Reuse of rockwool slabs and perlite grow-bags in a low-cost greenhouse: Substrates' physical properties and crop production

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Abstract

Multiannual inert substrates, especially perlite grow-bags and rockwool slabs, are widely used over several cropping seasons in low-cost plastic greenhouses in mild winter climates, such as the Mediterranean coast of South-east Spain. This work analyses how the physical properties of rockwool slabs and perlite grow-bags change with time and use, as well as studying the response of sweet pepper and melon crops grown in new and reused perlite grow-bags and rockwool slabs. The main aims are to reduce expenditure and the environmental impacts of soilless crops grown in low-cost greenhouse areas. The main physical properties, including air capacity and easily available water, of reused rockwool slabs remained quite steady over three cropping years, and no negative effects were found in the fertigation, growth and productivity of sweet pepper and melon crops when grown in reused slabs, compared to new ones. The main physical properties of 5-year-old reused perlite grow-bags also remained steady and had no negative effect on the fertigation, growth and productivity of sweet pepper and melon crops. Therefore, the life-span of rockwool slabs and perlite grow-bags can be extended to 3 or 5 cropping years, respectively, for both crops.

Keywords

Air capacity, *Capsicum annuum*, *Cucumis melo*, Dissolved oxygen, Life-span, Water content

1. Introduction

Substrate culture has been used increasingly over recent decades in the greenhouse industry, and inert substrates (especially rockwool slabs and perlite grow-bags) are commonly used for fruit vegetable production. On the Mediterranean coast of South-east Spain, which represents the largest greenhouse area in Europe (Castilla and Hernández, 2005), between 15 and 20% of the greenhouse area uses substrates (perlite grow-bags, above all, and rockwool slabs) as growing medium (Céspedes et al., 2009). Greenhouses in this region are mostly low-cost structures covered with plastic film and without climate control systems (Pérez-Parra et al., 2004). Over the last 30 years, the area of low-cost plastic greenhouses has risen dramatically in Europe as well as in other areas of the world, such as North Africa, South America and China (Baille et al., 2006).

In temperate greenhouse areas (Northern Europe and America) inert substrates are normally used for only one cropping season, in particular to avoid or reduce plant disease proliferation. The main inert substrates (rockwool and perlite) are not biodegradable, they originate from non-renewable resources and require a large amount of energy and generate great environmental impacts in their manufacturing processes (Torrellas et al., 2012). As a result, more environmentally sound substitutes are currently being assessed by the greenhouse industry (Allaire et al., 2005). In mild winter climates, such as the Mediterranean coast of South-east Spain, multiannual inert substrates are widely used in greenhouses over several cropping seasons, mainly to reduce expenses. In this region, the life-span of rockwool slabs or perlite grow-bags varies between 2 and 5 years depending mostly on substrate type and management, crop rotation and the growers' experience (Urrestarazu et al., 2008). However, physical, chemical and biological substrate properties can change and deteriorate with time and use, which may affect both crop management and behaviour. Mechanical degradation of substrates can alter the pore structure, which may in turn affect retention and movement of nutrient solution and root aeration (Orozco and Marfà, 1995, Giuffrida et al., 2007, Verhagen, 2009). Ensuring an adequate oxygen supply to the roots is a difficult task even when crops are grown on well-aerated substrates, such as rockwool and perlite (Bonachela et al., 2010a). Accumulation of salts may also occur in reused substrates (Giuffrida et al., 2007), possibly affecting the establishment, growth and/or productivity of greenhouse crops, especially in those which are more sensitive to salinity, such as beans and sweet pepper. Our knowledge as to how the reuse of inert substrates, mainly rockwool and perlite, affects their physical properties and life-span, as well as the productive response of greenhouse horticultural crops, is incomplete and inconclusive (Böhme, 1995, Hanna, 2005, Giuffrida et al., 2007). A deeper understanding is required in order to improve inert substrate reuse and management, especially for low-cost greenhouses areas.

This work analyses how the physical properties of rockwool slabs and perlite grow-bags change with time and use, and studies the response of sweet pepper and melon crops grown in new (N) and reused (R) perlite grow-bags and rockwool slabs. Its main aim was to study the life-span of these two inert substrates in order to reduce expenditure and environmental impacts of soilless crops grown in low-cost greenhouse areas.

2. Materials and methods

2.1. Experiments

Four experiments were carried out over two cropping seasons (2003/2004 and 2004/2005) at the Cajamar Foundation Research Station (2°43′ W, 36°48′ N, 155 m a.s.l.), on the Almería coast. This is located in the Mediterranean region of South-east Spain, where a mild winter climate prevails. Experiments were conducted in a "parral" type greenhouse of 500 m^2 covered with a three-layer plastic film (0.2 mm thickness), without active systems of climate control and passively ventilated by sidewall rolling and roof vents (Pérez-Parra et al., 2004). An autumn–winter sweet pepper (cv. Bárdenas®) and a spring melon crop (cv. Sirio®) were grown in new and 2-year-old reused rockwool slabs during the 2003/2004 cropping season, and in new and 4-year-old reused 40 l perlite grow-bags during the 2004/2005 season. Rockwool slabs were Med Horizontal Grodan® (Med, Grodan Med S.A., Almería, Spain) of 100 cm (length) × 10 cm (height) × 15 cm (width), whereas perlite grow-bags were B12 type (particle size Ø 0–5.0 mm) and 100 cm long. Reused rockwool slabs had previously been used in a commercial greenhouse for an autumn–winter cucumber cycle and a spring melon cycle during the 2001/2002 season, and an autumn-spring tomato cycle in 2002/2003. Reused perlite grow-bags had previously been used for an autumn–winter sweet pepper cycle and a spring watermelon cycle in 1999/2000 and 2000/2001, and for an autumn–winter sweet pepper cycle and a spring melon cycle in 2001/2002 and 2002/2003. At the beginning of each cropping year, the perlite located around the old roots of each plant in the reused grow-bags was extracted with a cylinder (Ø 0.1 m) and replaced by new perlite (the replaced perlite accounted for approximately 6–8% of the grow-bag volume). This is a frequent practice in the region in order to facilitate the establishment and growth of new crops in reused perlite grow-bags. Moreover, reused substrates were irrigated weekly with water during the period without cropping (summer) to lixiviate accumulated salts. Both reused substrates were also disinfested by applying a biocide through the irrigation system before the new crop cycle (rockwool slabs and perlite bags were saturated of water with biocide for 1 day and, later on, irrigated to eliminate the applied biocides before planting).

