Reducing Solid Waste Streams Specific to Soilless Horticulture

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ADDITIONAL INDEX WORDS. horticulture, soilless cultivation, environmental effects, recycling, substrate, plastics, Flanders-Belgium

SUMMARY. The solid waste streams specific to soilless horticulture (substrate slabs, propagation cubes, and plastic films to cover the soil and to wrap the substrate slabs) were determined quantitatively and qualitatively, while methods to reduce these waste streams without yield loss were evaluated in a case study applied to the Flanders region of Belgium and based on an explorative inquiry among horticulturists. Rockwool used for substrate slabs and propagation cubes was found to be by far the most important waste stream. The use of long-lived, polyurethane (PUR) slabs could reduce the total slab waste stream by $\approx 90\%$. Moreover, if substrate blocks are used instead of slabs, this reduction could even increase to 95%. The introduction of new cultivation techniques could further reduce the required volume of substrate slabs. Rockwool propagation cubes could be successfully replaced with peat pots that can be composted after 1 year of use. The reuse of plastic films to cover the soil or to wrap the substrate slabs cannot be considered because of the danger of plant diseases. Due to the susceptibility of these films to contamination, they cannot yet be recycled on a large

scale. The use of thinner films and the cultivation on profiled concrete floors were found to allow drastic reductions (of up to 80%) of the quantity of plastics used.

Since the beginning of the 1980s, soilless horticulture has become a more and more common practice in commercial greenhouses. As an example, Fig. 1 gives a scheme of some typical equipment and dimensions. Apart from its obvious technical advantages, soilless cultivation also offers the possibility to solve some ecological problems, mainly because soil disinfection with, for instance, methyl bromide, was no longer necessary. Yet, soilless horticulture has some negative environmental effects, some of which are inherent to all kinds of protected plant cultivation. Tognoni and Serra (1994) calculated that $>40\%$ of the total yearly plastic film consumption in Europe is used to clad Italian and Spanish greenhouses. Gouin (1991), Bartok (1992), Roberts and Swanekamp (1992), and Kasrawi et al. (1994) investigated the environmental impact of greenhouse, tunnel cladding, and mulching plastics. The use of fertilizers and pesticides, the emission of gases and contaminants, and the visual impact are other environmental problems caused by all greenhouse operations (Mugnozza, 1995).

One of the most obvious environmental problems specific to soilless horticulture is the use of $\approx 20\%$ excess nutrient solution, resulting in the yearly disposal of $\approx 2000 \text{ m}^3$ of nutrient solu-

tion and $\approx 5 \text{ t}$ of fertilizers per ha (Benoit and Ceustermans, 1989). Many authors, including Bradley and Segal (1990), Vernooij (1991), Biernbaum (1992), Guillaumin (1992), Van Os (1994), and Jeannequin and Fabre (1995), have studied the possibilities of reducing this waste stream by recirculating the nutrient solution.

Of course, substrate slabs, which consist primarily of rockwool, and the films in which they are wrapped form an important waste stream emerging from soilless horticulture. Benoit and Ceustermans (1989), Gamliel et al. (1989), and Bradley and Segal (1990) described attempts to decrease this waste stream by replacing the rockwool slabs with biodegradable substrates or with other inert substrate materials that can be reused or recycled. Most of these alternative materials require specific cultivation techniques, while most of the biodegradable substrates require special arrangements for pH and nutrient supply control, since they can exchange ions and protons with the nutrient solution. As a consequence, these alternative substrate materials are not yet widely used in commercial greenhouses.

Other waste streams that are typical for soilless production systems are plastic films for covering the soil (mulches) and propagation cubes. To our knowledge, these waste streams

Fig. 1. Typical system components used in soilless horticulture: (left) system with gutters and (right) system without gutters.

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have not received specific attention in literature.

Sustainability has become a major concern in our society. This includes minimizing the environmental impact of any kind of human activity and, thus, also of horticulture. With respect to waste streams, the best way to achieve this goal is prevention. But even if a clean technology can be found at an acceptable economic cost, not all waste can be prevented. In that case, a useful application should be found for the waste materials. In order of descending priority, these applications can be reuse (using the same product possibly after a nondestructive treatment), closed-loop recycling (using the waste material as the raw material for making the same product), open-loop recycling (using the waste material as the raw material for making another product that cannot be used for the same purpose), or use as an energy source. If none of the above can be applied to the waste material under investigation, only then can landfilling be considered.

