of potentially available N (N_{fert}, ANM and $N_{min-initial}$).

$$NUE = \frac{N_{crop}}{N_{fert} + N_{min-initial} + ANM} \quad (4)$$

Leaf greenness in the escarole plants was monitored by measuring light transmittance eleven times in 2005 and six times in 2006 with twenty readings per replicate, using a SPAD meter (model 502, Minolta Camera, Ltd., Osaka, Japan). This measurement may provide information about the N status of plants since most leaf N is contained in the chlorophyll molecules (GOEL et al. 2003).

The experimental setup was a factorial design with two factors: a fixed factor, covers, and a random factor, years. The three levels of the fixed factor were: uncovered control (OA), plastic mulch (PM), and plastic mulch plus floating cover (PM-FC), and the two levels of the random factor were year 2005 and 2006. All treatments had three replicates. Analysis of variance was performed to evaluate differences among the means. Separation of means at the 95% confidence level was done with the Bonferroni's T-test.

Results

Crop Growth, Development and Yield

Mean daily values of air and soil temperatures and incident PAR are shown in Fig. 1 for all treatments and years. In 2005, seasonal cumulative PAR was 1154, 935 and 688 mol m^{-2} for the OA, PM and PM-FC treatments, respectively. In 2006, seasonal cumulative PAR was 1215, 934 and 778 mol m^{-2} for the OA, PM and PM-FC treatments, respectively. Both years there was an important reduction of PAR by the floating cover. Transmission of PAR under the floating cover was under 80%. Differences observed between OA and PM treatments are associated to differences in crop season length.

In general terms, air and soil temperatures were higher in 2006 than in 2005, and higher in protected crops (PM and PM-FC) than OA crops for the same year. The thermal integral was 967, 797 and 877 degree-days, for the OA, PM and PM-FC treatments in 2005, and 824, 722 and 815 degree-days for the OA, PM and PM-FC treatments in 2006, showing the need of a longer crop cycle for the OA treatment. Milder climatic conditions in 2006 shortened the crop cycle of escarole. The same effect had mulching and covers, reducing the period transplant-harvest in both years. It should be mentioned that climatic parameters of 2005 were similar to long-term averages. However, 2006 was warmer and sunnier than average.

The development of above-ground biomass is shown in Fig. 2. OA plants grew very slowly in the 2005 experiment and showed important damage due to low air temperatures at night at the beginning of winter. Biomass accumulation was significantly higher in protected treatments from 46 DAT until harvest. Maximum values of dry matter ranged from 2470 kg DW ha^{-1} in mulched crops to 1260 kg DW ha^{-1} in the OA treatment. However, in 2006, although protected crops showed a higher crop growth rate (CGR), final biomass was not significantly different among treatments, as the OA crops showed a longer crop season, which compensated for its reduced CGR.

The time course of LAI showed a similar pattern than the above-ground biomass (Fig. 2). The interaction cover x year (C x Y) was significant (P=0.0178). LAI of control plants was significantly lower than those of protected plants for most of the season, in both years. However, in the 2006 experiment no significant differences were observed among treatments in LAI at harvest, taking into account the longer cycle of OA crops. The time course of SLA is also shown in Fig. 2. Again, the interaction C x Y was significant (P=0.0030). In 2005, once the crops were well established (approximately 35 DAT), SLA values were approximately constant for OA and PM treatments, being slightly higher in PM than OA until the end of the cycle. In contrast, SLA gradually increased in the PM-FC treatment, reaching a maximum value of 30 $m^2\ kg^{-1}$ before harvest. In 2006, the observed pattern was different from that of the previous year. All crops showed a similar trend, with a maximum value at the middle of the cycle. Again, SLA was higher under the PM-FC treatment