For sweet pepper transplanting (3.08 plants m^{-2}) was carried out on 1 August 2003 and 3 August 2004, respectively, and crops ended on 21 February 2004 and 25 February 2005, respectively. For melon transplanting was carried out on 8 March 2004 and 11 March 2005, at a plant density of 1.59 and 2.05 m^{-2}, respectively, and crops ended on 21 June 2004 and 9 June 2005, respectively. Irrigation water of 0.4 dS m^{-1} electrical conductivity (EC) was applied by a non-recirculating drip irrigation system. The same nutrient solution was supplied by fertigation to all the treatments, and irrigation was activated automatically by a water level sensor located in a tray holding two representative two rockwool slabs in 2003/2004 or two perlite grow-bags in 2004/2005 (Bonachela et al., 2010b).

A 2 × 2 factorial experiment was arranged in a completely randomised experimental design with 6 (2003/2004) and 4 (2004/2005) replications per treatment combination. A complete crop row was the experimental unit. Two main factors were studied: the substrate age (new and reused) and the dissolved oxygen concentration in the nutrient solution (a super-saturated nutrient solution and a standard nutrient solution with a dissolved oxygen concentration below saturation). The nutrient solution oxygen enrichment was carried out by oxyfertigation (Bonachela et al., 2010a). This work only focuses on crop response to substrate age and the data presented are average values of the two levels of nutrient solution oxygen content, as no interactions were found between the two main factors for the parameters evaluated throughout the four crop cycles. For each crop and substrate type, a new (N) and reused (R) substrates were compared. Data were statistically analysed with the Stat graphics plus (v5.1) software and means were compared with the LSD test ($P \leq 0.05$).

2.2. Measurements

Water release curves and main physical properties (bulk density – BD, particle density – PD, total porosity – TP, air capacity – AC, easily available water – EAW, water buffering capacity – WBC and less readily available water – LRAW) of rockwool slabs and perlite grow-bags were determined (De Boodt et al., 1974) before and after each experimental cropping season. Unchanged subsamples of four representative rockwool slabs and perlite grow-bags were taken. Moreover, perlite samples were analysed for particle size distribution using standard sieves of 0.125, 0.25, 0.5, 1, 2, and 4 mm, and two particle size indexes (geometric mean diameter and standard deviation of geometric mean diameter) were calculated to describe particle alteration (Orozco et al., 1997). In the reused rockwool slabs, subsamples were taken in three different positions to consider spatial variation of physical properties within the slab due to spatial variation in root growth or fertigation distribution: in the lower part of the slab below (A) and between plants (B), and in the upper part of the slab between plants (C). Organic matter content, OM (AENOR, 2001) and saturated hydraulic conductivity, K_s, by means a constant-head permeameter (Klute and Dirksen, 1986) were also determined. The K_s value of 3-year-old rockwool slabs was not measured due to technical problems. These measurements were carried out at the Institut de Recerca i Tecnología Agroalimentaries (IRTA) in Cabrils, Barcelona (Spain).
Volume, EC and pH of nutrient solution from two drip emitters and of leached nutrient solution from two representative slabs or grow-bags were measured daily for each treatment. Dissolved oxygen (DO) in the substrate solution was measured with an oxygen probe (550A YSI, Ohio, USA) with ±0.1 mg L^{-1} resolution and automatic temperature compensation. Substrate solution was taken from 4 replications per treatment in the central part of the slab/bag, 1 cm above the substrate bottom, between 12:00 and 14:00 p.m., when DO values are theoretically lowest. They were extracted with a moisture sampler (Rhyzon SMS, Eijkelkamp, Giesbeek, The Netherlands), which had been previously calibrated (Acuña, 2007). Volumetric water content (VWC) of rockwool slabs was measured periodically throughout the 2003/2004 sweet pepper and melon cycles with a FDR-type sensor (WMC, Grodan, Roermond, The Netherlands), calibrated for this substrate. Measurements were taken at eight points distributed within each rockwool slab (Fig. 1) and in four slabs per treatment (Acuña, 2007). In the sweet pepper crop, data of VWC were only available for the second part of the cycle due to technical problems with the FDR sensor.

Plant height, leaf area index (LAI) and total aboveground, leaf, stem and fruit biomass were measured in 4 plants per replication at the beginning and end of each cycle, and at flowering time. Additionally, plant height and leaf length (*L*, cm) were measured during the crop cycles every 3–4 weeks from one plant per replication. LAI values were obtained from a narrow curvilinear relationship between leaf area and *L* values, previously determined for each crop (Bonachela et al., 2010a). Total and marketable yield, and marketable yield components were measured in 18 (sweet pepper crop cycles), 9 (melon in the 2003/2004 season) and 12 (melon in the 2004/2005 season) plants per replication. Marketable fruits were classified in two categories, according to the official journal of the European Communities (OJ, 2001). At harvest, melons were also classified by size, and two melon fruits per replication and size group were randomly selected for quality analysis. Morphologic parameters (transversal and longitudinal perimeter, and peel and pulp thickness) of each fruit were measured. Total soluble solids (TSS) contents, expressed as °Brix index, and pH were determined in the liquid extract obtained by liquefying and filtering the mesocarp of each fruit.

