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Evolution of organic matter and drainages in wood fibre and coconut fibre substrates

I. Domeño *, N. Irigoyen, J. Muro

Departamento de Producción Agraria, Universidad Pública de Navarra, Campus de Arrosadia, 31006 Pamplona, Spain

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ABSTRACT

New organic substrates have been introduced in hydroponic culture in order to substitute peat, because is a non-renewable resource, and in less rockwool or perlite due to their problematical recycling. The objective of this work is to evaluate the evolution of two renewable organic substrates, wood fibre (WF) and coconut fibre (CF) throughout one cultivation cycle. Two trials were set up, one with and a second one without crop. Volume, pH and EC of the input solution and the drainage solution were measured in both trials. In the trial without crop the content of NO_3^-, Cl^-, $(SO_4)^{2-}$,Ca^{2+}, Mg^{2+}, Na^+, P and K^+ was also determined. Physico-chemical characterization of the substrates was determined at the beginning and at the end of the trials. In order to know the loss of organic matter (OM), the dry matter content of the substrates was determined at the beginning and at the end of both trials. It has been observed that in both substrates retention of elements like NO_3^-, Ca^{2+}, P and Mg^{2+} occurs. In the study of the physico-chemical properties, it has been observed that the air capacity decreases considerably in both substrates in the trial with crop, especially in the CF, as well as a greater reduction of the C/N rate and percentage of OM. The data of organic matter loosed shows that in the trial with crop both substrates have lost more OM and this loss is slightly superior in CF. Therefore it is important to consider the possible retention of nutrients in the organic substrates to optimise cultivation management, as well as their degradability, which influences on the physico-chemical properties throughout the crop cycle.

1. Introduction

The proper management of a substrate is determined by the knowledge of its physico-chemical properties prior to its use and the subsequent adaptation of the substrate as well as the growing slab. The know-how of these characteristics at the beginning and the alterations that it experiments during the cultivation cycles is necessary (Salas and Urrestarazu, 2001).

Organic substrates, like coco fibre (CF) or wood fibre (WF), have been introduced in hydroponic culture in order to substitute peat, because it is a non-renewable resource, and in less rockwool or perlite due to their problematical recycling.

In case of the organic substrates, the evolution of its physico-chemical properties and its behaviour during the cultivation cycle are in relation with its stability. Apart from the physical origin of the instability, like mechanical or hydric degradation, in this case, biological causes also appear. When the substrate has certain quantity of biodegradable organic material, it can produce aerobic decomposition processes that can modify the organic matter. This decomposition, caused by microbial activity, is notably accelerated due to the environmental conditions of the hydroponic culture (Riviere, 1999).

Likewise, other processes have to be taken into account like the nutrient elements immobilization that occurs with this type of substrates by microorganisms. Nitrogen immobilization has been the most studied one, mainly with wood fibre substrates (Gruda, 2000; Gruda and Schnitzler, 1997; Handreck, 1992), but as Benoit and Ceustermans (1994) indicates, other elements, like P and Ca^{2+}, can also be immobilized.

The objective of this study is to evaluate the evolution of two organic substrates: one European substrate made of wood fibre (FIBRALUR®), and another one made of coconut fibre, with and without a crop cultivated on the substrate, carrying out the monitoring of the drainage, nutrients, physical–chemical characteristics and organic matter during a cultivation cycle.

2. Materials and methods

Two trials were set up, one without crop and one with crop grown on the substrate. In the trial without crop, nine bags with CF and nine bags with WF were put on two platforms, one for each type of substrate. The platforms had certain inclination and small

* Corresponding author.
E-mail address: itziar.domeno@unavarra.es (I. Domeño).

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Table 1
Nutrient solutions used in the experiments with and without crop.

	Without crop	With crop	
		Vegetative phase	Fruit development phase
NO_3^- (mmol L^{-1})	12.5	12.5	13.5
$PO_4H_2^-$ (mmol L^{-1})	2.5	2.5	2.5
SO_4^{2-} (mmol L^{-1})	2	2	2.5
CO_3H^- (mmol L^{-1})	0.5	0.5	0.5
Cl^- (mmol L^{-1})	1	1	1
K^+ (mmol L^{-1})	6	6	7.5
Ca^{2+} (mmol L^{-1})	5	5	6.5
Mg^{2+} (mmol L^{-1})	2	2	2.5
NH_4^+ (mmol L^{-1})	0	1.5	1.5
pH	5.8	5.8	5.8
EC (dS m^{-1})	2.4	2.4	3

gutters were put in to lead the drainage solution to a closed tank where it was collected with the help of a funnel and a hose.

