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ENGINEERING ASPECTS OF SUSTAINABLE GREENHOUSE PRODUCTION IN THE NETHERLANDS

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1. Greenhouse production in the Netherlands

Greenhouse production in the Netherlands has certainly risen in importance over the years. Traditionally, vegetables such as tomatoes, cucumbers and lettuce were the most important crops, but they have been increasingly superseded by floricultural products, in particular cut flowers and pot plants.
In 1990, the area devoted to greenhouse horticulture in the Netherlands was about 9600 ha (Kwin, 1991). Of this, 4450 ha was used for vegetables, 3950 ha for cut flowers and 1200 ha for pot plants.
The growth of greenhouse production is well reflected in the way production value has increased (Sectornota, 1992). Between 1980-1990 this grew from NLG 3.9 billion to over NLG 7 billion. Growth was stronger in this sector than growth in other agricultural sectors. Consequently the share of greenhouse production in the total production value of all agricultural activities increased from 14 to 19% during the same period. This production was realized on just 0.5% of the total acreage available for agriculture in the Netherlands!
Light is the limiting factor in greenhouse production. Therefore greenhouses are mainly situated in coastal areas, where light conditions are relatively favourable. Well-known locations are Aalsmeer and Westland. Westland is situated in Zuid-Holland, a province that houses no less than 62% of Dutch greenhouse acreage.

Approximately 10,000 growers specialize in greenhouse production. The overall investments (exclusive of site) vary from NLG 100/m^2 for lettuce to NLG 250/m^2 for pot plants. The average acreage per company devoted to vegetables is approximately 8000 m^2 and to ornamentals approximately 5000 m^2. New companies often have an acreage of more than 30,000 m^2.
Because of these developments in production, greenhouse operations offer employment to increasing numbers of people. Fifty percent of the companies mobilize not only family members, but non-family members too. In small companies the contribution of family members is relatively high and even in big companies they account for an average of 25% of the total labour force. This ratio has not changed much in the eighties and therefore greenhouse production is still considered small scale industry.

Most greenhouse crops are exported to EC countries. About 12% of agricultural export value originates in greenhouses. The export value of greenhouse crops has increased from NLG 3.4 billion in 1980 to NLG 6.5 billion in 1990, an increase of 85%. This percentage is higher than the average percentage for agriculture as a whole (58%).
According to experts, greenhouse production in the Netherlands is economically strong with considerable growth potential (Alleblas en Rodewijk, 1992).

2. Production systems

2.1 Greenhouse construction

Two construction principles are used for glass-covered greenhouses, namely the so-called wide span greenhouse (Fig. 1) and the Venlo-greenhouse (Fig.2).
A wide span house is traditional in construction, i.e. with steel (or aluminium) purlins attached to steel trusses. These purlins together with the steel (or aluminium) gutter support the glazing bars on which the glass or other light transmitting material is placed. The span width is standardized for a ratch measurement of 0.80 m, namely 6.40, 8.00, 9.60 and 12.80 m.
A characteristic feature of the wide span house is the greater number of panes on the top of one another from gutter to ridge and a continuous ventilation-window over the whole length of the roof.
The Venlo-house is, however, the most popular type of construction at present. About 80% of newly built greenhouses in the Netherlands are of the Venlo-type. Here glass panes are placed in glazing bars. These bars and the glass panes rest against one another according to the principle of the three joint truss on top of supporting gutters. The standard span width is 3.20 m. In most cases two roofs are joined together to a span width of 6.40 m. There is only one glass pane with a height of 1.65 m on the roof surface. The width of the glass panes are 1.00, 1.125 and 1.25 m.

The construction of greenhouses in the Netherlands has always been considerably influenced by the need for more natural light, as 1% more light means roughly a 1% higher yield (Buitelaar, 1984). In order to obtain a sufficiently high crop production level even during periods of the year when light level is low, it has become necessary to design greenhouses with better light transmission. Developments have been made to increase the light coming through the cover by reducing the shading parts, i.e the construction, and by the continued use of single glazing which is the traditional material.
Research carried out at IMAG-DLO (Waaijenberg, 1989) has resulted in the following improvements being made to Venlo-houses:
a. use of 1.00 m wide glass instead of 0.75 m (fewer bars);
b. reduction in gutter width from 0.22 to approximately 0.17 m;
c. increase in truss spacing from 3 to 4 m (fewer trusses).
These three measures increased the total transmission of diffuse light from 65% to 72% in Venlo-houses in the wavelength 400-700 nm. To get an even better result, a Venlo-house with a span width of 4 m recently has been developed.

