Row covers for quality improvement of Chinese cabbage (*Brassica rapa* subsp. *Pekinensis*)

J. HERNANDEZ

Department of Crop Production

University of Almeria

04120 Almeria .Spain

email: jhrodri@ual.es

T. SORIANO

M.I. MORALES

N. CASTILLA

Department of Horticulture

CIFA-Apartado 2027

18080-Granada. Spain

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Abstract Row covers of polypropylene sheeting have been studied in relation to the quality in Chinese cabbage (*Brassica rapa* subsp. *Pekinensis* “Nagaoka 50”) for 3 years (1999, 2000 and 2001) in the area of Granada, Spain, under a Mediterranean continental temperate climate, on 55-day cycles with transplanting in mid March. The mean commercial yield for the 3 years was 11.9 kg m $^{-2}$ under row covers, but only 2.1 kg m $^{-2}$ in open air, due primarily to the important number of non-commercial cabbages. The cabbages

grown in the open air were exposed to lower temperatures than under covers and showed a higher number of plants with bolting and plants lost in the field. The better thermal regime under the covers and the least vapour pressure deficit favoured heading, reducing the number of malformed cabbages. The foliar calcium (Ca) content in the outer leaves was significantly greater in the open air than under the row cover, whereas the reverse was true in the inner leaves. These lower Ca contents in the inner leaves of the open air plants, encouraged tipburn. The use of the row cover constitutes a low-cost technique to improve open air spring cultivation of this leafy vegetable in this type of Mediterranean continental climate.

INTRODUCTION

In the cultivation of Chinese cabbage (*Brassica rapa* subsp. *Pekinensis*), tipburn and bolting causes large economic losses. The first symptoms of tipburn appear along the margins of young leaves which dry and turn brown; this necrosis results from the weakening of the cell walls and subsequent cell break-up (Lucena 1992). When symptoms appear only in the outer leaves, margin rot results, causing light commercial-yield losses; however when symptoms appear at the budding of the inner leaves, heart rot often develops together with bacterial infections, primarily by *Erwinia carotovora* (Takahashi 1981), leaving soft, putrefied areas and rendering the cabbage unmarketable. The causes of this disorder are varied, though a lack of available calcium (Ca) in the affected tissues is the most common factor (Shear 1975; Kuo et al. 1981; Collier 1982; Stratton & Nagata 1994; Maroto et al. 1996; Saure 1998). The translocation of this ion, mainly through the xylem, depends on transpiration. Thus Ca deficiency is more evident in young inner leaves, where transpiration is reduced (Kuo et al. 1981; Collier 1982). Some authors indicate that high night-time humidity can limit the incidence of this disorder (Kuo et al. 1981; van Berkel 1988). Also, the foliar application of calcium salts (Gruebesck & Zandstra 1988) can be useful, primarily against margin rot, although efficiency is poor after the plant has begun head formation. Tipburn incidence is more severe when environmental conditions induce high growth rates (Borkowski & Szwonek 1994; Gaudreau et al. 1994; Stratton & Nagata 1994; Balvoll 1995), necessitating a greater Ca flow. As a prevention for this problem, growth regulators have been tested, such as paclobutrazol in lettuce (Obispo 1997) or chlormequat (Maroto et al. 1996) and daminozide (Aloni 1986) in Chinese cabbage, although results have proven inconsistent (Saure 1998). Nitrogenous fertilisers, mainly in the form of ammonium, promote the development of this physiopathy (Collier 1982; Brumm et al. 1993), as does irrigation water with high electrical conductivity (Hochmuth et al. 1993; Pascale & Barvieri 1995; Miao et al. 1998). The disorder can also appear after harvest during cold storage (Kim & Klieber 1997).

Another problem in Chinese cabbage cultivation is premature bolting, which results in the malformation of the head. Chinese cabbage needs long days and a vernalising stimulus for flowering (Pressman & Negbi 1981) although photoperiod appears to be less crucial than vernalisation (Moe & Guttormsen 1985). Palada et al. (1987) consider any temperature below 10°C to stimulate vernalisation whereas Elers & Wiebe (1984) propose a range between 5 and 8°C for at least 3 weeks to reach complete vernalisation.

Covering the crop with plastic materials (row cover) is an inexpensive technique that helps regulate microclimatic conditions affecting transpiration. Row covers reduce solar radiation (Loy & Wells 1982; Wells & Loy 1985; Benoit & Ceustermans 1987) and wind (Wells & Loy 1993; Mermier et al. 1995) while increasing air humidity (Mermier et al. 1995; Choukr-Allah et al 1994) as well as the soil (Hemphill 1989; Wolfe et al. 1989) and air temperatures (Wells & Loy 1985; Hemphill & Mansour 1986; Hemphill & Crabtree 1988; Motsenbocker & Bonano 1989; Wolfe et al. 1989). These changes reduce the incidence of tipburn, and avoid the vernalisation of cabbage plants and thus premature bolting and malformation of the head.