3. Results

3.1. Physical substrate characteristics

3.1.1. Rockwool slabs

Regardless of the substrate age and use, and position in the slab, the water retention curve of the rockwool presented very high water content at saturation (Fig. 2), which decreased sharply at low suction, and very low water retained at suction of over 5 kPa. Fig. 3 shows how the physical properties of rockwool slabs varied with time and use. Over the two first cropping years, no clear changes were observed for bulk density (BD) and total porosity (TP) values, which remained at around 0.07 g cm^3 and 97% (v/v), respectively, whereas after the third cropping year the BD increased and the TP decreased. Moreover, there was a progressive increment of the organic matter content (OM) over the three cropping years, which led to a slight decrease in particle density (PD). With regard to aeration and water retention characteristics, the air capacity (AC) and the easily available water (EAW) remained around or above 30% and 40%, respectively, over the three cropping years, whereas the water buffering capacity (WBC) was practically negligible (Fig. 3). However, some changes were observed for these characteristics. After the first cropping year, the EAW decreased while the AC increased, whereas the opposite occurred after the third cropping year (Fig. 3). In addition, the less readily available water (LRAW), initially close to zero, increased progressively and reached a value of about 7% (v/v) at the end of the third cropping year (Fig. 3). Most of these changes occurred firstly in the lower parts of the rockwool slabs and extended progressively to the upper parts (Fig. 2). Moreover, hydraulic conductivity values at saturation (K_s) were relatively high (Da Silva et al., 1995): 17.3 mm s^{-1} in the new rockwool, decreasing to 2.3 and 1.9 mm s^{-1} in 1 and 2 years old slabs, respectively.

3.1.2. Perlite grow-bags

Fig. 4 shows how the particle size distribution curve (cumulative values) in the perlite grow-bag varies depending on time and use. During the first cropping year, the perlite grow-bag lost most of the finer particles, especially those with a diameter of less than 0.5 mm (Fig. 4), whereas the relative size distribution of perlite particles remained quite steady over the following cropping years. Consequently, the geometric mean of perlite particle size (d_g) increased and the standard deviation of the geometric mean diameter (σ_g) decreased after the first cropping year (Table 1), whereas both particle size indexes varied little over the following cropping years.

Fig. 5 shows the evolution of the main physical properties of perlite grow-bags with time and use. The BD decreased and the TP increased slightly after the first cropping year, whereas both properties remained steady at around 0.12 g cm^3 and 95%, respectively, throughout the following cropping years (Fig. 5). A progressive increment of the OM with the cropping years was also observed. With regard to water retention and aeration characteristics, the EAW stayed close to 10% throughout the cropping years, although it decreased slightly with time and use (Fig. 5); the WBC decreased slightly after the first cropping year, but thereafter remained steady at around 6%; the LRAW varied, but was always higher than 25%; and the AC was always higher than 45%. Moreover, K_s values were relatively high compared to those found for the same perlite type by Orozco and Marfà (1995) and they increased after the first cropping year (Table 1).

3.2. Water use and fertigation

The total amount and the seasonal dynamics of supplied, uptake and leached nutrient solution were similar in the new and reused substrate for each of the four studied crops. The average seasonal values of cumulative crop water uptake were 274 (N) *vs.* 268 mm (R) for sweet pepper grown on rockwool slabs; 211 (N) *vs.* 201 mm (R) for melon grown on rockwool slabs; 248 (N) *vs.* 250 mm (R) for sweet pepper grown on perlite grow-bags; and 234 (N) *vs.* 250 mm (R) for melon grown on perlite grow-bags. Average seasonal percentages of leached nutrient solution were slightly higher than 30% for the four crops and similar for new and reused substrates. Similar dynamics of EC and pH values in the leached nutrient solution were also measured for crops in new and reused substrates. Average seasonal EC values in the leached nutrient solution were similar for crops in new and reused substrates: 2.7 dS m^{-1} for the sweet pepper grown on rockwool slabs, 3.5 dS m^{-1} for the melon grown on rockwool slabs, 3.1 and 3.2 dS m^{-1} for the sweet pepper grown on new and reused perlite grow-bags, respectively, and 3.0 and 2.9 dS m^{-1} for the melon grown on new and reused perlite grow-bags, respectively. Average seasonal pH values in the leached nutrient solution were around or slightly higher than 6 for all crops and treatments. These values are common for commercial substrate-grown crops in the region.
The seasonal dynamics of the volumetric water content (VWC) in the rockwool was similar for new and reused slabs throughout most of the sweet pepper and melon crop cycles, except at their beginning (Fig. 6). VWC values throughout the sweet pepper crop were at the lower extreme of the recommended range for this substrate (Stradiot, 2001). No significant differences were observed between new and reused slabs for the average seasonal VWC value (41.1 for N *vs.* 49.7% for R in the sweet pepper, and 59.9 for N *vs.* 57.1% for R in the melon crop). However, new and reused rockwool slabs presented clear differences in the spatial distribution of VWC within the slabs (Fig. 6): the new slabs presented

rather homogeneous VWC values within the slabs, whereas the reused ones showed variable VWC values with the highest ones around the drippers.

3.3. Growth and crop productivity

No significant differences were found between crops grown on new and reused substrates for most of the growth parameters evaluated: crop height and LAI values throughout the crop cycles (Fig. 7), and aboveground biomass and its partitioning at the end of cycles (Table 3). Aboveground biomass values were similar to those measured by Bonachela et al. (2006) in the same area but with crops grown in gravel/sand mulched soils.

