Enhancing Environmental Quality in Agricultural Systems

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Abstract

Greenhouses have been extremely successful in providing abundant, cheap and high-quality produce, by using resources (water, minerals, pesticides) with a very high economic efficiency. Marginal agricultural land is being rapidly converted into protected cultivation in many (semi-arid) regions of the world, hoping to prosper both from primary and secondary activities. Water use efficiency of greenhouse production is about five times as high as field production of vegetables. However, in spite of using resources more efficiently, greenhouse areas have an enormous visual and environmental impact: diversion of limited good water resources; contamination due to pollutants released with over-abundant irrigation; production of plastic and mineral waste and biological by-products; contamination due to plant protection chemicals and emission of "greenhouse" gases (CO_2) by heating with fossil fuels in Northern countries. In addition, greenhouse production has an "image" problem: there is a general perception among European consumers that such an "industrial" production of food is non-natural and unhealthy, although in the Americas, for instance, the "cleanliness" of the production process is considered an advantage. Since, the "polluter pays" very seldom, environment-friendly production is more expensive. Therefore a large market in "eco-labels" has developed in response to consumers' misgivings and in the hope of recovering (part of) the costs through higher prices. However, there is little clarity about agricultural practices associated to each label and there are doubts about enforcement. This paper analyses advantages and draw-backs of greenhouse production, and attempts to review the items where improvement is necessary in order to ensure that greenhouse production is sustainable, yet profitable also in the future.

INTRODUCTION

Consumers in developed countries are so used to get appealing, clean looking and cheap vegetables the whole year round, that very few of them are aware that such a luxury was unthinkable just 20 years ago. This abundance is most commonly generated under shelters (protected cultivation) that, for a large fraction of the year, ensure growing conditions much better suited for crop production than open field. This is not new: the advantages of ambient modification in this respect were certainly known in ancient Rome, as Plinius (77A.D.) maintained that the emperor Tiberius could eat year-round cucumbers from plants that were withdrawn under semi-transparent shelters whenever conditions were unfavourable. Similarly, *orangeries* (buildings devoted to create growing conditions of citrus where citrus would not grow) have been built in the gardens of rich people for many centuries. What is new of the last 20 years is that year-round abundance is so cheap as to be taken for granted. This has been caused by the large-scale application of horticulture under plastic that has transformed formerly marginal agricultural land into a highly efficient and profitable crop production. The most striking example is the "explosion" of protected cultivation in the Mediterranean region: according to the FAO, from nihil in 1950 to 120 000 ha of greenhouses and tunnels in 1985, on to 200 000 in 1997 (Baudoin, 1999).

ECONOMIC WATER USE EFFICIENCY

One of the world's largest concentrations of greenhouses is in the province of Almeria (South-Eastern Spain), whose economic ranking among the Spanish provinces has grown from third from bottom to third from top, in 20 years, largely thanks to this and the associated secondary industry. Recent estimates of the fast-growing greenhouse area in the province put it at 25 000 ha, with a total production of 2.6 million ton/year of vegetables, whose value is € 1600 million (a mean of 64 000 €/ha). Value of quality-labelled tomatoes from insular Italy easily exceeds 120 000 €/ha. Some flower-crops in Dutch glasshouses gross more than 400 000 €/ha. Little wonder that other regions and countries are developing their greenhouse industry fast.

The whole agricultural sector in the Mediterranean basin is facing a decreasing amount of water resources, often coupled to an increase in their price. The ongoing economic development causes a shifting in priorities, whereby, under scarcity, water is allocated to sectors of high social priority, such as household, or economic importance, such as tourism. This tendency towards allocating water where it is most economically used, is strengthened by recent European regulations enunciating the "cost recovery" principle. That is that the price of water must reflect the real costs of provision, including environmental costs; in short the "polluter pays" principle, such as stated in the "Water framework directive" (European Parliament and Council, 2000). The combined pressure of these two factors (scarcity and price) on water resources for agriculture (which is still the largest single user by far) simply reinforces the above-mentioned tendency for "marginal" agriculture to disappear from many regions, to be replaced by cash crops, of high water use efficiency. That greenhouse production has higher water use efficiency is the consequence of at least three factors: reduced potential evaporation (less sun radiation; less wind and higher humidity); increased production (better control of pathologies; better control of climate parameters); application of advanced irrigation techniques (drip irrigation; re-use of drain water)

As Table 1 makes clear, the combined effect of these factors can increase water use efficiency by a factor up to five. Since greenhouse products, being more attractive and of more uniform quality, often sell for a higher price than field products the income produced per unit of water used has increased by even more (Table 2). Presently about 2/3 of the greenhouse area in Holland is substrate cultivation. The reason for growing on substrate is purely economical: better returns. A very recent study comparing returns of substrate and soil-grown sweet pepper in Almeria (Table 3) points to the same trend.