Objective

In this paper, the solid waste streams specific to soilless horticulture (substrate slabs, propagation cubes, and plastic mulches and wrappings) and the possibilities to reduce them are assessed. Methods for reducing and recycling waste materials without damage to the viability of the horticultural sector is discussed. A case study applied to Flemish horticulture and based on an explorative inquiry in this sector is described.

Procedures

This case study was restricted to soilless horticulture in Flanders, the northern region of Belgium, adjacent to The Netherlands. Because of common language and interests, information is readily exchanged between growers and extension workers from Flanders and The Netherlands, so cultivation techniques in both regions are almost the same.

The total heated greenhouse surface area in Flanders is ≈ 1600 ha (Nationaal Instituut voor de Statistiek, 1995). About 470 ha of these are used for soilless horticulture, namely 54 ha for ornamental plant production and 416 ha for vegetable production, mainly for tomatoes (365 ha), peppers, cucumbers, and eggplants.

Information about the quantita-

tive and qualitative aspects of the waste streams emerging from soilless horticulture was gathered by organizing an anonymous, explorative (orientating) inquiry among a restricted number of horticulturists growing repeatedly harvested vegetables, all of them being members of a professional study group and highly concerned with environmental issues in horticultural practice.

The first part of the inquiry contained questions about the type of horticultural enterprise. To this end, the growers were asked to estimate the surface area planted to each crop and to specify the cultivation system used. Distinction was made between 1) wrapped substrate slabs on plastic film, 2) wrapped slabs in gutters, 3) wrapped slabs in containers, 4) nutrient film technique (NFT), and 5) others (to be specified). Another question concerned the way in which the nutrient solution was administered.

The second part of the inquiry contained questions that allowed the authors to define the waste streams quantitatively and qualitatively. At this stage, no distinction was made between waste streams that are specific to soilless horticulture and those that are not. The cultivation equipment and materials considered were plastic films used as mulches or wrappings, substrate slabs, packing materials used for the transportation of the slabs, trickle irrigation tubes, NFT gutters, containers, cords, and organic materials (plants). For each of these materials, the grower was asked to specify the crops for which they were used and the materials used [plastic (to be specified), rockwool, paper or cardboard, or other (to be specified)]—the quantity used, the period of the year when disposal occurs (i.e., continuously, spring, summer, fall, or winter)—and the lifetime (number of years). The grower was also asked whether he expected a decrease or an increase of the used quantities. Finally, the grower was invited to indicate the method of disposal and the accompanying costs for each of the above mentioned materials and equipment.

Combining the results of this inquiry and the data about the total surface area used for soilless horticulture allowed the authors to estimate the total solid waste stream from this sector as well as the possible reductions that can be obtained by using other materials or cultivation techniques that are already in use or described in literature.

Results and discussion

INQUIRY

The 12 respondents to the explorative inquiry cultivated 11.6 ha (only soilless crops were taken into account), of which 90.5% was used for producing tomatoes, 6.9% for cucumbers, and 2.6% for eggplants. All growers had tomato cultivation as their main production. It was found that mainly three techniques for soilless cultivation were used: wrapped substrate slabs in gutters were by far the most popular (52%), while wrapped slabs put directly on a plastic mulch and in containers were used on 28% and 20%, respectively, of the total surface area. No relation between these systems and the type of crop could be found. As a consequence, distinction between the several crop types could be omitted from this study.

The growers reported the following solid waste streams as the most important ones (in order): substrate slabs, propagation cubes, plastic mulches, plastic wrappings, cords to guide the plants, trickle irrigation tubes, organic material (plants), plastic packing materials for fertilizers and phytopharmaceutical products, gutters and containers, paper and cardboard, and greenhouse cladding materials.

As already stated, only the waste streams specific to soilless cultivation were considered. Furthermore, gutters and containers were not treated in this study because the results of the inquiry showed that they have a lifetime >10 years. As a result, only the waste streams of substrate slabs, propagation cubes, plastic mulches, and plastic wrappings were considered.