At the end of the sweet pepper and melon cycles no significant differences were found between the crop grown in new and reused rockwool slabs for the fresh weight of total, marketable, first or second class fruits (Table 4). The sweet pepper marketable yield was 8.5 kg m^{-2} for N and 8.8 kg m^{-2} for R slabs, whereas the melon marketable yield was 6.0 kg m^{-2} for N and 5.9 kg m^{-2} for R slabs. Neither were significant differences found between the sweet pepper grown in new and reused perlite grow-bags for the total or marketable yield (Table 4), although values were slightly higher in the crop grown in the new grow-bags. However, the total, marketable and first class fruit yields of melon were significantly higher in the crop grown in the reused perlite grow-bags. In general, crop productivity values were slightly higher than those measured by Fernández et al. (2007) in the same area but with crops grown in gravel/sand mulched soils. Finally, no significant differences were found for most of the studied fruit quality parameters between the melon grown in new and reused rockwool slabs (Table 5).

4. Discussion

4.1. Rockwool slabs

In general, water retention curves of the rockwool slabs (Fig. 2), regardless of age and use, were similar to those found by Da Silva et al. (1995) and Bougoul et al. (2005). However, physical properties of rockwool slabs, including air–water relationships, changed with time and use. After the first cropping year, the EAW decreased by about 15% and the AC increased to a similar degree (Fig. 3). The loss of the wetting agent used to impregnate wool fibres might have produced these changes (Da Silva et al., 1995), but we do not have data to confirm this hypothesis. No changes in TP were observed for the two first cropping years despite the OM content increased progressively, but the total slab volume was not measured. However, the relative volume of pores occupied by the buffering (WBC) and the less readily available water (RLAW) increased throughout the two first cropping years (Fig. 3), which can be associated to the progressive increment of the OM (Cannavo and Michel, 2013), Moreover, at the end of third cropping year, the AC and, to a lesser extent, the TP of the reused rockwool decreased, whereas the EAW, the LRAW and the BD increased (Fig. 3). These changes can be attributed to the compactation of the rockwool slabs, which is expected to occur in fibrous media with time and use (Verhagen, 2009). In fact, at the end of the third cropping year, most rockwool slabs appeared to be physically deteriorated with certain parts compacted. This could apparently be due to the loss or wash of the additives used for binding the wool fibres together. Despite these changes, main physical properties of 3-year used rockwool slabs, including water retention and aeration characteristics (Fig. 3), were within the recommended values for growing fruit vegetable crops (Rivière, 1988, Morel et al., 2000, Raviv et al., 2002, Verhagen, 2009). Nevertheless, some local growers use rockwool slabs for a fourth cropping year by growing low-demanding crops, such as tomato or eggplant.

The changes of physical properties observed in the reused rockwool slabs did not appear to affect crop water use or substrate solution characteristics in the two studied crops: autumn–winter sweet pepper and spring melon. In both crop cycles, the total amount and the seasonal dynamics of supplied, uptake and leached nutrient solution were similar in new and reused rockwool slabs, and no significant differences between them were found for the mean VWC in the slabs (Fig. 6) or for the dissolved oxygen content in the substrate solution (Table 2). Spatial VWC distribution within the rockwool slabs is not usually uniform (De Rijck and Schrevens, 1998, De Rijck et al., 1998, Bougoul and Bourlard, 2006), but it was clearly more variable in the reused than in the new slabs (Fig. 6). The variation coefficient of VWC values within the rockwool slabs was 27.5% for the sweet pepper grown in reused slabs *vs.* 10.3% for that grown in new slabs, and 23.3% for the melon crop grown in reused slabs *vs.* 4.7% for that grown in new slabs. The higher VWC spatial variability found in the reused slabs may be associated with the greater spatial variation found in their water retention curves (Fig. 2), and appears to be related to the emitters' location (Fig. 1) and, consequently, to the spatial root distribution within the slabs.

Overall, the reuse of rockwool slabs for three cropping seasons did not affect aboveground biomass and biomass partitioning (Table 3), fresh weight of total and marketable sweet pepper or melon fruits (Table 4) or melon fruit quality parameters (Table 5). This response may be attributed to the fact that the main rockwool physical properties, especially water retention and aeration characteristics, remained within or close to the recommended values for crop production, as well as to the absence of chemical problems, such as slab salt accumulation. Nevertheless, the higher VWC spatial variation found within the reused slabs should be considered for crop fertigation management (Stradiot, 2001). The number and characteristics of the emitters, and their location in the substrate, together with the location of the transplanting cubes at each crop cycle influence the fertigation distribution within the substrate and, consequently, the root accumulation, which can affect the uniformity of the physical properties within new and reused substrates (Cannavo and Michel, 2013).

4.2. Perlite grow-bags

The particle size distribution of perlite grow-bags remained steady from year 2 (Fig. 4), after most of the finer particles had been lost during the first cropping year. This loss, possibly caused by the leaching of fine particles (less than 0.5 mm diameter) through irrigation water drainage (Orozco and Marfà, 1995), did not appear to affect the main physical properties of perlite grow-bags, with the exception of BD, which fell as expected. Water retention and aeration characteristics of perlite grow-bags hardly changed throughout the five studied greenhouse cropping seasons (Fig. 5): the AC was always high (45–55%), which facilitates an adequate oxygen supply to crop roots, whereas the EAW stayed relatively low (close to 10%), which should be considered for fertigation management. However, these low EAW values can be partially compensated by the higher volume of the perlite grow-bags (40 l), compared to the rockwool slabs (15 l). Moreover, fractioning of coarse particles into finer ones was not observed. The small changes in the physical properties of reused perlite grow-bags did not affect fertigation parameters throughout the sweet pepper and melon crops. In both cycles, supplied, uptake and leached nutrient solution were similar in the crops grown in new and reused bags (Section 3.2), and no significant differences were found between them for the dissolved oxygen content in the substrate solution (Table 2). The reuse of perlite grow-bags did not affect either the aboveground biomass and the biomass partitioning of sweet pepper and melon crops (Table 3), or the fresh weight of total and first class sweet pepper fruits (Table 4). However, the fresh weight of marketable and first class melon fruits was higher in the crop grown on reused perlite bags (Table 4). No biomass or yield differences had been found for several vegetable crops in previous studies (Giuffrida et al., 2007). The yearly replacement of old perlite with new particles in those parts of the grow-bags where new seedlings are transplanted may reduce salt and root accumulation and its negative effects on seedlings. Nevertheless, a deeper insight into water and salt distribution within reused perlite grow-bags is required in order to extend the life-span of this substrate and to improve its management.