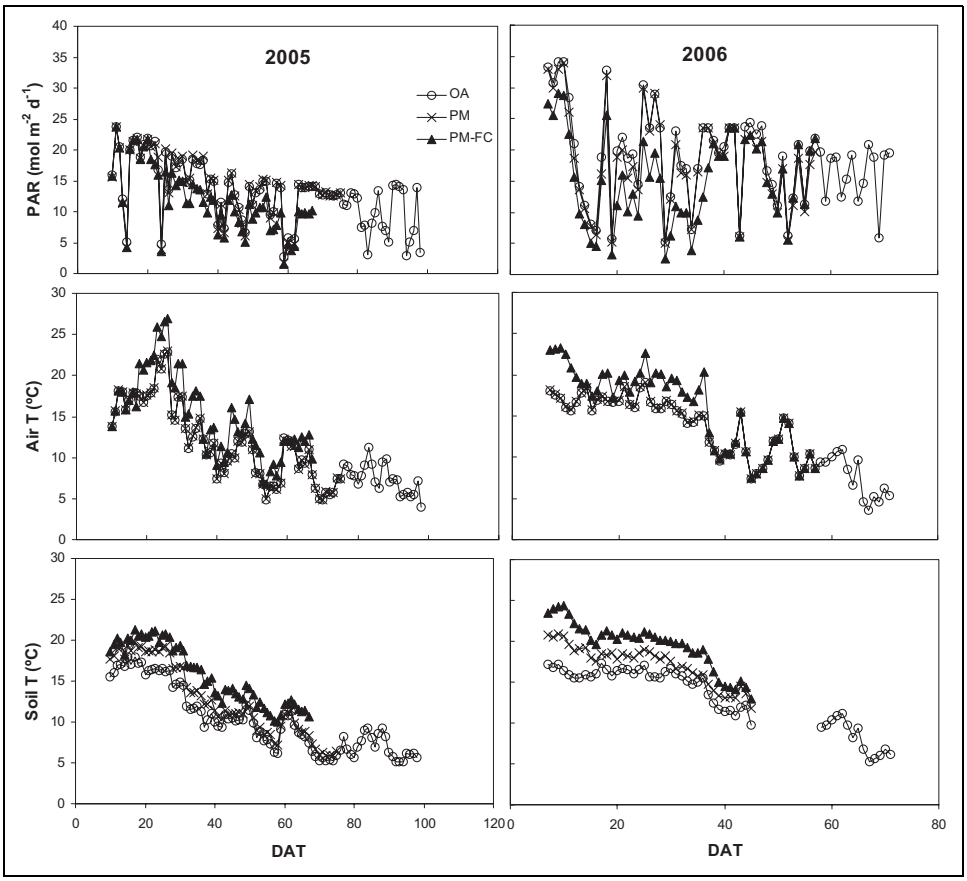


Fig. 1. Daily incident photosynthetic active radiation (PAR) at canopy level, and mean daily air and soil temperatures for the 2005 and 2006 experiments (DAT = days after transplanting).

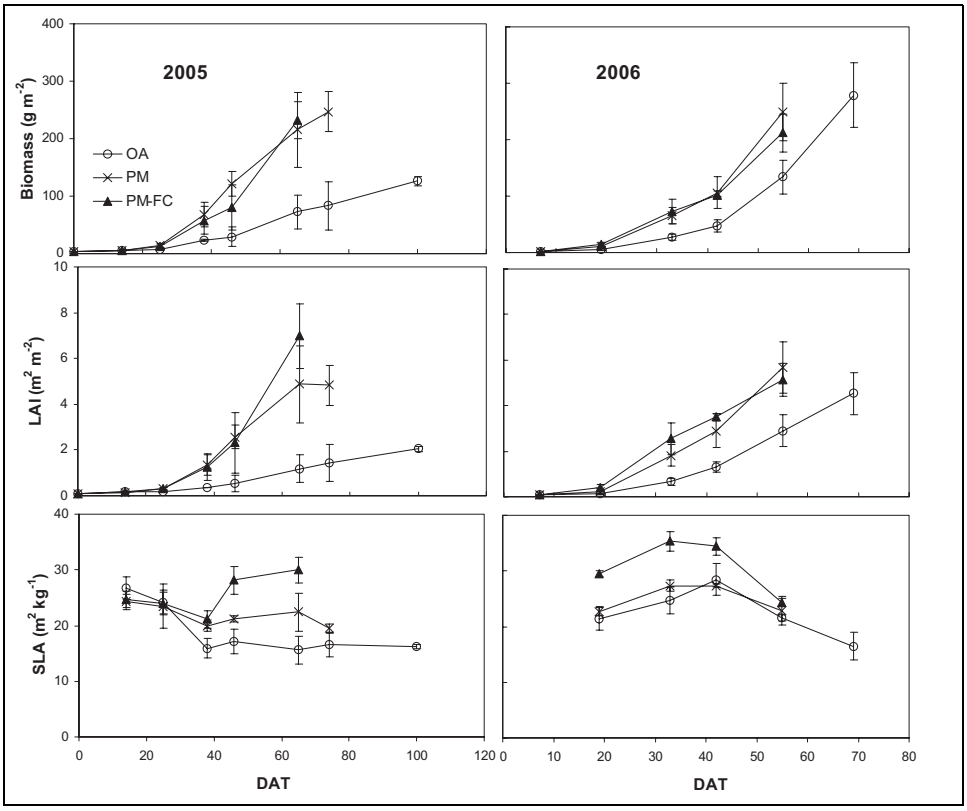


Fig. 2. Cumulative biomass (DW), leaf area index (LAI) and specific leaf area (SLA) for each treatment and year. Values are means of three replicates. Bars denote one standard deviation from the mean (DAT = days after transplanting).