In Table 1, these waste streams are listed with the materials from which they are made, their typical dimensions, and the yearly released quantities per hectare and for the Flanders region. Substrate slabs represent the most important waste stream resulting from soilless horticulture. They are responsible for $\approx 75\%$ of the yearly total solid waste stream. From the inquiry it was found that 85% of the used slabs were made of rockwool, while 15% were made of recycled polyurethane (PUR). From the inquiry it was also found that $\approx 75\%$ of the growers used their rockwool slabs during one year, while 25% used them during 2 successive years without steaming (needed to prevent the spreading of plant diseases

in the case of reuse after 1 year). From their study, Goethals and Viaene (1994), however, found that only 15% of the Flemish horticulturists use their rockwool slabs twice. The higher values found here are to be explained by the recent economical problems of the Flemish horticultural sector. As a consequence, an increasing number of growers use their slabs more than once, even without steaming. For this study the more representative values found by Goethals and Viaene (1994) were used. The inquiry pointed out that, in most cases, old rockwool slabs are landfilled since recycling them is economically not advantageous under Flemish conditions. In the Netherlands, however, where landfilling of the rockwool slabs is forbidden, all rockwool slabs are recycled.

From Table 1 it follows that propagation cubes are the second most important solid waste stream (13% of the total). They are all made of rockwool and used for only 1 year.

Plastic films to cover the soil and to wrap the substrate slabs represent $\approx 8.6\%$ and 3.4% , respectively, of the total stream of solid wastes that are specific to soilless horticulture. Both kinds of films were found to be made of low-density polyethylene (LDPE). Slab wrappings are removed every year for steaming or for disposal. Mulches, on the contrary, were found to be used for 1 (75%) or 2 (25%) years, although reuse is not advisable for sanitary reasons (spreading of plant diseases). Based on Table 1, it can be concluded that they have an overlap of $\approx 10\%$. Since their role is not only to prevent weed growth between the plants, but also to reflect as much light as possible, these films are always white.

Plastic films used for packing the substrate slabs during transport are not mentioned in Table 1, since it was not possible to obtain quantitative data for them. Mostly, these films are transparent and they are much less dirty

than the mulches and wrappings. As a consequence they can be recycled more easily; main problem is the logistical problems involved (for instance the selective collection of these packing materials).

All these materials were found to be released during fall. Only 14% of the substrate slabs and 25% of the mulches are disposed of during summer. This is the simple consequence of the fact that most growers empty their greenhouse just before winter, when the heating costs are highest and natural light levels are very low. For recycling purposes, the fact that a high amount of waste material becomes available in a short time period is to be considered an advantage, since it facilitates the selective collection (by the waste management company) or delivery (by the growers) of the slabs, cubes, and plastic films.

PREVENTION AND REUSE

As already stated, the first concern in trying to reduce the negative effects of soilless horticulture on the environment is to prevent waste streams from being formed or at least reduce them. Ways to do so and possibilities to reuse or recycle solid waste materials, preferably within the horticultural sector, were considered. It is not sufficient to look at whether other (sustainable) materials can be used, but also whether other (sustainable) cultivation techniques can allow these goals to be reached. From the previous discussion it can be concluded, together with Lataster et al. (1993) and Van Os (1994), that a cultivation system is sustainable if it uses materials and substrates having a long lifetime (at least 4 years), that can easily be steamed to prevent the propagation of plant diseases, thus allowing reuse of the materials or substrates, or that give rise to small or negligible amounts of waste.

SUBSTRATE MATERIALS. As already stated, rockwool slabs, currently very

popular, can be reused. Because $\approx 25\%$ of the slabs get damaged (breaking, etc.) during the handling and steaming of the 1-year slabs, most Flemish horticulturists—unlike their Dutch colleagues facing other economical and legislative constraints—prefer to use new slabs every year. Used rockwool slabs can be recycled. In the production process of new slabs, only 15% of recycled rockwool can be used. The other 85% can be used in the production of insulating materials. As many other materials can be used to this end, most used rockwool slabs are simply landfilled in Belgium.