5. Conclusions

The main physical properties of reused rockwool slabs remained quite steady over three cropping years and no negative effects were found on the fertigation, growth and productivity of sweet pepper and melon crops when grown in reused slabs.

The physical properties of reused perlite grow-bags remained quite steady over five cropping years and perlite reuse had no negative effect on the fertigation, growth and productivity of sweet pepper and melon crops.

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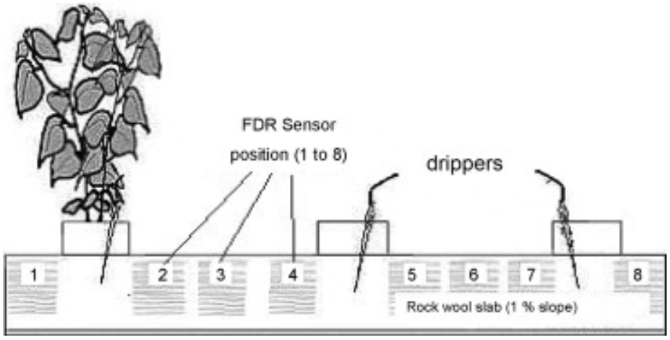

Fig. 1. Location within each rockwool slab of drip emitters, transplanting cubes and the eight measurements points of volumetric water content.

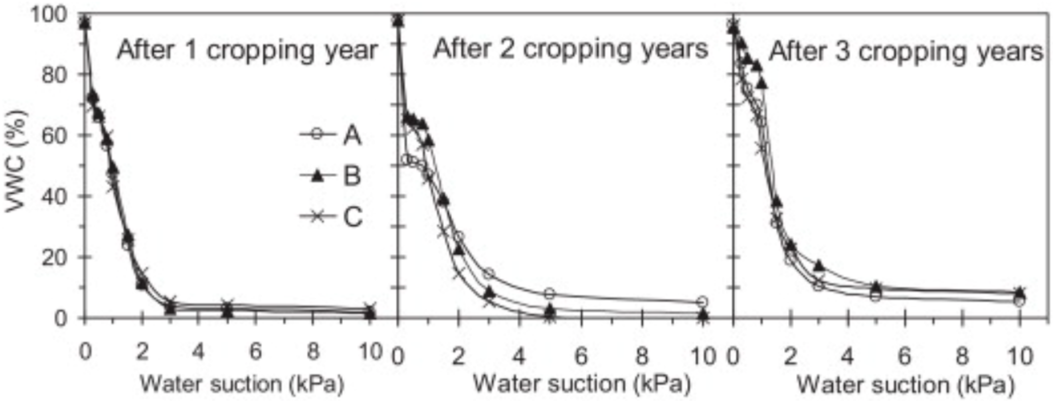

Fig. 2. Water retention curves of rockwool slabs after 1, 2 and 3 cropping years in three positions within the slabs: in the lower part of the slab below (A) and between plants (B), and in the upper part of the slab between plants (C).

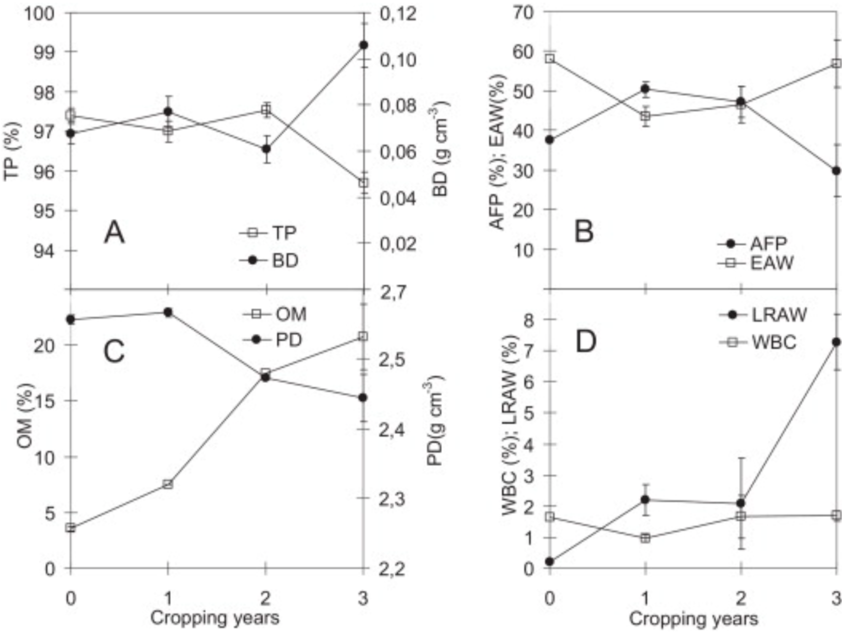

Fig. 3. Evolution of physical properties of rockwool slabs with time of use (years): (A) total porosity (TP, v/v) and bulk density (BD, g cm^{-3}); (B) air-filled porosity (AFP, v/v) and easily available water (EAW, v/v); (C) water buffering capacity (WBC, v/v) and less readily available water (EAW, v/v); (D) organic matter content (OM, w/w) and particle density (PD, g cm^{-3}).