throughout the season except at harvest time, where it was similar to that of the PM treatment, and significantly higher than that of the OA treatment (with a longer cycle).

Table 1. Crop cycle length, total biomass, marketable yield, seasonal reference evapotranspiration (ETo), seasonal crop evapotranspiration (ET), and water use efficiency (WUE) on a dry weight (DW) basis for all treatments and years.

Year	Treatment (Cover)	Cycle length (d)	Biomass (kg DW ha^{-1})	Marketable yield (t FW ha^{-1})	ETo (mm)	ET (mm)	WUE (kg ha^{-1} mm^{-1})
2005	OA	108	1260 b	––[§]	––	––	––
	PM	77	2470 a	38.4 b	102	102	24.5 b
	PM-FC	70	2320 a	52.1 a	98	101	22.8 b
2006	OA	71	2790 a	32.1 a	102	115	24.1 a
	PM	57	2490 a	41.9 a	90	71	35.2 a
	PM-FC	57	2120 a	41.6 a	90	78	27.2 a
Cover (C)							NS
Year (Y)							**
C x Y[+]			**	**			NS

**, NS: Significant at P<0.05;or not significant, respectively, according to Bonferroni's T test.
[+]When the interaction C x Y is significant (**), for each year, mean values followed by different letters, indicate significant differences among treatments.
[§]No commercial product was reached that year for OA escaroles.

The reduction in PAR throughout the cycle in the PM-FC treatment did not seem to negatively affect biomass production, leaf area, or yield. The increase in air temperature under the floating cover could have compensated the effect of PAR decrease, as suggested by Berninger (1989).

It has been shown that plastic mulch and floating cover shortened the length of cycle in protected escarole (Table 1). OA treatment was harvested after 108 DAT and 71 DAT in 2005 and 2006, respectively. There was a seven days difference in length of season between the protected treatments in 2005 and no difference in 2006. In the 2005 experiment, no commercial production was obtained in the OA treatment. And, although total biomass at harvest for the protected treatments did not show significant differences, marketable yield was significantly higher for the PM-FC treatment than for the PM treatment. In 2006, milder climatic conditions resulted in shorter cycles for all crops compared to the previous year. OA crops did not show any frost damage, and it was necessary to remove the floating cover 37 DAT in PM-FC to prevent a reduction of crop quality due to high air temperature under the cover (Fig. 1). No significant differences were detected between treatments in marketable yield in 2006 (Table 1).

Crop Evapotranspiration and Water Use Efficiency

Following the criterion described previously to schedule irrigation, 194, 160 and 160 mm of water were received (including rainfall) by OA, PM and PM-FC treatments respectively, in the 2005 experiment. The high amount of irrigation applied to the OA treatment was a failed attempt to promote crop growth in this treatment, limited by low temperatures. Seasonal ET was similar in mulched crops, 102 and 101 mm for PM and PM-FC treatments, respectively (Table 1). In 2006, the total amount of rainfall plus irrigation was 146, 137, and 137 mm for the OA, PM, and PM-FC treatments, respectively. Cumulative crop ET was 115 mm for the OA treatment, 71 mm for the PM treatment, and 78 mm for the PM-FC treatment. Crop ET data should be considered with caution, as they result from just one lysimeter each.

Water use efficiency (WUE), calculated as the ratio biomass/crop ET, was similar for both protected treatments (PM and PM-FC) in 2005. No significant differences were found in WUE among treatments in 2006 (Table 1) either. For the same treatment, WUE was higher in 2006 because crop ET was lower for the same production of biomass. Significant differences were not detected among covers (P=0.0670).

Nitrogen Balance and Nitrogen Use Efficiency

Using equation 3, a nitrogen balance in escarole was set using measured data of initial and final soil mineral N, crop N uptake, N content of drainage water and added N as fertilizer and in the irrigation water. The balance result was an estimate of the apparent net mineralization (Table 2).