The trial with the crop was part of a comparative experiment for different substrates for the hydroponic culture of greenhouse tomato (*Lycopersicon esculentum* Mill). This trial was carried out throughout one crop cycle from March to July and tomato plants cv. Caramba were used. Every bag had four tomato plants and the planting density was 1.6 plants m^{-2}. Devices were set up to collect the drainage of one bag for each substrate (WF and CF). In addition, a recipient was placed for collecting the input solution from a free stake.

In the trial without crop, the bags were automatically irrigated with nutrient solution, daily at first and then on alternate days. The nutrient solution was adjusted to the one used in the hydroponic culture of tomato, according to the recommendations given by Martinez and García (1993). In this trial all nitrogen was supplied in nitrate form. The following fertilizers were used: calcium nitrate, potassium nitrate, magnesium sulphate, potassium sulphate, mono potassium phosphate and Nutrel C (micronutrients). In addition, the pH was regulated to 5.8 by adding nitric acid (59%). In the trial with crop the composition of the feed solution was changed in relation to the growing stage of the tomato crop using two different compositions. The input solution is shown in Table 1.

In both experiments the volume of the feed solution and the drain were measured to calculate the drain percentage. The pH (HI 9024C Hanna instruments) and the electric conductivity were measured (HI 98312 Hanna instruments) of both the input solution and the drainage solution. Weekly measurements were taken on site.

In the experiment without crop every week at first and then every month, the NO_3^-, Cl^-, $(SO_4)^{2-}$, Ca^{2+}, Mg^{2+}, Na^+, P and K^+ content was determined with an ICP (ICP variant, model VISTA, radial and axial), of both the feed solution as the drainage solution.

A physico-chemical characterization of the substrates was conducted before initiating the experiments. The air water relationships were determined according to the methodology of De Boodt et al. (1974), obtaining the retained water volumes with suction pressures of pF 1, 1.7 and 2. Four subsamples of one bag of each substrate were analysed. Additionally, the following properties were determined: bulk density (BD), particle density (PD), total pore space (TPS), air capacity (AC), as the amount of air at pF 1, easily available water (EAW), as the amount of free water when the tension is increased from pF 1 to pF 1.7, water buffering capacity (WBC), as the amount of free water when the tension is increased from pF 1.7 to pF 2, and less readily available water (LRAW), as the amount of water retained at tension of pF 2. After the experiments had finished, in both trials two bags of each substrate type were put aside in order to repeat the physico-chemical characterization and to compare them with the initial ones, evaluate their evolution and carry out a comparison between the experiments.

In order to know the loss of organic matter of the substrates, before putting up the trials with and without crop, the fresh weight and the humidity level were determined in all bags. After 6 months, once the cultivation cycle was finished samples were taken from the bags to calculate the dry matter content. In the case of the experiment with tomato crop, the quantity of dry matter added by the plug of the cultivated plants was taken into account as well as an estimation of the weight of the roots that had grown. For this purpose, the increase in weight of bags with perlite substrate, in similar growing conditions during the cultivation, was taken as a reference. The increase in dry matter was 0.74 kg/bag, which corresponded to 0.20 kg added by the plugs (made up of peat) and 0.54 kg added by the roots developed during the cultivation cycle.

3. Results and discussion

The drain percentage of the experiment without crop oscillated between 50% and 95% because of the loss of water due to gravity and, to a lesser degree, through evaporation trough the holes of the bags. The differences between CF and WF were irrelevant.

In the experiment with crop the drain percentage oscillated between 10% and 60% throughout the growing cycle, the drain percentage of WF was the lowest, maintaining between percentages 10% and 30%, below the drain percentage of CF (data non shown).

With regard to the course of the pH in the trial without crop an increase of the pH is observed in the drainages in respect to the input solution. This fact is more remarkable in the case of WF, which rose to exceed a pH of 11 while CF stayed around a pH of 8 (Fig. 1a). On the contrary, in the trial with the culture crop, the pH of the drain followed the tendency of the input solution (Fig. 1b),