In the Netherlands film-covered constructions are becoming more and more popular for forcing crops grown in the open air or offering protection against night frost and hail. Because of their price, film-covered constructions are very well suited for these purposes. The constructions vary from rather simple sheds to designs that roughly compete with traditional greenhouses made of glass.
Despite this, film-covered constructions are not used much for growing greenhouse crops in the Netherlands: the light transmittance leaves a great deal to be desired, as does the service life of the films.
The Netherlands will only become a big market for film-covered greenhouses if new types are developed. Therefore IMAG-DLO is promoting co-operation with more southernly situated countries such as Spain, Italy and Greece: countries where film-covered greenhouses already play a prominent role.
In co-operation with Greece, IMAG-DLO is working out a research proposal on the

material properties of the cover and the relation this has with the climate inside the greenhouse. The strength of film-covered greenhouses is an aspect that also requires further attention.
A cable supported greenhouse has also been designed, allowing a very high transmission of diffuse light. Working in close co-operation with Dutch industry, IMAG-DLO has been able to produce a prototype of this.

2.2 Cultivation methods

The sector uses intensive cultivation systems. As a result, the amount of fertilizer applied is high, as are subsequent emissions to the soil and groundwater. Due to the heavy physical concentration of these companies in particular areas, these unwanted effects are more obvious. Efforts are being made to reduce such emissions. One possibility is to separate the root zone of crops from the sub-soil. In this way the penetration of nutrient water containing fertilizers into ground and surface water is prevented.
There are various ways to separate the root zone from the sub-soil. The most common way is to apply substrates such as rockwool, peat and clay granulates, in combination with drip irrigation (Van Os *et al.*, 1991a). Propagation in a nutrient water film (NFT) or frequently moistening the roots with nutrient solution (aeroponics) could also be considered.
Vegetable crops with a long growing season and a planting density of two to five plants per m^2 (tomatoes, cucumber, sweet pepper, aubergines) or crops where space utilization can be increased (roses, carnations), offer the best perspectives for soilless growing methods. Present estimates indicate that soilless growing methods are being used for cultivating 2500 ha of vegetables and 550 ha of floriculture.
Changes to soilless cultures is stagnating for crops harvested in one operation (lettuce, crisphead lettuce, chrysanthemums), because the economic prospects are insufficient (Van Os *et al.*, 1991b).

Three important issues have to be taken into consideration in recycling the surplus nutrient solution:

a. the concentration of the relevant ions in the circulating nutrient solution will vary, as the crop will consume water with a selection of various ions. Therefore the nutrient solution has to be adjusted depending on the results of frequent analyses;
b. the recycling solution passes the root zone frequently and will therefore be a very good carrier and spreader of diseases which may be prevelant elsewhere in the system. To prevent this, the circulating water has to be disinfected with adequate frequency;
c. every fresh water supply contains some salts; these are hardly taken up by the crop at all. In the long term this can mean salination of the nutrient solution and then after some time complete substitution of the nutrient solution in the system becomes necessary. The quality of the refill water, therefore, is of crucial importance, otherwise salination of the root zone would poison the crop.

As a consequence, closed loop watering systems require that the composition of the nutrient solution be monitored. The various ion concentrations relevant to root uptake and to the salination of the solution are needed for the proper control of the closed loop watering system. This has to replace monitoring the electrical conductivity of the solution as a measure for total ion concentration.

Measuring gas components, especially the oxygen content, is also of great importance as is the sensing of disease germs. This would restrict disinfection of the solution to periods in which problems could really occur. The alternative is disinfecting continuously at high costs as an insurance against problems. Research is particularly oriented towards the application of sensors and the control of the supply system (Gieling *et al.*, 1991).
One also has to keep in mind that there are also disadvantages to growing on substrate. Temporarily an increasing amount of waste in the shape of synthetic and substrate materials has to be taken for granted, because not all of the recycling possibilities can be made use of yet. Aeroponics are not finding acceptance on account of their vulnerability. Growers who stick to growing in soil use less synthetic materials, but they have more trouble in controlling direct flows to ground and surface water.

3. Crop protection

Almost 60% of the pesticides in greenhouse production are used for soil disinfection and 21% for fungicides and insecticides. What is also noteworthy is the considerable amount of chemicals used to disinfect the greenhouse and to clean the glass before a new crop is planted (10%).
To reduce dependence on chemicals for crop protection and to reduce chemical consumption, the Dutch government has drafted a Multi Year Crop Protection Plan (MJP-G, 1991). The main aim is to reduce pesticide consumption in agriculture by 35% in 1995 and by more than 50% in 2000 compared to the average amount consumed between 1984-1988. These percentages are even higher for greenhouse production: 50% in 1995 and 65% in 2000. By the turn of the century the use of soil disinfection products should have been decreased by 75%.