N_{crop} was greater for both protected treatments than for the control treatment in 2005. However, it was higher for the OA plots in 2006. N_{crop} ranged from 39 to 98 kg N ha^{-1} in the 2005 experiment and from 70 to 88 kg N ha^{-1} in 2006 (Table 2). The lower N_{crop} value of OA crop in 2005 resulted from a poor growth of escaroles, the final biomass being just half of the protected treatments. As a consequence of the higher crop N uptake in protected escaroles that year, the values obtained for NUE were higher than for the control treatment (Table 2). However, in 2006 all treatments resulted in similar values for NUE.

Nitrate concentration in plant leaves is shown in Table 3. The interaction C x Y was also significant (P=0.0062). Leaf nitrate concentration expressed on a fresh weight (FW) basis was highest in escaroles grown

Table 2. Initial ($N_{min-initial}$) and final ($N_{min-final}$) mineral nitrogen content in the soil profile (0–60 cm depth), total crop nitrogen uptake (N_{crop}), nitrate-N leaching during the crop cycle ($N_{leached}$), apparent net mineralization (ANM) which includes other gains and losses, and nitrogen use efficiency (NUE) for all treatments and years.

Year	Treatment	$N_{min-initial}$	$N_{min-final}$	N_{crop}	$N_{leached}$	ANM	NUE+
		(kg ha^{-1})					
2005	OA	137	61	39	79	−28	0.22
	PM	137	90	78	12	−16	0.43
	PM-FC	137	56	98	21	−21	0.56
2006	OA	128	57	88	17	6	0.54
	PM	112	30	74	33	−3	0.54
	PM-FC	104	36	70	28	2	0.52

+NUE calculated as the ratio between crop N uptake (N_{crop}) and N supply (N_{fert} + $N_{min-initial}$ + ANM).

Table 3. Nitrate concentration in leaves at harvest and in leachates. Leaf NO_3^- values are means of three replicates in each treatment and are expressed on a fresh weight basis (FW) (SD = standard deviation from the mean). NO_3^- concentration in leachates is weighed average of volumes collected throughout the experiments.

Year	Treatment (Cover)	Leaf NO_3^- (mg kg^{-1} FW)		NO_3^- concentration in leachates (mg L^{-1})
		Mean	SD	
2005	OA	458 b	33.8	457
	PM	842 ab	205.6	110
	PM-FC	1143 a	303.4	169
2006	OA	859 a	100.1	243
	PM	487 b	74.9	222
	PM-FC	977 a	151.6	208
C x Y+		**		

**, NS: Significant at P<0.05 or not significant, respectively, according to Bonferroni's T test. C: cover; Y: year.
+When the interaction C x Y is significant (**), for each year, mean values followed by different letters indicate significant differences among treatments.

with the PM-FC cover in both years (1143 and 977 mg kg^{-1} FW in 2005 and 2006, respectively), although not significantly different from the OA treatment in 2006. Generally, the values found in these experiments are well below those recommended by the European Union for leafy vegetables (lettuce and spinach) grown at open air (Anonymous 1997).

The opposite trend was observed in nitrate concentration in drainage water (Table 3). Substantial differences were found between OA treatment (457 mg L^{-1}) and that of PM and PM-FC crops (110 and 169 mg L^{-1}, respectively) in 2005 (Table 3) as OA plants were frost damaged that year. This resulted in a N leaching of 79 kg N ha^{-1} in OA crops compared to 12 and 21 kg N ha^{-1} in PM and PM-FC crops, respectively. Considering the high probability of frost in our climate during the crop season, in 2006 it was applied less than half of N fertilizer applied in 2005, in order to reduce nitrate content in the leachates. Nevertheless, the nitrate concentration in the drainage water in 2006 was higher than that of the previous year in mulched crops. Total leached N was 17, 33 and 28 kg N ha^{-1} for OA, PM and PM-FC crops, respectively that year.

Fig. 3 shows the time course of chlorophyll content index (in SPAD units) for both years. No significant differences were found among covers in 2005, although the values recorded for the OA treatment were slightly below those recorded for the protected treatments. In 2006, again no significant differences were found among treatments. Leaf nitrogen content (Kjeldhal N) and chlorophyll content index showed a significant but weak correlation (Pearson's r) in 2005 (P=0.0199, r=0.4228), and no significant correlation (P=0.0736) was found in 2006.