Substrate cultivation of course makes it rather easy to collect drain-water and re-use it (closed systems), which allows for some saving on the costs of fertilisers and water. Indeed, Dutch growers started to grow on closed systems for this purely economic reason (Ruijs & Van Os, 1991). Later, however, environmental considerations (high population density, shallow water table) have caused the government to issue regulations whereby recollection and re-use of drain water is getting increasingly compulsory. Obviously, the main point of national regulations is not water saving (not in Holland), but to prevent percolation of nutrients.

BACK-SIDE OF COIN: EMISSION, CONTAMINATION AND SOLID WASTE

Indeed, in spite of the high economic efficiency of greenhouse production (and also the very high resource use efficiency), it is beyond doubt that such an intensive growing method has a large impact on the environment. For instance, it has been recently estimated that yearly plant-protection chemicals application in Dutch greenhouses is 31 kg/ha (active component), Table 4. Application rates in Mediterranean countries are at least as high. Very little is known about the deposition and dispersion rate of sprayed plant protection chemicals. Van Os et al. (1994) have calculated that 30 to 50% leave the greenhouse through the air. This fraction applies to ventilation rates of 0.5 h^{-1} and would be higher in more ventilated greenhouses, such as in the Mediterranean region. Total fertilisers application on greenhouse tomato in Sicily is some 6 ton/ha per year, which is comparable, for instance, to the Dutch estimate of 1200 and 250 kg/ha of the elements N and P, respectively (Table 4). Nutrient uptake, however, does not exceed 500 kg/ha, so that more than 50% of the application percolates in the subsoil, a fraction that can be reduced to virtually nothing in closed soil-less systems (Table 5).

On the other hand, consumption of energy for heating in the Mediterranean is nearly negligible with respect to the 800 ton/ha·year of carbon dioxide released for heating Dutch greenhouses. Carbon dioxide equivalent to carbon fixed into the crop (about 50 ton/ha·year) is less than 200 t_{CO2}/ha·year. In addition, there is quite an amount of solid waste that is produced each year. A recent review from Cajamar in Almeria gauges the production of plastic waste for renewing the polyethylene covers (each 2-3 years) at 1.1 ton/ha·year. Mulching generates about 1 ton/ha·year of plastic waste: in Almeria, for instance, it is applied to less than 10% of the greenhouses, whereas in The Netherlands to 100%. Roughly the same penetration figures apply to energy screens/double covers (life span 5 years). Estimated production of plastic from tomato houses in Sicily is 2.9 ton/ha·year. In addition, even plastic strings used as tutoring lines generate 112 kg/ha·year of waste and polypropylene chromatic traps for insects another 50 kg/ha·year. Plastic from irrigation systems, containers, etc. is another 500 kg/ha·year.

Soilless growing systems on one hand greatly reduce contamination from chemicals and fertilisers and impact on resources (such as water), but on the other hand generate some 2 ton/ha·year of mineral (rock wool, perlite) or organic (such as peat) waste. The most common substrate in Holland is Rockwool®, that the producer is compelled to take back and recycle after the useful life. The same rule applies also in Germany, but not (yet) in the Mediterranean region. Even then, substrate goes with quite some plastic packaging. Finally, all fruit crops (and some other) produce a significant amount of non-yield biomass. For instance, that is some 250 ton/ha·year for tomatoes.

WHAT IS BEING DONE

Several approaches have been identified (and sometimes applied) to reduce waste:

- application of integrated and biological management of pests and diseases;
- reduction of chemical disinfection of the soil;
- smart scheduling of irrigation and fertilisation;
- use of closed-loop growing systems;
- improvement of climate control and use of energy saving technologies;
- routing of exhaust gases from heating through the greenhouse for CO_2 enrichment;
- use of long-life plastic film or glass as covering material;
- recycling of plastics;
- use of biodegradable mulching;
- recycling organic and mineral material.