The objective of this study was to analyse the effects of row covers on the market quality of Chinese cabbage, under real field conditions.

MATERIAL AND METHODS

The field experiments were run in the Centre for Agricultural Research and Development in Granada (Spain; 37° 10'' N, 3° 38'' W, 600 m altitude), for three years (1999, 2000 and 2001). The climate of the zone is Mediterranean continental temperate that is warm summers and cool winters with low relative humidity and 2800 h of sunlight per year. The 3 years had a similar climatology (table 1) and the crops were grown in identical cycles and with the same cultivation practices. The thermal integral in the open air was 1361, 1349 and 1320 degree-days, for the first, second and third years, respectively, with a base temperature of 0ºC. Last frosts occurred in 72, 70, and 74 julian days during the first, second and third year, respectively.

Each of the 3 years, “Nagaoka 50” Chinese cabbage seeds were sown at the end of February in a greenhouse nursery while maintaining minimum temperatures over 10°C. Four weeks after sowing (mid March), the cabbages were hand transplanted at a density of 11.11 plants/m^2 (0.3 m between rows and 0.3 among plants in the row). Immediately after transplanting, half of the plots were covered with a colourless spunbonded non-woven polypropylene fabric of 17 g m^{-2} of density (Agryl P17, Sodoca). According to the maker, the filaments of the fabric form a barrier where 50% of the spaces measure less than 50 µ. The material was placed above the plants, covering four rows, and anchored laterally to the soil, creating an enclosure 0.4 m high approximately, without necessity of support elements. The covers were maintained until harvest days (in mid May). The soil (typical Xerofluvent, USDA) had the following characteristics: sand 45.06%; silt 42.10%; clay 10.20%; oxidable organic matter 1.32%; total $CaCO_3$ 4.20%; total N 0.12%; P 38.0 ppm ; K 103.0 ppm; pH 8.0; E.C. 0.88 dS m^{-1}; C.E.C. 12.18 meq/100 g. Surface irrigation following local practices was applied once per week. Crop evapotranspiration (ETc) was calculated by the Penman-Montheith method (Doorenbos & Pruitt 1975). Cumulated ETc reached 116.9, 110.5 and 108.3 mm, in the years 1999, 2000 and 2001, respectively. Before planting, 750 kg ha^{-1} N-P-K fertiliser (15-15-15) was incorporated into the soil. In addition, a total of 170 kg ha^{-1} of ammonium nitrosulphate (26% N) and 360 kg ha^{-1} of KNO_3 (13% N, 45 % K_20) were supplied at 25 and 40 days after transplanting (DAT), respectively.

The two treatments used were: open air (OA) and row cover (RC), in a randomised block design with four replicates. The experimental plots had 48 plants each. The data of the three experiments were submitted to a combined analysis of variance over years (Gomez & Gomez 1984). No significant interactions between treatments and years were found for any of the analysed parameters.

For the calculation of the aboveground biomass and for the foliar analyses complete plants, without root, were taken at 15, 25, 35, 45, and 55 DAT. For plant analysis the material was washed with 1% alkaline detergent and three times with deionised water. The samples were dried at 80°C for 48 h, ground, and stored in an oven at 60°C until analysis. Nitrogen was determined by the Kjeldahl procedure. For other element determinations, the stored samples were ashed in a muffle furnace at 600°C for 12 h, and dissolved in 0.1*N* HCl. Total P was determined by colorimetry using the method described by Murphy & Riley (1962). Boron was determined in the extract by colorimetry (Greweling 1976). The remaining elements (K, Mg, Ca, Zn, Mn, Fe, and Cu) were measured using an atomic absorption spectrophotometer Perkin–Elmer 1.100 B. The Ca content was quantified separately in the inner and outer leaves, as well as tipburn-affected and healthy plants. The chlorophylls (*a* and *b*) were extracted by soaked disks of fresh tissue in assay tubes with methanol and measured by colorimetry following Wellburn (1994).

The cabbages were harvested at 55 DAT. Heads with tipburn, those with irregular or deformed shapes (without characteristics of the cultivar), and those that were bolting were considered non-commercial.

The microclimate was monitored every 5 min in both treatments with a datalogger (Campbell CR 21X). Sensors for radiation (LI-200SZ pyranometer sensor from Licor, inc.) and the temperature and relative air humidity (HMP35AC temperature and relative-humidity probe from Vaisala) were placed to 0.30 m above the soil under the covers and in open air. The probes of soil temperature (107 temperature probes from Campbell Sci.) were placed to 0.15 m deep. In all the cases two sensors were placed per treatment.

RESULTS

Air temperatures during the 3 cycles were statistically similar (Table 1). The absence of significative interactions between years and treatments for all the factors studied allows the grouping of the results, as the tendency was the same in the 3 years studied.