Discussion

Although climatic conditions during the two crop seasons were different enough to produce changes in crop behaviour, for the same treatment the thermal integrals were similar in both years because of different cycle lengths. The first year of the study (2005), characterized by cooler air and soil temperatures, limiting for OA crops, and below-average solar radiation, season length was longer than expected for all treatments. This year, total biomass in OA crops was significantly smaller than in mulched crops, approximately 50 %, with no commercial yield, as plants were frost damaged. Commercial yield was higher in PM-FC than in PM treatment. The second year (2006), with milder climatic conditions less limiting for OA crops, lower crop growth rate of OA crops was compensated by longer crop cycle, and no significant differences were observed between treatments in either, total biomass or commercial yield.

The greenhouse effect created by the floating cover increased air and soil temperatures in PM-FC treatment compared to the other treatments. The average increment in air temperature in PM-FC over the OA treatment was 1.56 °C in 2005, and 2.47 °C in 2006. Plastic mulch

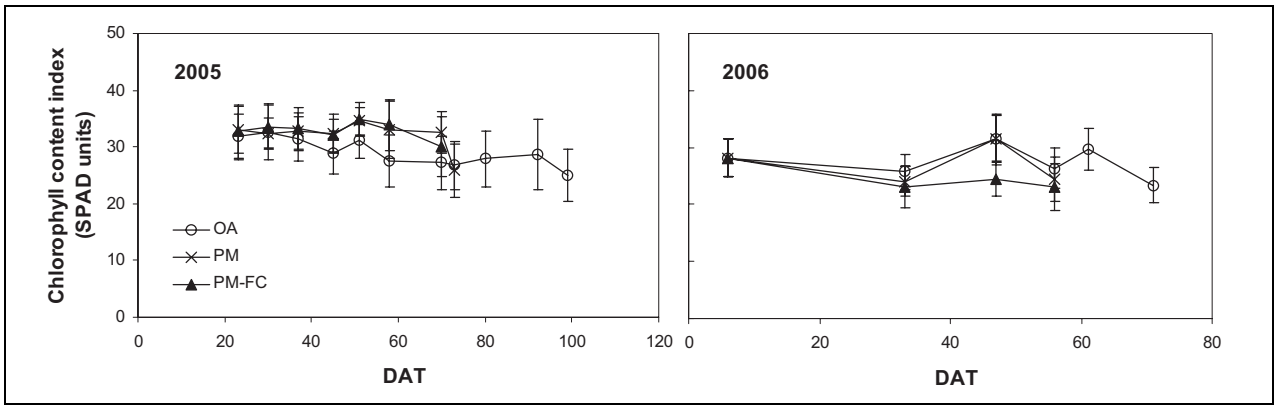


Fig. 3. Time course of chlorophyll content index (SPAD units). Values are means of twenty replicates. Bars denote one standard deviation from the mean (DAT = days after transplanting).

heats the soil. Therefore, soil temperatures were always lower in the OA treatment than in any of the protected treatments (Fig. 1). The average increment in soil temperature in the PM treatment over the control was 1.32 and 2.11 °C in the 2005 and 2006 seasons, respectively. Those increments were even higher in the PM-FC treatment over the control, averaging 3.53 and 4.47 °C in 2005 and 2006 seasons, respectively. Gimenez et al. (2002), studying horticultural crops such as Chinese cabbage, lettuce and spinach, demonstrated that the thermal increase generated under floating covers promoted growth in protected crops.

SLA was significantly higher for the PM-FC treatment than the PM and OA treatment from the middle cycle until harvest in 2005, and again in 2006 until the removal of the floating cover (Fig. 2). It can be drawn from LAI and SLA values that plants receiving less PAR (PM-FC treatment) tended to produce larger leaf areas to maintain their photosynthetic capacity. SLA may also be used as a quality parameter in leafy vegetables (Gimenez et al. 2002) with higher SLA values indicating higher crop quality because of thinner leaves.