Currently however, consistent results in terms of waste reduction have been obtained only in few countries, and only with respect to selected items, such as application of integrated pest management or cultivation in closed-loop hydroponic systems or composting of all biologic waste. In The Netherlands an agreement between government and growers requires the sector to reduce its consumption of plant protection chemicals by 20% in the next 10 years, whereas consumption of N and P must be reduced by 46 and 37%, respectively. Consumption of energy must go down by 22% (Tab. 4). In spite of the enormous research effort, in particular on this latter topic, it is far from clear how the profitability of the sector can be maintained under these targets, not to mention possibly stricter ones. Similarly, it is not clear how the greenhouse industry in several countries will adapt to the EU-enforced phasing out of some chemicals, such as methyl-bromide for soil desinfection.

Collection and recycling of plastics is increasingly been applied, though a limit is the size of the potential market for lower-grade recycled material. An EU directive demands phasing out of disposal in landfills, starting from this year. In Almeria there is a plant that burns plastic waste for energy production. Landfilling of ashes is presently allowed. The main causes for the lack of success of such schemes are:

- recycling of plastic materials is limited by costs and by the size of the potential market for recycled (lower-grade) material;
- recycling of biologic waste (non-yield biomass) requires a good collection and processing infrastructure, for a relatively low-value product;

- recycling of irrigation water (to limit both contamination and pressure on resources) is limited by costs and by quality of water resources;
- growers, or their associations, are seldom pro-active in applying waste- and emission-reducing techniques.

In order to increase consumer awareness (and willingness to pay more for environmental friendly products) labels have been introduced in many countries, to increase market potential of products resulting from more environment-friendly (but often more expensive) processes. However, there is a strong lack of indicators to identify which aspects of the production process have the largest effects on the environmental impact of greenhouse production. Similarly, there is a need of coupling unambiguously such indicators to eco-labels in order to increase consumers' awareness about the environmental impact of the products that they buy. Indeed, there is a need for an unambiguous indicator of environmental impact of waste from the various growing systems.

Regarding protected horticulture, there are a few papers (for instance, Jolliet, 1993) to evaluate several tomato crop production systems in greenhouses, heating, artificial lighting, carbonic fertilization and transport to the market. Nienhuis et al. (1996) compared soil and substrate crop with free drainage and with recirculation for round tomatoes and small-flowers in Holland; Woerden (2001) applied LCA to glasshouse horticulture to describe environmental effects of future developments in crop production systems and to compare organic and conventional horticulture. Applications of Life Cycle Analysis (LCA) to South-European protected horticulture are even scarcer, though recently Antón et al. (2002) used LCA methodology to evaluate the environmental impact of Mediterranean greenhouses. However, the results of the different studies are dependent upon a number of critical assumptions. Still there is no general agreement on which indicators should be used in greenhouse production to assess impact categories.

CONCLUSIONS

Probably the most serious effort been made to set global targets for reducing contamination and emission from protected cultivation has been the GLAMI (Glasshouse & Environment) covenant between the Dutch government and the growers' board. Each possible "environmental improvement" was given a mark and the growers were let free to choose what to do, provided they reached an agreed total. That this was a (partial) failure is attested to by the new version (that reverts to specific targets, as listed above). What happened was that the grading was highly biased towards energy-efficiency, so that the required mark was rather easily reached by a small energy saving coupled to the underlying trend of increasing production.

Another facet marred by lack of standards is environmental certification (or "ecolabelling"). Labels themselves provide a market-oriented instrument to achieve environmental goals and thereby avoid the inefficiencies associated with mandatory standards or bans. In addition, eco-labels are educational tools to inform consumers about the environmental impacts of the products and thereby induce a change in their purchasing behaviour. Labels increase attractiveness (and market potential) of products, by guaranteeing an environmental friendly production process. However, it is often left to the fantasy of the consumer to guess which steps of the process are taken into account and which not. Most eco-labelling schemes differ in their design; some of them are based on a single criterion (f.i. chemical residuals on the product); some are based on the analysis of the production process; a very few others on the LCA analysis of the product-on-the-shelf, that is taking into account also transport, packaging and conservation (Jungbluth et al., 2000).