The row covers altered the thermohygrometric regime of the protected zone, increasing the temperature and air humidity. The thermal differences between the protected crop and open air were greater at the beginning of the cycle but practically disappeared towards the middle (Fig. 1). The contrary occurred with the hygrometric values. At the beginning of the cycle, the vapour-pressure deficit (VPD) of both treatments proved almost identical. However, toward the middle of the cycle, and towards the end of spring, the VPD values of the OA treatment registered 3 kPa, while the RC hardly reached 1 kPa (Fig. 2).

The fabric filtered the radiation reaching the crop, so that OA received some 20.5% more radiation (Radiation under cover = Radiation in open air x 0.8353; R^2=0.95). Consequently, the covered plants presented a concentration of 49.5± 6.1 mg of chlorophyll (*a*+*b*) per 100 g fresh weight, as opposed to 60.8±8.2 mg/100 g fresh weight among the uncovered plants.

The total uptake of nutrients proved greater in the RC plants, with significant statistical differences for N, P, K, and B (Table 2). The mean foliar concentration in nutrients at the end of the cycle indicated that the plants under the cover accumulated more B and P but less Cu, Fe, Mg, and Ca than did uncovered ones (Table 2).

The biomass proved significantly greater in the RC treatment over the entire cycle (Fig. 3), the final values being 28.6% higher for the covered than for the uncovered cabbages (Table 3). The maximum net biomass accumulation rate was 10.3 and 13.8 g DW per day, in the OA and RC, respectively. These rate differences were higher at the beginning of the cycles. Between 15 and 25 DAT the protected plants tripled the growth rate of the unprotected cabbage (Fig. 3)

Under the row cover (RC), commercial yield (mean of the 3 years) was five-fold greater than in the open air (OA) (Table 3). The low OA yield was due to the great number of non-commercial cabbages (those that did not form heads or had malformed ones or were bolting) and to the tipburn incidence, which afflicted 13.4% of the heads (Table 4). Besides, the number of plants lost along the cycle, before harvest, was very high in the OA.

In both treatments, Ca accumulated in greater concentrations in the outer leaves (Fig 4) than in the inner leaves, the difference being marked (almost double) in the OA plants but less pronounced (roughly 14%) in the RC plants. The Ca concentration in the outer leaves proved significantly lower in the RC plants than in OA, the reverse being true for the inner leaves (Fig. 4). Tipburn was unappreciable until 35 DAT, when symptoms appeared on the margins of the inner leaves. The mean foliar concentration of the leaves having tipburn was 6.1±2.8 mg Ca/g dry weight. On the contrary, the lowest foliar concentration of healthy inner leaves was 10.0 mg Ca/g dry weight.

DISCUSSION

In the present experiment, the row covers (RC) altered the energy balance of the Chinese cabbage crop, raising soil and air temperatures (Wells & Loy 1985), and increasing air humidity by reducing wind-related turbulent flow (Mermier et al. 1995). These changes depended on the phase of crop development. In the earliest phases, when the leaf area was small, most of the energy dissipated as heat, and therefore air temperature rose notably, whereas when the leaf area became considerable, a greater part of the energy was used in transpiration, thus decreasing the temperature differences with respect to the open air (Giménez et al. 2002). This change in the energy balance improved the thermal conditions of the crop at the beginning of the cycle, when temperature is the most limiting factor for the development of Chinese cabbage. The open-air (OA) crop was affected by the lowest temperatures (nearly 0ºC; Fig. 1A), which caused the loss of a significant number of plants and also produced a high vernalising stimulus and therefore increased bolting (Table 4).

However, under the cover, the temperatures were consistently above 0ºC, as water condensation on the inner surface of the plastic during the night limited the loss of heat by long-wavelength radiation (Giménez et al. 2002). The first phase of development in Chinese cabbage is temperature dependent

(Benoit & Ceustermans 1990) and requires high thermal integrals in order to grow as many leaves as possible for the subsequent formation of the head (Runham 1990). Giménez et al. (2002), studying winter crops such as Chinese cabbage, lettuce and spinach, demonstrated that the thermal increases generated by the plastic covers promoted a greater leaf area in protected versus unprotected crops. Thus, although radiation is reduced under the cover, and chlorophyll concentrations fall somewhat, protected crops intercept the radiation more effectively and therefore produce more biomass. Crop growth affected the thermohygrometric regime under the cover, so that when a substantial transpirational canopy developed, the thermal increases with respect to the exterior were unappreciable (Fig. 1). This was largely because the energy was used in the form of latent heat (Giménez et al. 2002) and therefore it was possible for temperatures under the cover to be lower than in the open air (Choukr-Allah 1994). This effect is similar to the oasis effect, described for greenhouses (Arbel et al. 1990).