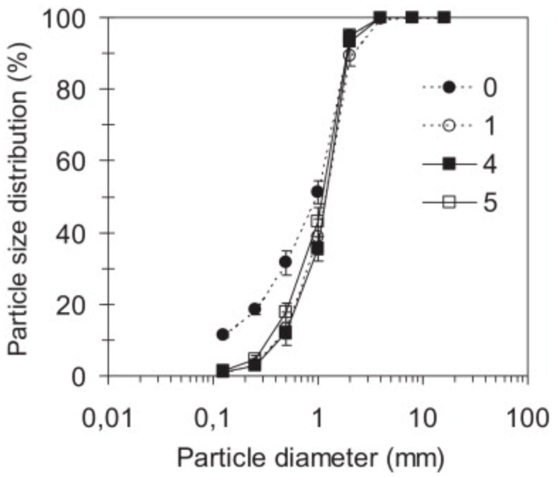

Fig. 4. Cumulative curve of particle size distribution in new (0 years) and reused (1, 4 and 5 years) perlite grow-bags. Vertical bars are the standard error of the mean.

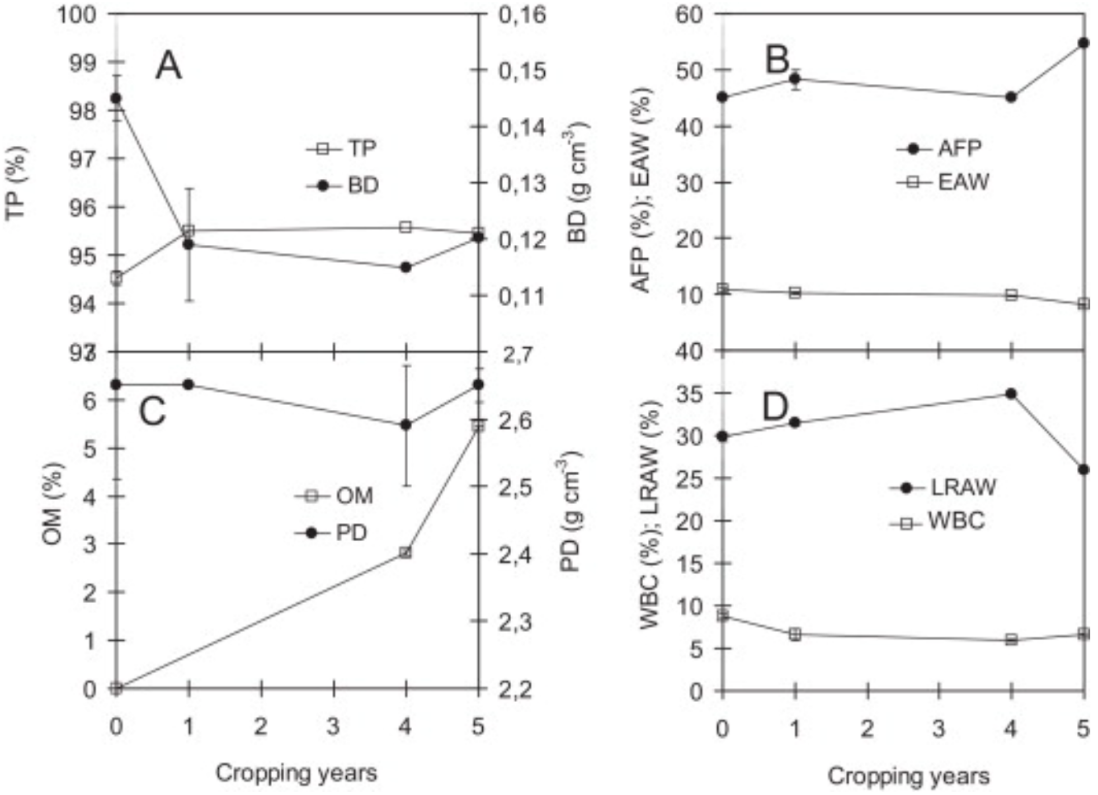

Fig. 5. Evolution of physical properties of perlite grow-bags with time of use (years): (A) total porosity (TP, v/v) and bulk density (BD, g cm^{-3}); (B) air-filled porosity (AFP, v/v) and easily available water (EAW, v/v); (C) water buffering capacity (WBC, v/v) and less readily available water (EAW, v/v); (D) organic matter content (OM, w/w) and particle density (PD, g cm^{-3}).