Use of other materials to make long-lived slabs might contribute to the reduction of slab waste streams. PUR slabs are made of recycled polyurethane waste from furniture and other industries. They can easily be steamed and reused for ≥ 10 years without loss of production capacity (Benoit and Ceustermans, 1989). After 10 years, they can be recycled into new slabs or into insulating materials, which can be used as building materials. Based on the values of Table 1, it is calculated that, if all 1- or 2-year rockwool slabs are replaced with PUR slabs, the total yearly amount of substrate slabs waste would be reduced by $\approx 90\%$. Costs for landfilling slabs ($\approx \$0.3/1\text{-m slab}$) are about twice the costs for steaming the PUR slabs, while the steamed PUR slabs give the same or even higher yields than new PUR or rockwool slabs (Benoit and Ceustermans, 1989). From an economic point of view this implies that the 30% higher investment costs of these slabs ($\approx \$2.6$ and $\$2.0$ for PUR and rockwool slabs, respectively) are more than compensated for by their longer lifetime.

During the last few years, other sustainable materials, such as expanded clay, pumice, and perlite, have been studied with respect to their use as substrate materials. These substrates have a lifetime of ≈ 5 years and can

Table 1. Characterization of waste streams from soilless horticulture in Flanders.

Waste stream	Material	Dimensions (mm)	Quantity used/ha	Yearly disposal (ton)/	
				ha	Flanders
Substrate slabs	Rockwool	1,000 × 150 × 75	10,000	6.25	2210
	PUR	1,000 × 170 × 50	10,000	0.68	42
Propagation cubes	Rockwool	100 × 100 × 65	25,000	0.98	408
Mulches	LDPE	0.07	11,000 m ²	0.63	262
Wrappings	LDPE	0.07	5,000 m ²	0.32	133
Total					3055

easily be steamed. Gunnlaugsson and Adalsteinsson (1995) demonstrated that tomatoes, peppers, paprikas, and cucumbers can be grown successfully and economically on pumice substrate. Biodegradable substrate materials are often considered the most sustainable materials, since they can be composted after 1 year of use. It should be considered, however, that each hectare of soilless horticulture for repeatedly harvested vegetables (tomatoes, peppers, cucumbers, etc.) gives rise to 30 tons of biodegradable material. A decisive answer to the question as to which material is the most environmentally friendly (rockwool, PUR, biodegradable materials, etc.) can only be given by means of a life-cycle analysis.

The introduction of new cultivation techniques could further decrease the amount of substrate materials to be used. One of these possibilities is to grow two rows of plants on the same substrate slab (Benoit and Ceustermans, 1994; Lataster et al., 1993). A scheme of this system is given in Fig. 2. In this case, the plants are no longer guided vertically but rather in a V-configuration. Although the substrate volume per plant reduces to 50%, so that based on the results of Ismail et al. (1993) a decrease of the yield could be expected, Benoit and Ceustermans (1994) found statistically identical yields for cherry tomatoes grown with the V-system and with the

classic system. Slabs used with the V-system have often a width of 20 cm instead of 17 cm because of ergonomic reasons. This implies that waste stream reductions of $\approx 50\%$ should be considered to be the maximum that can be achieved by means of this system, while 40% seems to be a more realistic value.

Research from Benoit and Ceustermans (1995) showed that these reductions can be increased even more, without yield losses, by using substrate blocks with dimensions $20 \times 10 \times 6.5$ cm instead of slabs. Use of such blocks, on which one plant is grown and which are laid in a gutter, gives rise to a yearly substrate waste stream of only 0.26 ton/ha. This is a reduction of 62% and 95% with respect to the culture on conventional PUR slabs and rockwool slabs, respectively. In this case the gutters have the supplemental advantage of allowing to recirculate the nutrient solution relatively easily. On the other hand, they give rise to a new solid waste stream. To keep this latter effect as small as possible, the gutters should be made of sustainable materials with a lifetime of at least 10 years. Aluminum, coated steel, polyethylene (PE), or polypropylene (PP) could be used. The production of steel and especially aluminum, however, requires large amounts of energy. They are also more expensive than PE and PP, but their value at the end of their useful life is also higher. Most present gutters are made of PP with a lifetime of 5 to 6 years. Here again, a life cycle analysis should point out which material is

most environmentally friendly.