Most of the biomass produced by the RC crop promoted greater nutrient uptake than in the OA plants (primarily N, P, K; Table 2). However, Ca uptake was similar in both treatments. In terms of foliar concentrations, the RC plants had higher concentrations of B and P. The foliar concentration in P was found to be related to temperature. Pulgar et al. (2000) demonstrated that under RC, the higher soil temperatures with respect to OA boosted foliar acid phosphatase activity (FAPA) and P levels. This ion affects the Fe concentration, thereby playing an antagonistic role (Romheld & Marschner 1991). In addition, the Fe levels are related to radiation, lowering the foliar concentration with the shading of the crop (Zhang et al. 1996). This would explain the lower foliar concentrations of Fe found under the cover, where radiation was filtered. The higher B levels found in the RC crop may be due to the synergetic effect between B and P reported in other cabbages (Singh et al. 1994) and to the antagonistic effect with respect to Ca and Mg (Gupta & Macleod 1977).

All leaves pooled, the OA crop presented a higher foliar concentration in Ca than did RC, because the lower energy under the cover prompted less evapotranspiration with respect to the open air, and thus a lower water supply. This effect furthermore was reinforced by the VPD of the open air, which was greater than under the cover, fundamentally when the crop was more fully grown (Fig. 2C). In addition, an uneven distribution pattern of Ca was found in relation to the location in the leaves, as this element accumulated more in the outer leaves. Kuo et al. (1981) indicated that in Chinese cabbage the outer leaves could reach 7-fold the Ca concentration of the inner leaves, and Collier (1982) reported a similar effect in lettuce. The inner leaves are subject to lower VPD than the external leaves and therefore they present lower transpiration (Goto & Takakura 1992). Barta & Tibbitts (2000) demonstrated in immature lettuce leaves that the leaves enclosed within a developing head presented less Ca than did the outer leaves which, free to transpire, did not develop tipburn whereas enclosed leaves, with transpiration restriction, developed the injury.

In the present experiment, the mean Ca concentration in the inner leaves reached 30% of the that of the outer leaves in the OA crop. By contrast, in the RC plants, the differences between outer and inner leaves in the Ca concentration were lower, and notable only after 45 DAT (Fig. 4). This fact can be explained by the high night-time humidity and low VPD under the cover (0 Kpa during many hours of the night), as noted by Mermier et al. (1995). These conditions could provoke episodes of gutation, moving the Ca to the interior leaves (Kuo et al. 1981; van Berkel 1988). Everaarts & Blom-Zandstra (2001) reported that because of the absence of transpiration of the inner leaves of cabbage, Ca transport to the interior of the head is due exclusively to flow pressure from the roots, or to the sink effect of the meristem during the night. This Ca-transport effect mainly at night was noted by Cresswell (1991), who recommended applications of calcium nitrate at night to reduce tipburn in lettuce.

Calcium deficiency primarily in young leaves triggered tipburn in OA plants (the incidence in the RC crop was 1% as opposed to 13% in OA). The disorder did not appear before 35 DAT, and the first symptoms coincided with the heading process. For adequate heading, the inner leaves must develop an optimal degree of turgidity, and they must curve and develop hooked structures (Kuo et al. 1988). The high number of non heading plants and deformed heads in the OA treatment, as opposed to RC, could indicate better water transport towards the inner leaves in the protected plants, which would have a greater turgidity than in the OA plants. The foliar Ca concentration in plants with tipburn symptoms was 6.1±2.8 mg Ca g^{-1} dry weight. At 35 DAT, the inner leaves of the OA plants presented a Ca content of 7.0±0.9 mg Ca g^{-1} dry weight, as compared with 12.0±0.9 mg Ca g^{-1} dry weight in RC plants. Therefore, when the heading process began, the OA plants presented a foliar Ca concentration in the inner leaves that could trigger tipburn. In the most critical period of the crop, the heading process, when the greatest number of leaves is forming per unit of time (Runham 1990), the Ca demand by the young leaves could not be supplied in the OA plants under the conditions tested. The relevant role of Ca for the firmness of the cell-wall composition has been remarked (Fritz et al, 1988). In a similar study, Moreno et al (2002) found higher contents of monosaccharides in cell-wall fractions of Chinese cabbage leaves grown under row covers as compared with open air grown plants, inducing higher firmness and subsequently, lower tipburn incidence in the row covered plants.

Consequently, the use of row coverings improves yield in Chinese cabbage by 1) raising temperatures under the cover and thereby reducing the number of deformed heads, the amount of bolting, and the number of losses of plants in the field; 2) better water transport in the inner leaves, to provide the turgidity needed for heading, thereby augmenting the number of marketable heads; and 3) reducing the incidence of tipburn. This protective technique, for the cultivation of low-growing table vegetables, offers a low-cost alternative to open air growing for the spring production in this type of Mediterranean continental climate in various zones of the world.