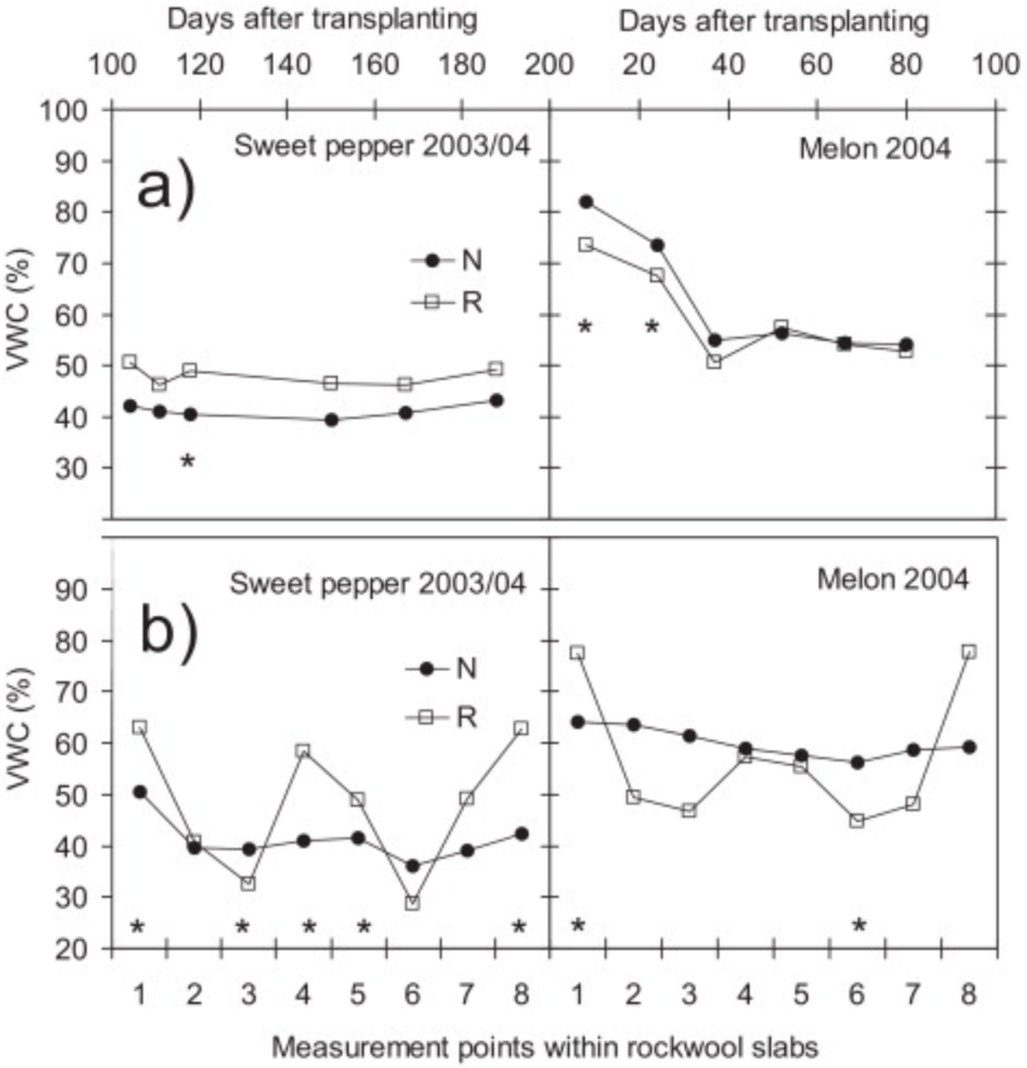

Fig. 6. (a) Seasonal dynamics of the volumetric water content (VWC) in new (N) and reused (R) rockwool slabs throughout the sweet pepper and melon crops (N: • and R: □); and (b) spatial distribution of VWC within the rockwool slabs. The symbol * indicates the dates when there were significant differences ($P < 0.05$).

Values of dissolved oxygen content (DO) in the substrate solution were similar for new and reused substrates throughout the four studied crop cycles and no significant differences were found for their average seasonal DO values (Table 2). The substrate DO ranged between 3.6 and 6.1 mg O_2 L^{-1} in the melon grown in new rockwool slabs and between 3.3 and 6.2 mg O_2 L^{-1} in that grown in the reused ones, and between 1.8 and 4.5 mg O_2 L^{-1} in the melon grown in new perlite bags and between 2.1 and 5.2 mg O_2 L^{-1} in that grown in the reused ones. In sweet pepper, the substrate DO ranged between 1.9 and 4.9 mg O_2 L^{-1} in the crop grown in new bags and between 2.3 and 4.1 mg O_2 L^{-1} in that grown in the reused ones.