The greenhouse production sector is working hard to achieve these targets. The introduction of biological control has led to a considerable reduction in the use of insecticides in many vegetable crops. The application of biological control for ornamentals is only slowly gaining ground because exporting to some countries is only possible when the products are absolutely free of insects, the so-called zero toleration. For an effective application of biological control, however, a certain minimum level of insects must always be accepted.
Growing crops on substrate can also help to achieve the government aims, as soil disinfection and weed control are no longer necessary for crops grown on substrate. Attention has also been paid to the purification of waste water polluted by pesticides. It was found that complete purification could be achieved by means of chemical treatment and filtration (Maaskant *et al.*, 1992). To reduce emissions of pesticides to the air, for instance after a space treatment with Low Volume Mist, various purification systems were examined. The results did not live up to expectations (Van Os *et al.*, 1993).

Realization of the Multi Year Crop Protection Plan depends to a large extent on current and new agricultural research. According to this plan, approximately NLG 50 million were available for crop protection research at Wageningen Agricultural University, the DLO-institutes and the research stations in 1989. As yet this budget will be maintained at the same level. Moreover additional funds will become available for a number of priorities, including improved spraying techniques with low emission. Within this framework, IMAG-DLO in co-operation with other research institutions, is working on the development of measuring methods and on the development of basic principles of totally new spraying techniques for greenhouse crops. The research is aimed primarily at crops which are grown on transportable benches, but will be expanded in a later stage to tomatoes, cucumbers and chrysanthemums.

4. Energy savings and energy efficiency

In greenhouse horticulture energy savings remain a high priority. It is important that in the future we are able to grow products in a way which is not only competitive but also acceptable to the society in which we live. Greenhouse cultivation uses 80% of Dutch agricultures total energy requirements. The most important fossil energy source is natural gas (98% natural gas and 2% electricity); 4 billion m^3 each year.
Energy costs in 1989 for the glasshouse horticultural sector were NLG 667 million. Of this amount 285 million was spent in growing vegetables under glass. In 1989 the average gas bill for each grower was more than NLG 91,000. In glasshouse vegetable cultivation, energy costs make up 16% of the total production costs. For ornamentals this figure is 11%.

Energy consumption can be calculated per product unit and per area unit (absolute). Research at IMAG-DLO is mainly focused on reducing absolute energy consumption because of the direct relation with the CO_2-emission. Absolute energy consumption is determined by the lay-out and insulating properties of the greenhouse itself and by the way the greenhouse is used as a production tool. The quality of the products as well as yield are controlled by heating and ventilation. To make sure that energy is used as economical as possible, research is being carried out into a new way of controlling the production process, which continually weigh the costs against the yield that can be expected. This results in an optimal strategy for the setpoints, i.e. the levels of the greenhouse climate factors (Bot, 1992). Energy saving is not the main objective: the energy price determines the profitability of a higher or lower input of energy.
Energy saving does play an important role in the research to improve the insulation of the greenhouse cover. Research in the eighties showed the thermal screen as being one of the most important energy saving tools. Unfortunately thermal screens are not so commonly used in practise as one might have been expected. IMAG-DLO is now performing additional research to improve the application of these screens.
Double glazing was introduced in the same period and did not break through as an energy saving technique either. Interception of light - about 15% additional loss - was raised as a big disadvantage, because it lead to a lower yield. As a result application was not profitable and certainly dit not repay the high investment costs involved. Coatings (Out, 1993) make it possible to increase the insulation of glass with only a slight decrease in the transmittance of light (15-20% energy saving versus 1-2% light loss). Attention has to be paid to the durability of coated glass.

The application of energy friendly greenhouse covering materials affects the climate in the greenhouse. This is mainly caused by the increased temperature of the greenhouse cover. As a consequence extra ventilation is necessary to remove water vapour. At the same time more heat is being removed than is strictly necessary and therefore this extra ventilation is also costing extra energy. In energy friendly greenhouses this can only be prevented by independent control of the cooling and the dehumidification process (De Jong *et al.*, 1993). A feasibility study concluded that in the Netherlands cooling by natural ventilation still remains the most economic. Dehumidification by means of an indirect evaporative cooler is a possible alternative. Further research is being done to get information on the potency of this alternative.