PROPAGATION CUBES. As pointed out by the inquiry, all propagation cubes are made of rockwool, giving rise to a supplemental yearly waste stream of >400 ton/year. Benoit (1991) studied the possibilities of pressed peat pots as an alternative. Using peat pots allows complete elimination of the rockwool waste stream. Apart from this ecological advantage, they also offer ergonomic and economic advantages; the biodegradable peat pots can be disposed of together with the plants, while their inexpensiveness results in yearly savings of $\approx \$5,000/\text{ha}$ for a plant density of 25,000/ha.

MULCHES. Plant parts stick to the mulches; therefore, the reuse of these films increases the risk of plant diseases and lowers the light reflectance. As a consequence, most growers prefer to renew the plastic every year. A possible solution could be found in the use of plastic films that can be steamed. Commercially available, steamable LDPE films, however, are five times more expensive than the traditionally used LDPE mulches. Furthermore, these films are more rigid, so that they are more difficult to treat. Instead of LDPE, PP could be used since it can be steamed without problems and used for ≈ 4 years. However, the higher price and lower flexibility of PP with respect to LDPE (it may result in more cracks and, thus, more weed growth), it is not very likely that PP will replace the LDPE films in the next few years. Hence, reuse of mulching plastics cannot be considered a solution to the reduction of the waste streams from soilless horticulture. On the long term, the risk of spreading plant diseases in monocultural systems could be decreased by, for instance, the use of resistant or tolerant plant varieties. In that case, plastics could possibly be reused without major sanitary risks.

Reducing the plastic waste stream can also be obtained by using thinner films. Estimates of the effect that could be obtained by means of this method range between 0% and 10% (Project-groep Kunststofafval, 1991). In fact, the use of thinner films will also result in more mechanical damage to the films, resulting in more weed growth and possibly in unsafe working conditions. This problem, however, could be solved by using two thin films. The lower film can be made of recycled

Fig. 2. The conventional system with two slabs and the V-system.

LDPE and could be used for several years, while only the upper film has to be replaced every year. Instead of using a single 0.07-mm LDPE film, which is replaced every year, two 0.05-mm LDPE films with lifetimes of 5 years and 1 year, respectively, could be used. This method would result in a reduction of the yearly mulch waste stream of $\approx 14\%$. Apart from the resulting waste stream reduction, this method has still another advantage. Theoretically, the lower film is not contaminated with plant parts, which highly facilitates the recycling process of these films, although soil particles that stick to the lower surface of the film can still cause problems.

Contamination of the mulches with plant parts, chemicals, and other materials makes recycling very difficult, resulting in the necessity of a thorough cleaning before recycling. Moreover, their exposure to ultraviolet (UV) radiation modifies the molecular structure in an unpredictable manner, creating erratic plastic flow during reprocessing. Recently, however, a Dutch firm developed a technique to take mulches out of the greenhouse, recycle them, and use the recycled material for the production of new mulches. The light reflectance of these films is somewhat lower than new films, but is still $>80\%$. The actual capacity, however, does not yet allow for the large-scale recycling of mulches.

The application of UV degradable or biodegradable films is still in the experimental phase. UV-degradable films are easily degraded by UV radiation. As a consequence, they can only be used in greenhouses covered with claddings that are not transparent to UV. On the other hand, after the growing season, the films are removed from the greenhouse and piled up, which stops the UV degradation. Besides these practical problems, these films have still another disadvantage—the films are not degraded but only reduced to fragments that remain unaltered in the soil (Gielis, 1992). The use of biodegradable films seems to be somewhat more promising. Several firms are developing films that biodegrade after 1 year of use, i.e., after the culture period. Since these developments are proprietary, the possibilities these materials will offer are not yet publicly known (Gielis, 1992). Nevertheless, the price of these plastics will probably be much higher than the

price of the conventional plastic films. As a consequence, at the present state, UV and biodegradable plastics cannot be considered a viable alternative to the contemporary mulching materials.

The use of profiled concrete floors could eliminate the necessity of mulching. Concrete can easily be steamed and has a lifetime that is much longer than 10 years. On the other hand, $\approx 1000 \text{ m}^3$ of concrete is needed per hectare, giving rise to a new and large waste stream, while the system reduces the flexibility of the greenhouse.