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Table 1. Monthly air temperatures (maximum, minimum and average, in ºC) in the open air along the cycles in the three years (mean±SD n=31 in March and May n=30 in April)

	March			April			May		
Year	Maximum	Minimun	Average	Maximum	Minimun	Average	Maximum	Minimun	Average
1999	18.7±4.2	4.2±2.6	11.5±2.3	23.4±3.8	6.5±2.3	14.9±2.3	27.9±5.7	11.5±3.8	19.7±4.3
2000	22.1±3.4	3.9±3.3	13.0±2.3	19.1±4.3	6.1±3.2	12.6±2.9	23.1±3.7	9.8±3.1	16.5±2.7
2001	20.5±2.8	3.8±2.2	12.1±1.4	18.1±3.8	6.1±2.5	12.1±2.1	25.8±4.9	11.2±2.8	18.5±3.5

Table 2. Aboveground nutrient uptake and nutrient concentration in the leaf at end of the cycles. The values are means of the three cycles. (LSD: least significant difference at $P < 0.05$; NS, non significant differences; DW, dry weight).

Ion	Open air	Row cover	LSD
Aboveground nutrient uptake			
B (mg m^{-2})	10.5	15.6	3.1
Ca (g m^{-2})	12.1	11.4	NS
Cu (mg m^{-2})	4.2	4.3	NS
Fe (mg m^{-2})	213.9	160.6	NS
K (g m^{-2})	27.3	37.5	3.7
Mg (g m^{-2})	2.0	1.9	NS
Mn (mg m^{-2})	24.9	30.7	NS
N (g m^{-2})	22.4	27.2	4.6
P (g m^{-2})	2.3	3.9	0.9
Zn (mg m^{-2})	29.6	37.7	NS
Leaf concentration			
B (µg g^{-1} DW)	19.0	22.0	2.1
Ca (mg g^{-1} DW)	22.0	16.1	4.1
Cu (µg g^{-1} DW)	7.7	6.0	1.4
Fe (µg g^{-1} DW)	387.6	226.3	94.1
K (mg g^{-1} DW)	49.4	52.8	NS
Mg (mg g^{-1} DW)	3.6	2.7	0.8
Mn (µg g^{-1} DW)	45.1	43.2	NS
N (mg g^{-1} DW)	40.6	38.3	NS
P (mg g^{-1} DW)	4.2	5.5	0.6
Zn (µg g^{-1} DW)	53.7	53.1	NS

Table 3 Aboveground biomass (dry weight), total and commercial yields (fresh weight) (LSD: least significant difference at P < 0.05). Values are means of the three cycles.

Treatment	Biomass ($g\ m^{-2}$)	Total yield ($kg\ m^{-2}$)	Commercial yield ($kg\ m^{-2}$)
Open air	551.8	8.4	2.1
Row cover	709.6	13.8	11.9
LSD	75.4	3.6	2.9

Table 4 Percentages (over the total transplanted cabbages) of plants lost in the field and plants without commercial heads (mean ±SD *n*=12). Values are the mean of three cycles.