To decrease significantly environmental impact of greenhouse cultivation will require quite some capital investment into new cropping systems, and will entail larger production costs. Indeed, it is expected that in Holland a large fraction of present holdings will not be able to survive under the new rules. In particular, it is forecast that consolidation will cause average size of holdings to grow from 1 ha (1990) to 4 ha (2010). Present trend confirms this forecast (AgriHolland, 2003). In addition, it is calculated that survival of 40% of the present holdings will depend on incomplete enforcement of the rules (Hietbrink et al., 1999). Nevertheless (but this depends on the hypotheses about enforcement), people expect the actual trend (stability of total surface, growth of ornamentals vs. vegetables) to set forth.

What is common to all countries is that the price structure both of inputs and of penalties does not give reason for a financial "optimisation": pollute and pay is still the cheapest option. For instance, the very high marginal prices of water in Tab. 2 and a demonstrated inelasticity of demand of irrigation water (OECD, 1999) give ground to the political consensus that regulations are a better option than substantially modify the pricing system. There is, however, the risk of "unintended consequences", whereby regulations are often announced (or enhanced) that afterwards prove (or are perceived) to threaten unacceptably the profitability of a sector. In short, there is a need for the overhead to better foresee consequences and for actors to determine the "optimal" management within the legislative and economic framework.

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Tables

Table 1. Litres of irrigation water used for one kg of product, in various places and various growing systems (Stanhill, 1980; Castilla and Fereres, 1990; KWIN, 2000; Pérez et al., 2002).

	Tomato	Sweet pepper
Israel & Almeria, field	60	300
Almeria, unheated plastic (1990)	40	
Israel, unheated glass	30	
Almeria, improved unheated plastic (2000)	27	74
Holland, climate-controlled glass with CO_2 injection	22	
Holland, as above, with re-use of drain water	15	

Table 2. Average productivity (income per unit applied) of irrigation water in open field and greenhouse vegetable production in the region of Almeria (column 2); “social efficiency” (mean water use for man-hour), column 3; and break-even price of water, that is the price that would cancel out the net income of growers (Colino and Martinez, 2002).

	Productivity €/m^3	m^3/man-hour	Break-even price of water, €/m^3
Open field vegetables	1.60	11.5	0.9
Greenhouse vegetables	6.12	4.2	3.7

Table 3. Profitability of the cultivation of sweet pepper (on soil and on substrate) in greenhouse in the province of Almeria (Caballero and de Miguel, 2002).

	Soil-grown	Substrate
Production (kg/ha)	105 000	160 000
Price (€/kg)	0.53	0.66
Gross income (€/ha)	56000	106000
Variable costs (€/ha)	31000	38000
Of which:		
• Water	1100	1600
• Energy		1500
• Fertilisers	2800	3400
• Phytochemicals & desinfection	7400	5200
• Manpower	14000	20000
Fixed cost (€/ha)	13000	27000
Capital costs (€/ha)	4000	8000
Break-even price (€/kg)	0.46	0.46
Net income (€/ha)	8000	33000

Table 4. Mean yearly use of energy, fertilisers and pesticides per sector of Dutch glass-house industry. Ruijs et al., 2000. 16000 GJ/ha are equivalent to some 45 $m^3{}_{gas}/m^2$ or some 40 l_{oil}/m^2. The last column gives the targets for reduction of application for the year 2010 that have been agreed with the government.

yearly use of…	Units	Cut flowers	Pot plants	Veget.	Mean	Target 2010 %
Energy	GJ/ha	15551	15251	13054	14541	-22
N	kg/ha	910	675	1670	1159	-46
P	kg/ha	173	141	367	242	-38
Fungicides	kg/ha	21.3	16.6	13.7	17.6	-13
Pesticides	kg/ha	11.3	5.2	5.9	8.2	-17
other …cides	kg/ha	7.0	2.5	4.2	5.1	-57
Total plant protection	$kg_{active\ matter}/ha$	39.6	24.3	23.7	30.8	-20

Table 5. Mean discharge (litres drain or percolation generated per gross € product) of the main Dutch greenhouse cultivations (Stanghellini et al., 2001)

	Soil-grown	Soilles
Gypsophilia	8.6	
Radish	7.6	
Chrysantemum	6.8	
Alstromeria	5.9	4.2
Freesia	5.4	
Carnation	4.9	
Rose & Gerbera	4.6	2.4
Lilium	2.9	
Strawberries		2.4
Sweet pepper; Aubergine & Ficus		2
Anthurium		1.5
Begonia		1.2
Tomato		1
Dracaena		0.7
Orchid		0