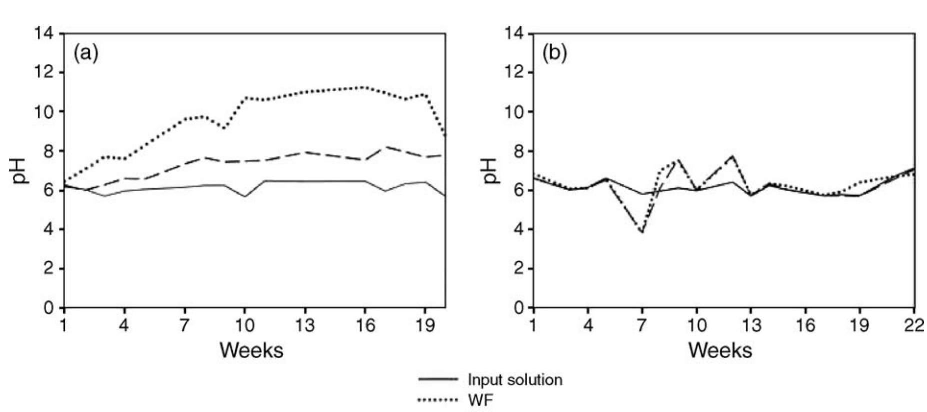

Fig. 1. The evolution of the pH of the input solution and the drainage of wood fibre (WF) and coconut fibre (CF) during the experiments: (a) without crop and (b) with crop.

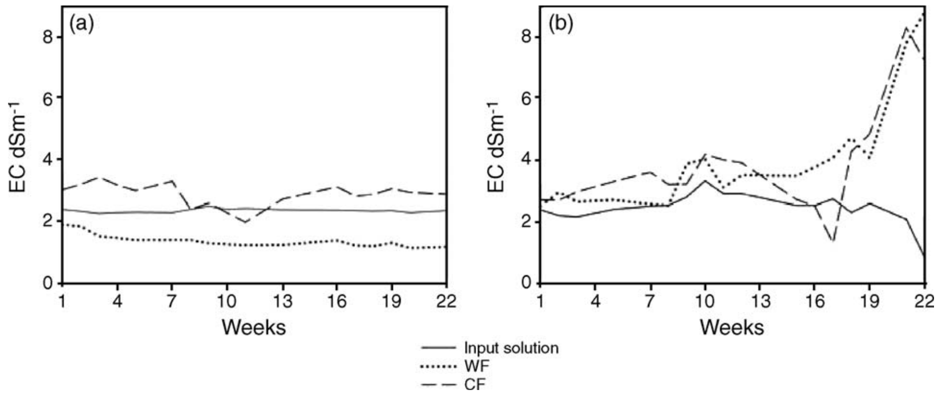

Fig. 2. The evolution of the EC of the input solution and the drainage of wood fibre (WF) and coconut fibre (CF) during the experiments: (a) without crop and (b) with crop.

maintaining percentages between 5.5 and 6.5 during the major part of the cycle.

The increase of the pH of an organic substrate can be justified by the activity of microorganisms that decompose the organic material and by being fed liberate hydroxyl ions to the environment (Barraud, 1990), but this increase of pH had not been observed in the experiment when roots were present. This increase of pH can also be due to the form of nitrogen supplied in the experiments. The nitrate form used in the trial without crop tends to alkalify the environment, while the ammonium form, used in the experiment with crop tends to acidify the environment (Tagliavini et al., 1997). This difference of pH between substrates in the trial without crop can also be explained according to the difference in buffer capacity of the two substrates. The difference in cation exchange capacity (CEC) could explain this, the CEC of CF is 175 mequiv./100 g against 25 mequiv./100 g for the wood fibre (Muro et al., 2002), giving the coco fibre more buffer capacity and therefore its pH changed less during the experiment.

The behaviour of the EC was substantially different in the two experiments as can be seen in Fig. 2. In the experiment without crop (Fig. 2a), the EC of the drainage solution of CF reached up to 3.5 dS m^{-1}, these values are higher than the input solution, that stayed between 2.2 and 2.5 dS m^{-1}, while in the case of WF the conductivity decreased to values of 1–1.5 dS m^{-1}. As will be analysed further on, the increase of the EC of the drainages in CF can probably be attributed to the high presence of sodium and chlorine in this substrate. CF showed values around 740 mg L^{-1} of Cl^- and 267 mg L^{-1} of Na^+ in the filtered of saturated extract, in opposition to WF, with values around 5.6 mg L^{-1} of Cl^- and 17.6 mg L^{-1} of Na^+. On the other hand, the decrease of the EC in WF is caused by the major removal of ions by the microorganisms in the decomposition of WF compared to the immobility in CF. The behaviour of the EC observed in the experiment with culture crop is rather different to the experiment without crop, showing more variability (Fig. 2b). High EC values were observed at the end of the cycle. These values coincided with a decrease of drain percentage probably caused by the high temperatures reached in greenhouse in that season.