Nitrate concentration in leaves (Table 3) at the end of the cycle was slightly higher for PM-FC escaroles. A possible explanation for that would be the reduction of incident radiation under the floating cover, which might decrease the activity of the enzyme nitrate reductase (Roorda van Eysinga and Van der Meijs 1985; Dapoigny et al. 2000). The activity of the enzyme nitrate reductase is enhanced by solar radiation, and thus, in conditions of high radiation, nitrate content of plants is reduced (Lillo 1994). In 2005, nitrate concentration in OA leaves was significantly lower than that of mulched crops. This was attributed not only to a higher incident radiation, but also to the lower capacity of nitrate absorption by the crop with a very low growth rate, consequence of cold temperatures. In 2006, nitrate content in the PM leaves was significantly lower than those measured in the OA and PM-FC treatments (Table 3). It was expected that leaf nitrate content in the PM-FC treatment would be higher than the other two. However, the OA treatment showed a similar value, which might be associated to the longer cycle of this treatment (14 days longer). OA crop growth rate was highest during the last season days and crop N uptake could have been also significant at this time, which would explain NO_3^- accumulation in leaves. Solar radiation and nitrogen supply were found to be the major factors influencing the nitrate content in an experiment with lettuce (Roorda van Eysinga and Van der Meijs 1985).

Benoit (1994) found that the lower nitrate leaching occurring in black plastic mulched treatments was associated with the higher nitrate levels present in curled endive leaves. In that study, nitrate concentration in soil and leaves was always higher for the mulched treatment than for the control treatment. In our study, escaroles grown in the OA treatment in 2005 showed a very slow growth rate and by January, most of them had clear freezing damage. At this time, the uptake of N was very small and a high nitrate concentration was measured in the leachates.

In a 2-year experiment with peppers transplanted in early May with fertigation and plastic mulch in lysimeters (Romic et al. 2003), nitrate concentration in leachates was always higher under the non-mulched treatment than under any of the mulched treatments. In that experiment, the nitrate concentration was approximately 85 mg L^{-1} without mulch, 58 mg L^{-1} with Biopack mulch, and 47 mg L^{-1} with black polyethylene mulch. In our study, mulching in escarole may have a positive effect on reducing nitrates in drainage water under unfavourable weather conditions since N uptake by the crop is enhanced by faster growth in the mulched treatments, and therefore, less N is leached to the groundwater. However, nitrate concentration in the leachates in mulched crops was still high, over 50 mg L^{-1}, suggesting that when using plastic mulch or plastic mulch with a floating cover, the amount of N fertilizer could be reduced in relation to the values calculated for an open air crop following the N_{min} method.

The estimated apparent net N mineralization in the soil was negative in all treatments in 2005 and small in 2006. ANM was calculated as shown in equation 3, and thus, any possible measurement error introduced in any of the equation terms and the estimation of N_{min} based on 1:2 soil extracts, is included in this value. The term ANM accounts for inputs and losses not considered in the calculations, which might be another source of error. Biological fixation is usually insignificant in agricultural soils (Vazquez et al. 2006). However, gaseous losses, especially in the uncovered treatments might have occurred. The negative values obtained for the ANM term may indicate denitrification and volatilization losses in the soil. Castilla and Fereres (1990) found that denitrification and volatilization losses were important factors to be taken into account when dealing with soils typical of greenhouses in

southern Spain, with values around 50 kg N ha^{-1} or higher. In a later study conducted by RAMOS et al. (2001) in the Valencian Community region (Spain) in several horticultural rotations and citrus orchards, the non measured values in the N balance (e.g., gaseous losses minus net mineralization) ranged from 35 to −127 kg N ha^{-1} for early potato, and from −65 to −91 kg N ha^{-1} for onion.

Chlorophyll meter readings (in SPAD units) were taken to obtain information about the N status of the plants with the different covers, but they did not show significant differences among them under our conditions because of the small range of SPAD readings for a given measurement date. MORENO et al. (2001) observed higher chlorophyll content (Chl a and Chl b) in Chinese cabbage grown in the open than in plants grown under floating cover, and associated the higher pigment concentration to higher direct sunlight and lower temperatures in the control plants.

Conclusions

Different covering techniques, mulching and mulching combined with a floating cover, were compared to an uncovered control treatment in an escarole crop in two consecutive years. The study focused on the characterization of crop growth under the different protecting methods and the effect of those on the accumulation of nitrate in leaves and on nitrate leaching. The results of these experiments have shown that commercial yield of OA, not-mulched escarole crops transplanted during the fall season, is highly dependent on favourable weather conditions. Mulching guarantees yield in case of cold weather during the cropping cycle. The use of a floating cover might be beneficial depending on weather conditions. When season temperatures are below average, it can increase the commercial yield of a mulched escarole crop, but in case of a warm season with temperatures above the average, it might even cause crop damage due to excessive air temperature under the cover. Mulching in escarole may have a positive effect on reducing nitrates in leachates under unfavourable weather conditions. Covering the crops did not have a significant effect on nitrate concentration in leaves.

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