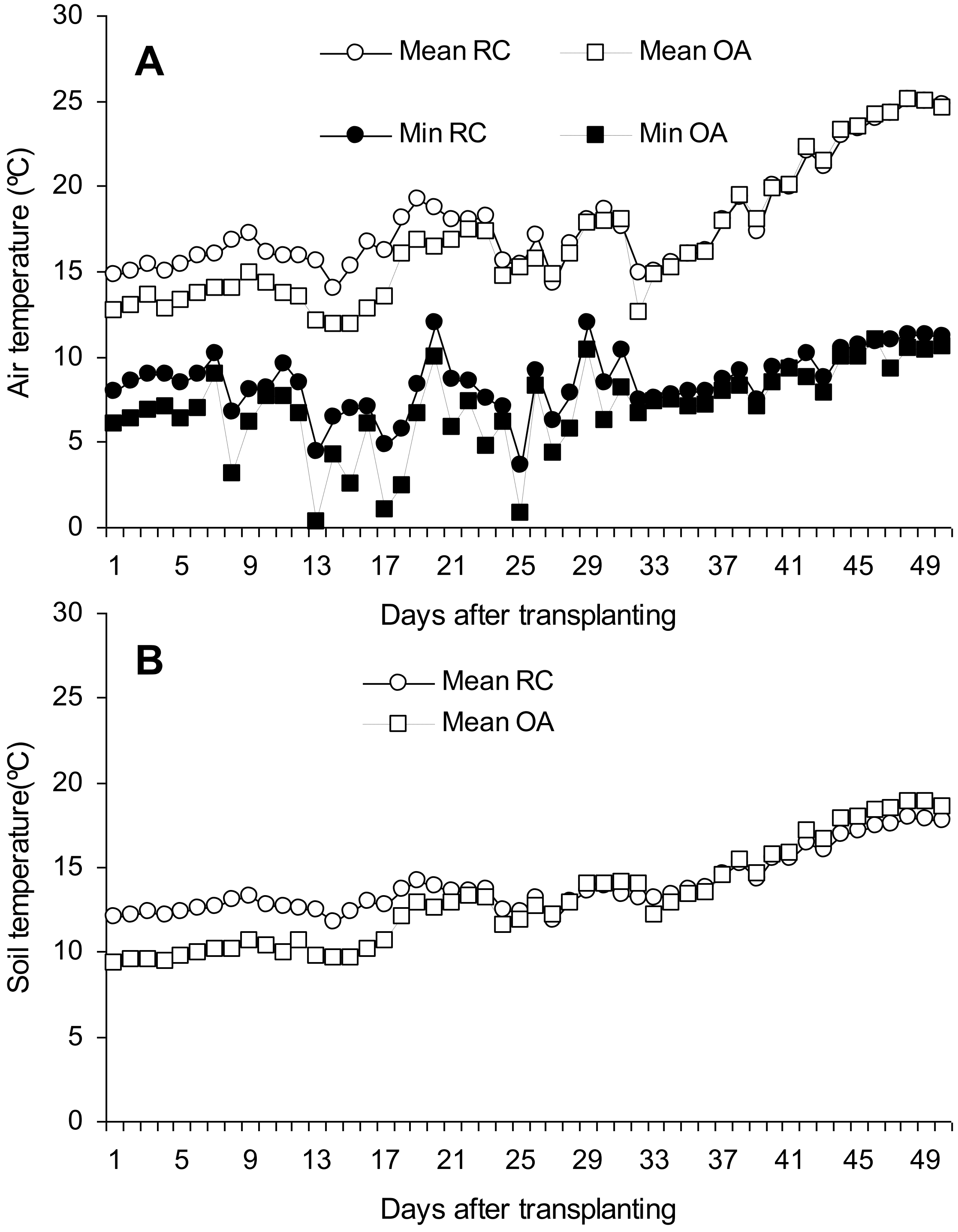
Treatment	Missing plants (%)	Tipburn affected (%)	Bolted plants (%)	Non heading plants (%)	Deformed heads (%)
Open air	15.3±2.2	13.4±2.3	18.4±3.1	20.6±3.8	16.2±3.4
Row cover	2.0±0.4	1.0±0.5	1.2±0.5	4.6±1.2	4.1±1.4

Fig. 1 A, Mean and minimum air temperatures and **B,** mean soil temperature at 0.15 deep over the cycle. Daily values are the 3-year mean. (RC, row cover OA, open air)

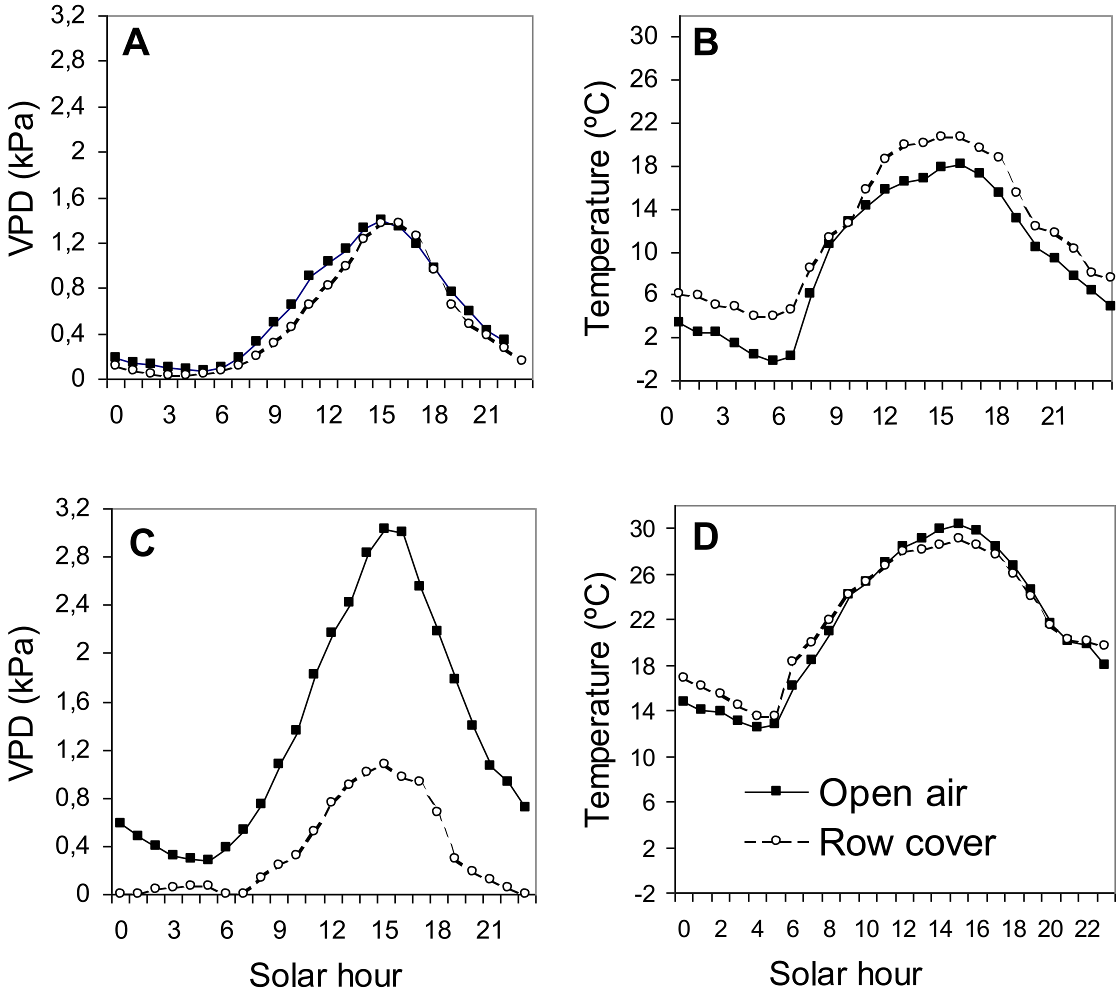
Fig. 2 Vapour pressure deficit (VPD) and air temperature (T) evolution over 24 hours at the beginning (15 DAT) and the middle of the cycle (30 DAT) **A**, VPD at 15 DAT **B**, T at 15 DAT **C**, VPD at 30 DAT **D**, T at 30 DAT