It is important to consider the possible immobilization of elements or salts that can occur in organic substrates due to microbial activity, as this fact can have repercussions on the crop nutrition. The CEC of WF is low as indicates Lemaire et al. (1989) and medium for CF (Noguera et al., 2000a). Because of not having planted a crop the differences in the concentrations of the nutrients between the input solution and the drainage solution has to be considered as a consequence of the microbial activity.

For the trial without crop the percentage of retention of ${NO_3}^-$, Cl^-, $(SO_4)^{2-}$, P, Ca^{2+}, Mg^{2+}, K^+ and Na^+ can be seen in Fig. 3. The concentration retained by each substrate has been calculated from the concentration of the nutrients of the input solution and of the run-off.

It can be observed in the drainage solution of CF how Na^+ and Cl^- were released by the substrate (negative values for the percentage of retention), as well as for K^+. This can be attributed to the fact that the CF substrates initially show high levels of sodium chloride and potassium chloride. The initially high levels of these elements can be related to the high extractions by the coconut palm of the saline environment or the contamination by sea water of the storage and processing zones of the coconut shell (Noguera et al., 2000b).

On the other hand, noticeable is the retention by both substrates of ${NO_3}^-$ and Ca^{2+}, with levels near to 100%. The retention of N has been verified by Handreck (1992) and Gruda (2000) and it is due to the activity of microorganisms in organic substrates. The initially low contents of N of both substrates makes the microorganisms to use the nitrogen supplied by the nutrient solution for its development. The retention of the nitrate was more notable in WF from the start and was more gradual in the case of CF. The higher retention of N in WF in the beginning coincides with higher C/N ratio and lower total nitrogen (Table 2). Benoit and Ceustermans (1993,1994,1995) show this process of immobilization of nitrogen and indicate the possibility of the immobilization of other elements like P and Ca^{2+}. Exactly, in this experiment, one can observe a high retention of P, Ca^{2+} and Mg^{2+} in both substrates but the retention of P in CF is lower. These differences in the retention of P can be explained because, according to Noguera et al. (2000a) CF presents initially high levels of this element. The retention of these nutrients in the case of WF can have its influence on the reduction of the EC of the drainage solutions (Fig. 2) (Benoit and Ceustermans, 1994). These retentions can be due to microbial activity and in to possible precipitation process. Retention due to sorption on exchange complex could be possible but the CEC values of two substrates were low.

Data of yield were compared between WF and CF and also with perlite as reference substrate. No significant differences were observed for marketable production and marketable number of fruit between substrates. Nevertheless WF showed slightly more production as can be seen in Table 3. These results of marketable production were similar to results obtained by Muro et al. (2005) with the same variety of tomato.

Table 2 shows the physico-chemical characterization of the substrates: unused and after a period of 6 months with and without crop. In the beginning both substrates had similar TPS but, WF had higher coarse texture and AC than CF. Consequently, CF showed more capacity to retain water. On regard of chemical properties it can be observed that EC of CF was much higher than WF. It can be explained by the high content of sodium chloride of