WRAPPING FILMS. For the same reasons as discussed for the mulching films, reuse of wrapping films is not advisable. However, to reduce or eliminate the waste streams of wrapping films, several possibilities are open. Slabs are wrapped entirely during the first year. After 1 year, the steamed slabs need only to be covered. That means that the use of long-lived slabs also results in a reduction of the plastics waste stream. For a slab lifetime of 10 years, the consequent reduction of wrapping plastic can be calculated to be at least 30% when compared to complete wrapping every year.

Thinner plastic films could be used. The application of 0.05-mm films instead of the common 0.07-mm films can further decrease the yearly wrapping plastic waste stream by $\approx 28\%$. In this way, the combined use of long-lived (10 years) slabs and thinner plastic films would decrease the actual waste stream of wrapping foil by $\approx 50\%$. As far as UV and biodegradable plastics are concerned, the problems mentioned for mulches will also be found for wrapping films.

Modifications of the cultivation technique could contribute considerably to the minimization of the plastic waste streams emerging from soilless horticulture. In case the substrate slabs are laid in gutters, the need for wrapping films can be highly reduced. Cultivation on profiled (as to allow recirculation of the nutrient solution) concrete floors has the additional advantage that mulching is no longer needed. In this system, described in, for instance, Lataster et al. (1993), substrate blocks are put directly on the concrete floor and need only to be covered with an LDPE film. In this way, only $\approx 3500 \text{ m}^2$ plastic film is needed per hectare. Furthermore, it can be expected that this film will not be as dirty at the end of the growing

season, so that it could be considered more valuable for recycling.

General conclusion

From the results of the explorative inquiry, it was found that each hectare of soilless horticulture in Flanders gives rise to on average 7.3 tons of solid waste specific to soilless cultivation. About 74% consists of substrate slabs. Although reuse and recycling are technically and economically feasible and allow waste stream reductions of up to 95% without major modifications to the cultivation system, they are not widely applied. Replacement of inert propagation cubes, now responsible for 13% of the total waste stream, with biodegradable peat pots, would not only contribute to a more sustainable horticulture but also to considerable savings on production costs. Reuse, large-scale recycling, and replacement with other materials of wrapping and mulching plastics are still hampered by technical and economical problems. Using thinner films and long-lived substrate slabs that only need to be covered instead of wrapped could help to reduce these waste streams by up to 50%. Based on these ascertainments, it can be concluded that government and extension workers have an important role to play to make horticulturists aware of these possibilities and to contribute to the image of the horticultural sector.

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Growth of Tomato and Coreopsis in Response to Coir Dust in Soilless Media

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ADDITIONAL INDEX WORDS. artificial media, *Cocos nucifera* L., *Coreopsis lanceolata* L., *Lycopersicon esculentum* Mill., potting compost, solution fertilization, slow-release fertilization

SUMMARY. We examined the efficacy of coir dust (CD)—the short fibers and dust from the mesocarp of coconuts (*Cocos nucifera* L.)—as an alternative to sphagnum peat (SP) in 50 SP : 50 vermiculite (% volume) medium. Shoot dry mass of coreopsis (*Coreopsis lanceolata* L.) or 'Red Robin' tomato (*Lycopersicon esculentum* Mill.) after 5 weeks' growth in up to 50 CD : 50 vermiculite (% volume) was similar to that in 50 SP : 50 vermiculite and a commercial peat-lite (Pro-Mix BX). These growth responses depended on preplant controlled-release fertilizer (CRF) [Osmocote 17N-3.9P-10.8K at 11.5 lb/yd³ (4 kg·m⁻³)] and/or a post-transplanting weekly solution fertilization (SF) at 350 ppm (mg·L⁻¹) N from 21N-2.2P-16.6K. Compared to SP, CD had lower bulk density and cation exchange capacity (volume basis) and higher C to N ratio, pH, total porosity, and container capacity. We conclude that CD is an adequate alternative to SP in soilless container media.

Sphagnum peat (SP), a common component of soilless container media, provides high water retention, high cation exchange capacity (CEC), and buffering against pH changes (Handreck, 1993a). The level of peatland exploitation is consid-

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