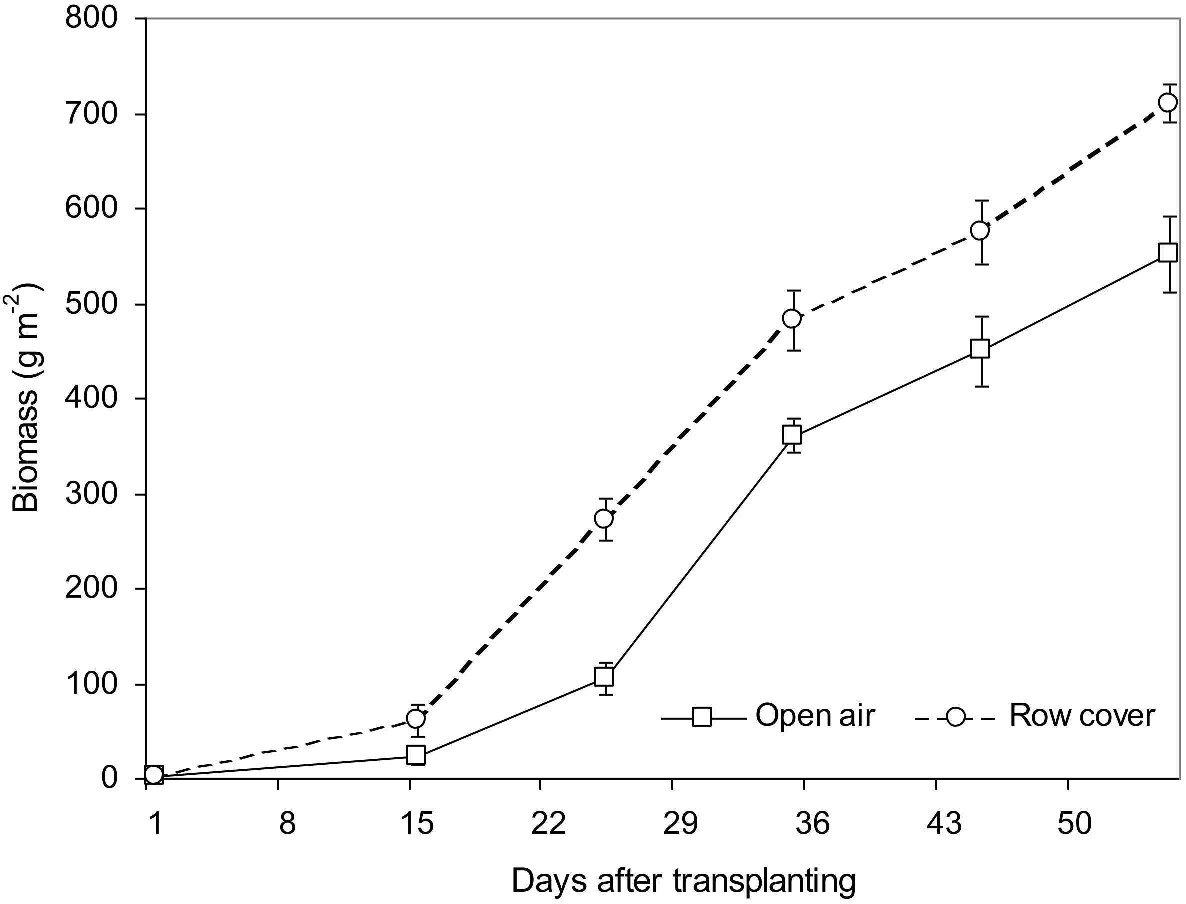
Fig. 3 Aboveground biomass (dry weight) over the cycle (bars represent standard errors of the means *n*=12). Values are means of the three cycles.