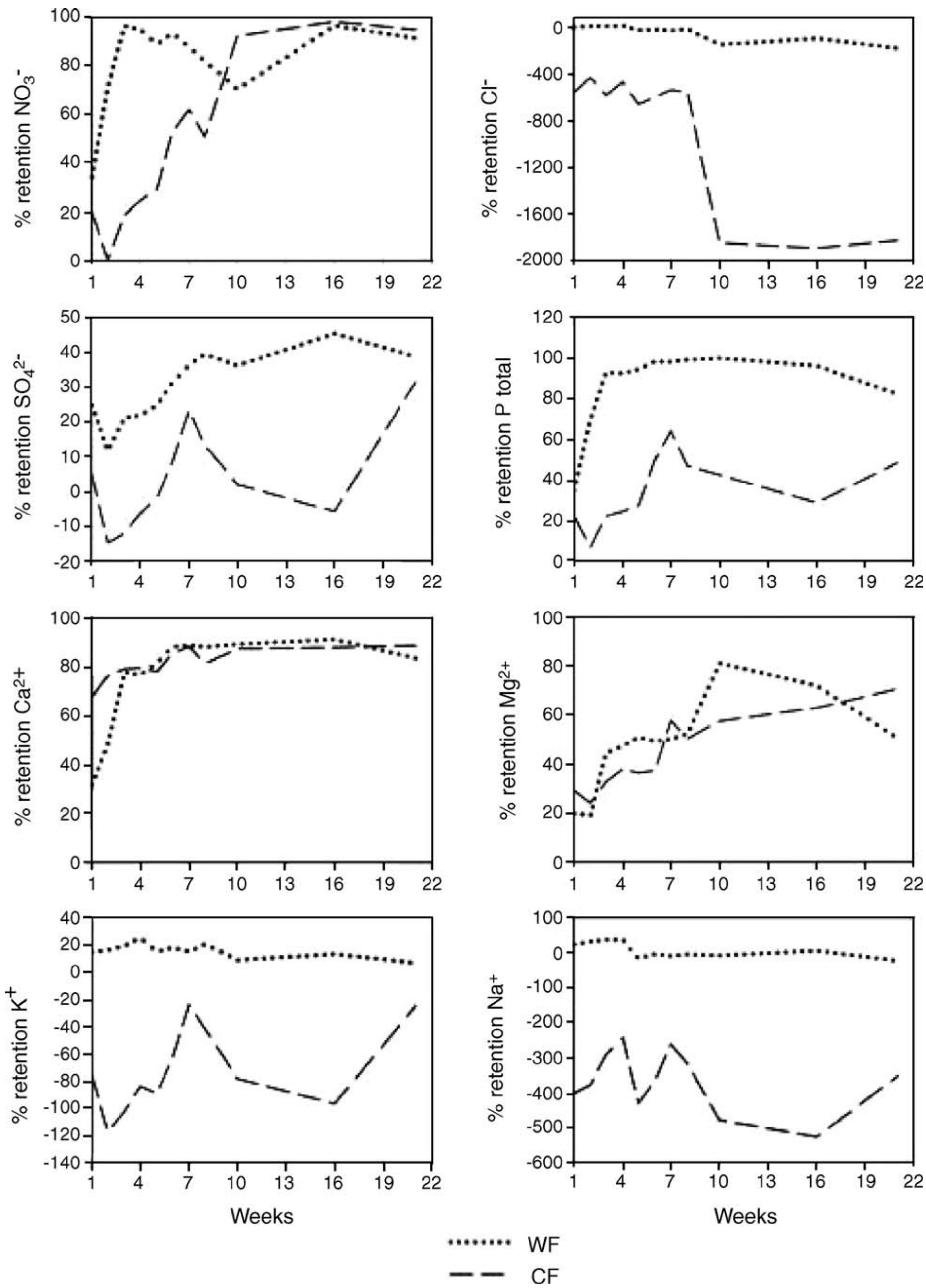

Fig. 3. The percentage of retention of NO_3^-, Cl^-, $(SO_4)^{2-}$, P, Ca^{2+}, Mg^{2+}, K^+ and Na^+ in wood fibre (WF) and coconut fibre (CF) during the experiment without crop. Negative values indicate release and positive values indicate retention.

this substrate. The difference in C/N ratio has to be taken into account. CF had a lower C/N ratio but it is above the ideal.

Concerning to the granulometry, in the case of WF the coarnesses index (CI, % particles Ø >1 mm) decreased in both trials (Table 2). On the other hand, in the case of CF an increase occurred of the CI due to the formation of agglomerations between the particles, especially in the experiment with crop.

In the case of the experiment with the culture crop a reduction can be observed of the air capacity (AC) and therefore, an increase in water retention in respect to the initial values of the bags. The reduction of AC was more apparent in the case of CF probably due to a major presence of fine particles caused by a major decomposition of the material. An increase of bulk density (BD) results in a reduction of AC (Gruda and Schnitzler, 2004). In spite of the important reduction of AC in CF, problems of aeration were not observed. On the contrary, in the experiment without a crop, the bags of WF lost AC, but in the case of CF, it was maintained and even increased slightly in respect to the initial values of the bags.

It is also to emphasize the reduction of the C/N ratio and the percentage of organic material of the substrates that can be seen in Table 2. In case of WF, a reduction of the two parameters in both trials occurred, but was significantly lower in the experiment with crop, which indicates a major decomposition of the substrate in the experiment mentioned before. CF also showed a reduction of the C/N ratio and of the organic matter due to the decomposition process. This reduction was more apparent in the trial with crop, but to a lower extend than in WF. Taking as a reference the C/N ratio and the percentage of organic matter, the degree of decomposition in the experiment without crop seems to be higher in CF than in WF.

Table 4 shows the loss in dry matter of the substrate bags for both experiments.