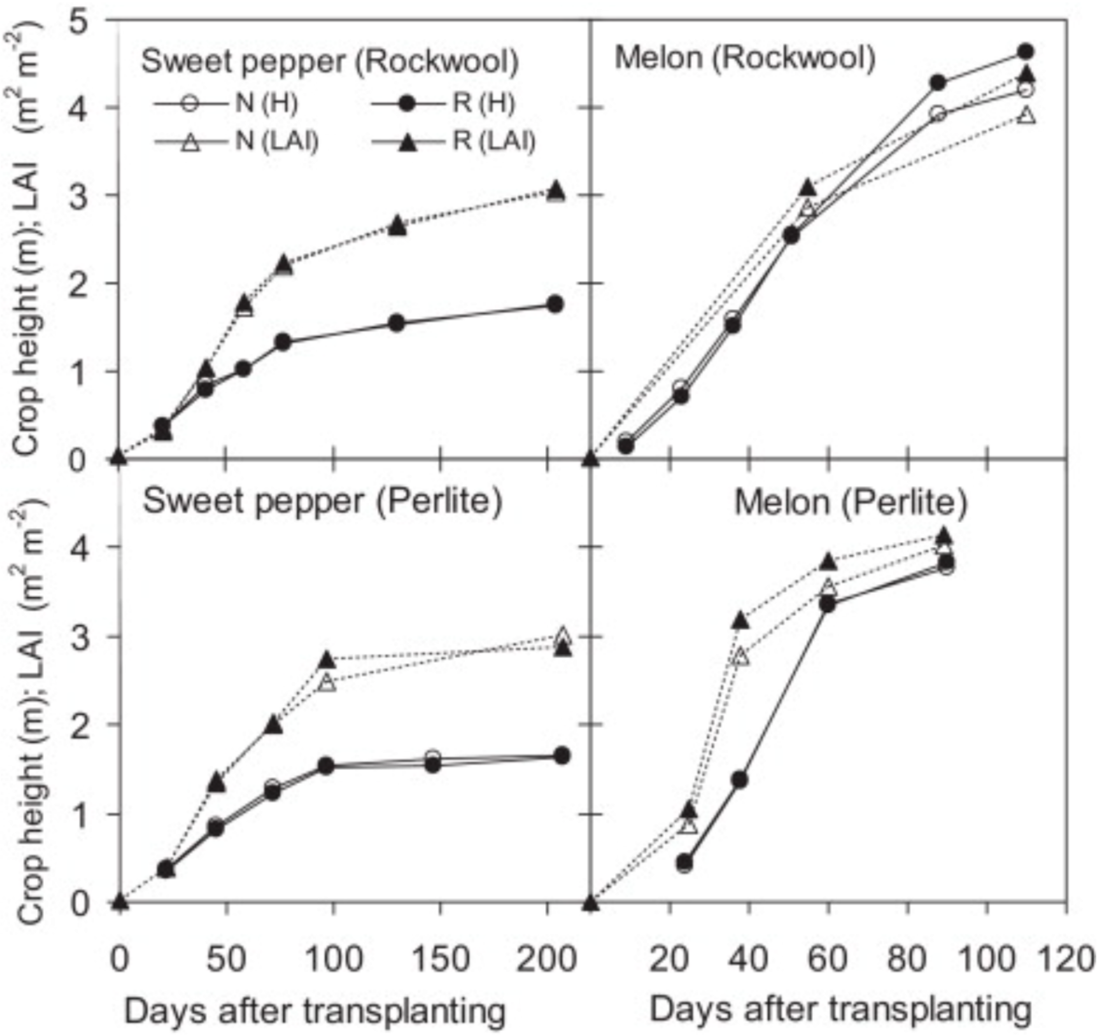

Fig. 7. Seasonal dynamics of crop height and leaf area index values of sweet pepper and melon crops grown on new (N) and reused (R) rockwool slabs (2003/2004 cropping season) or perlite grow-bags (2004/2005 cropping season). Table 3. Values of aboveground biomass, biomass partitioning and harvest index (HI) at the end of the sweet pepper and melon crop cycles grown on new (N) and reused (R) rockwool slabs (2003/2004 season) and perlite grow-bags (2004/2005 season).

Table 1. Geometric mean (d_g, mm) and standard deviation of the geometric mean (σ_g) of perlite particle size, and hydraulic conductivity at saturation (K_s, cm min^{-1}) of new (0 years) and reused (1, 4 and 5 years) perlite grow-bags.

	Cropping years			
	0	1	4	5
dg	1.31 ± 0.09	2.19 ± 0.18	2.20 ± 0.08	1.94 ± 0.10
σg	3.30 ± 0.07	1.98 ± 0.08	1.88 ± 0.03	2.04 ± 0.02
Ks	3.9 ± 0.08	19.4 ± 0.15	21.2 ± 1.00	26.6 ± 0.13

Table 2. Average seasonal dissolved oxygen values (mg L^{-1}) in the substrate solution of sweet pepper and melon crops grown on new (N) and reused (R) rockwool slabs or perlite grow-bags.

Values with the same letter within the same column are not significantly different ($P < 0.05$).

Substrate type	2003–2004 season (rockwool slabs)		2004–2005 season (perlite slabs)	
	Sweet pepper	Melon	Sweet pepper	Melon
N	6.7a	3.0a	4.7a	2.8a
R	6.7a	3.0a	4.7a	3.3a

*Values with different letters within the same column are significantly different (P < 0.05).

Table 3. Values of aboveground biomass, biomass partitioning and harvest index (HI) at the end of the sweet pepper and melon crop cycles grown on new (N) and reused (R) rockwool slabs (2003/2004 season) and perlite grow-bags (2004/2005 season).

Crops and substrate	Substrate type	Aboveground biomass (g m−2)					
		Leaf	Stem	Fruit	Vegetative	Total	HI (g g−1)
Sweet pepper (rockwool)	N	245a	323a	902a	569a	1470a	0.61a
	R	243a	328a	930a	571a	1501a	0.62a
Melon (rockwool)	N	269a*	137a	693a	405a	1098a	0.63b
	R	316b	164a	658a	480a	1138a	0.58a
Sweet pepper (perlite)	N	240a	324a	820a	564a	1384a	0.59a
	R	229a	294a	803a	523a	1326a	0.61a
Melon (perlite)	N	260a	175a	476a	436a	911a	0.52a
	R	278a	187a	506a	466a	971a	0.52a

*Values with different letters within the same column are significantly different (P < 0.05).

Table 4. Fresh weight of total, marketable, first and second class fruits (kg m^{-2}), and yield components [fruit number (fruits m^{-2}) and mean fruit weight (g $fruit^{-1}$)] at the end of the sweet pepper and melon crop cycles grown on new (N) and reused (R) rockwool slabs (2003/2004 season) and perlite grow-bags (2004/2005 season).

Crops and substrate	Substrate type	Fresh fruit weight				Yield components	
		Total	Marketable	First class	Second class	Fruit number	Fruit weight
Sweet pepper (rockwool)	N	9.4a	8.5a	5.8a[*]	2.7a	44.6a	190a
	R	9.8a	8.8a	6.4b	2.4a	45.0a	195b
Melon (rockwool)	N	6.1a	6.0a	4.9a	1.1a	9.7a	614a
	R	5.9a	5.9a	5.0a	0.9a	9.3a	630a
Sweet pepper (perlite)	N	8.6b	7.7a	5.6b	2.0a	38.2a	200a
	R	8.2a	7.4a	5.2a	2.2a	36.9a	202a
Melon (perlite)	N	5.6a	5.4a	4.8a	0.6a	7.5a	718a
	R	5.9b	5.7b	5.2b	0.5a	7.9a	728a

*Values with different letters within the same column are significantly different ($P < 0.05$).

Table 5. Fruit quality parameters of a melon crop grown on new (N) and reused (R) rockwool slabs (2003/2004 cropping season. Mean diameter (cm), peel and pulp thickness (cm), total soluble solids content (°Brix) and pH for three fruit sizes.

Substrate type	Mean fruit diameter	Peel thickness	Pulp thickness	Total soluble solids	pH
450–550 g					
N	9.9a	0.4a	2.6a	10.7a	5.7a
R	10.0a	0.4a	2.7a	10.1a	6.0a
550–650 g					
N	10.3a	0.4a	2.7a	11.1a	5.9b*
R	10.4a	0.4a	2.7a	10.5a	5.7a
650–850 g					
N	10.9a	0.5a	2.7a	12.7a	5.7a
R	11.0a	0.5a	2.8a	11.9a	5.8a

*Values with different letters within the same column are significantly different ($P < 0.05$).