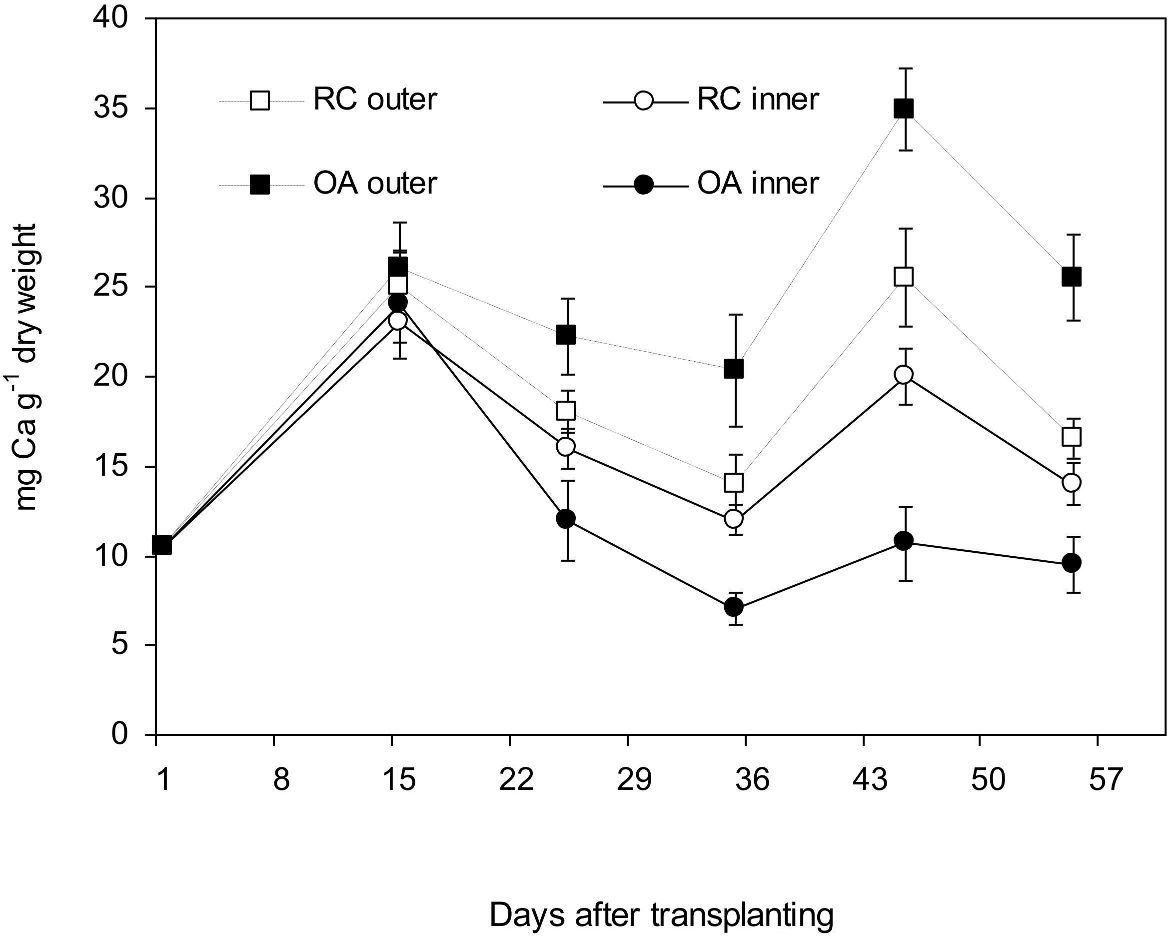
Fig. 4 Calcium concentration in outer and inner leaves over the cycle in both treatments (bars represent standard errors of the means *n*=12). Values are means of the three cycles. (RC, row cover OA, open air)


A
Mean RC
Mean OA
Min RC
Min OA
Air temperature (ºC)
Days after transplanting
B
Mean RC
Mean OA
Soil temperature(ºC)
Days after transplanting

1




800
700
600
500
400
300
200
100
0
Biomass (g m-2)
1
8
15
22
29
36
43
50
Days after transplanting
Open air
Row cover


40
35
30
25
20
15
10
5
0
RC outer
RC inner
OA outer
OA inner
mg Ca g-1 dry weight
1
8
15
22
29
36
43
50
57
Days after transplanting