Table 2
Physico-chemical properties of wood fibre substrate (WF) and coconut fibre substrate (CF) unused and after been used throughout 6 months as growing media with and without crop.

	WF			CF		
	Unused	After 6 months without crop	After 6 months with crop	Unused	After 6 months without crop	After 6 months with crop
Physical properties						
Coarnesses index (CI, %)	81.9	75.3	72.9	14.6	21.4	30.4
Bulk density (BD, g L^{-1})	66.0	72.4	80.6	78.4	75.4	79.9
Particle density (PD, g L^{-1})	1570.0	1580.0	1730.0	1610.0	1640.0	1720.0
Total pore space (TPS, vol.%)	95.8	95.4	95.4	95.1	95.4	95.4
Air capacity (AC, vol.%)	58.7	51.7	49.7	27.0	30.7	8.4
Easily available water (EAW, vol.%)	16.1	18.2	19.6	29.4	26.9	38.0
Water buffering capacity (WBC, vol.%)	1.2	< 1	1.2	3.3	1.3	5.4
Less readily available water (LRAW, vol.%)	15.6	20.7	20.2	30.6	31.9	39.1
Chemical properties						
pH	7.6	7.7	7.4	6.2	7.1	6.7
EC (dS m^{-1})	0.04	0.37	1.55	5.64	0.28	2.32
Dry matter (DM, g/100g)	30.4	53.3	87.9	52.6	18.8	84.9
Moisture (g/100g)	69.6	46.7	12.1	47.4	81.2	15.1
Organic matter (OM, g/100g)	96.9	95.2	75.3	91.1	86.7	76.5
Ash (g/100g)	3.1	4.8	24.7	8.9	13.3	23.5
Total nitrogen (g/100g)	0.1	0.1	0.4	0.5	0.7	0.9
C/N ratio	469.5	345.9	93.1	103.9	65.5	45.9

The loss of dry matter found was higher in the experiment with crop in both substrates, which indicates that in this case a major decomposition of the material has occurred but no significant differences were observed. The reduced decomposition in the experiment without crop is consistent with the lower reduction of the C/N ratio and of the percentage of organic matter.

Therefore, it can be observed that WF and CF are suitable substrates for tomato hydroponic culture, showing similar yield values to ones obtained in perlite culture. However it is important to take into account the possible nutrient element immobilization and the changes of their properties throughout culture cycles.

According to these data, nutrient element immobilization not seems to have been harmful for the tomato crop. However this possible immobilization could be solved. From the relationship between the supplied elements and those in the drainage solution, an estimation of the retention of mineral elements by the microorganisms can be made and the amount of these nutrients that could have been supplied with the object to minimize possible deficiencies to use this type of substrates sensitive to decomposition. These extra supplies can be done with the irrigation water or, by means of impregnation of the fibres during the manufacturing process (Penningsfeld and Baumann, 1995).

The evolution of the substrates is reflected in the change of the physical–chemical characteristics. According to Riviere (1999), the air–water content is influenced by the decomposition of the organic matter, evolving in most of the cases towards a reduction in aeration and in an increase of water retention, which can be an advantage when the reduction of the air capacity is not too high. This is similar to the observations in these trials, in those cases in which occurred a major decomposition (trial with crop) a clear reduction of the aeration is observed especially in CF. In this case it seems to be that the reduction of AC does not detrimental marketable production but it is important to take into account these physical changes throughout successive cycles.

Finally, the wood fibre substrate has resulted in a suitable substrate for tomato hydroponic culture, capable of replacing other problematic substrates. This substrate could be used as organic amendment when its use in hydroponic culture ends. This substrate seems to be more stable than coconut fibre used, in relation to their properties evolution, but it is important take into account its possible interference in the plant nutrition.

Table 3
Yield and number of fruit m^{-2} of tomato grown in wood fibre (WF), coconut fibre (CF) and perlite.

	Yield (kg m^{-2})		Fruit (fruit m^{-2})	
	Marketable	No marketable	Marketable	No marketable
WF	16.0a	1.2a	63a	11a
CF	14.4a	1.2a	55a	11a
Perlite	14.6a	1.1a	58a	10a

Mean separation within each column by Student–Newman–Keuls test ($P \leq 0.05$).

Table 4
Dry matter lost by wood fibre (WF) and coconut fibre (CF) after been used throughout 6 months as growing media with and without crop.

	Six months without crop	Six months with crop
WF	7.3a	25.8a
CF	14.4a	31.5a

Mean separation within each column by Student–Newman–Keuls test ($P \leq 0.05$).

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