Energy efficiency determines how well the energy of the primary energy carrier is being used to supply the energy required by the greenhouse. Through the development of a flue gas condenser, energy efficiency was improved considerably (5-15%). The heat demand of the greenhouse itself does not decrease, but part of this demand is being covered by the heat of condensation from the exhaust gases and in this way less natural gas is necessary to cover the heat demand.
Another important development in this field is small-scale co-generation. The first experiments by IMAG-DLO aimed at using generated electricity for artificial lighting of the crop (Huijs, 1992). At the moment small-scale as well as large-scale co-generation is being considered. In both cases the electricity can be supplied to the public net and the reject heat is consumed by the greenhouse industry. Attention is not only paid to practical matters like storing energy to overcome the time lag between supply of and demand for reject heat, but also to more fundamental questions connected with the combined use of energy from different sources (reject heat, stored heat, boiler heat and heat linked to the generation of CO_2).

5. Labour and management

For a long time greenhouse production could be characterized as a typical agricultural business. Most of the work was done by hand and concentrated on, or around the developing plant. Work planning very much depended on the outdoor climate. Even when handwork was replaced by machines the work was still executed at the plant's stationary development position in the greenhouse.
In modern greenhouse production industrial production methods are adapted and this is characterized by the use of stationary machines or workstations in combination with an internal transport system. The influence of the outdoor climate on work planning in the greenhouse is limited by the use of improved climate control systems and of artificial light.

The choice of transport and material handling systems in Dutch greenhouses depends very much on the type of production system. In this context a distinction can be made between production in the soil, production on substrate and production in pots or containers.
The level of mechanization and automation of internal transport and handling is lowest for production in the soil and highest for production in pots. This is due to the fact that with production in pots the negative effects of natural variability of plants on mechanization can be limited by grading. The relatively low level of mechanization and automation for production in the soil explains why most of the physical complaints originate from this sector (Van der Schilden, 1990).

Sometimes up to 35% of the greenhouse is taken up by the aisles between the plants. These are necessary in order to reach each individual plant. Throughout the years efforts have been made to achieve a better utilization of the greenhouse space, but it is impossible to optimize working conditions as well as production circumstances at the same time. Research of IMAG-DLO is now focused on the separation of these functions by creating a fully utilized production area with a climate especially

adjusted to the plant's needs and a work area where the climate and other working conditions can be adjusted to human needs (Van Weel, 1991). Both areas are linked together by an automatic internal transport system.
Some such design also requires less input of labour as walking distances are minimised. Moreover there are better opportunities for introducing machines and robots. These are major advantages, for labour is one of the most expensive productions factors in the Netherlands.

Management support is another important field of interest for IMAG-DLO. With the help of machines it will become fairly easy to collect data from the system. This will create an explosion of available data. The amount of data must be reduced and transformed into information that can be offered to a grower in order to optimize the decision process. In an integrated production system, data from the functioning (operational) system can be used for better short-term planning, such as the coming crop, or the coming year (tactical planning) and for the long term, such as training of personnel or expanding and renewing existing operation (strategic planning). Since there is a strong relation between the operational, tactical and strategic management level, a more integrated data exchange will undoubtedly improve the quality of the decisions of the grower or the operator. Current decision support systems, however, are not suited for that purpose (Van Uffelen *et al.*, 1992).

6. Conclusions

In the Netherlands, greenhouse production is being practised intensively and at a high technological level. The sector owes this strong position in the first place to the often vaunted dynamism of the growers and their urge to innovate. However, it cannot be denied that the efforts of agricultural research and extension have also contributed considerably.

The last decade has been characterized by a growing environmental consciousness, which requires the development of sustainable production methods with low emission of contaminants into the environment and a relatively low level of energy consumption. Growing on substrate is one of the options available for meeting the environmental standards of the government. For many crops, however, this is economically not yet feasible.
Complementary new spraying techniques have to be developed with low emission. Naturally this is also of great importance to the safety of the workers in the greenhouse.

The application of thermal screens, coated glass and flue gas condensers can reduce the consumption of energy in greenhouse production considerably. A promising development is co-generation. For the somewhat longer term new, energy-friendly greenhouses with well-adjusted climate control have to be developed.

Horticultural engineering is expected to develop creative solutions based on challenging technology, because sustainable greenhouse production also has to be competitive. In addition it should be remembered that it is not only the quality of the production process that has to be improved, working conditions also require more attention. To achieve both objectives, a separation of the production area from the work area will be necessary.

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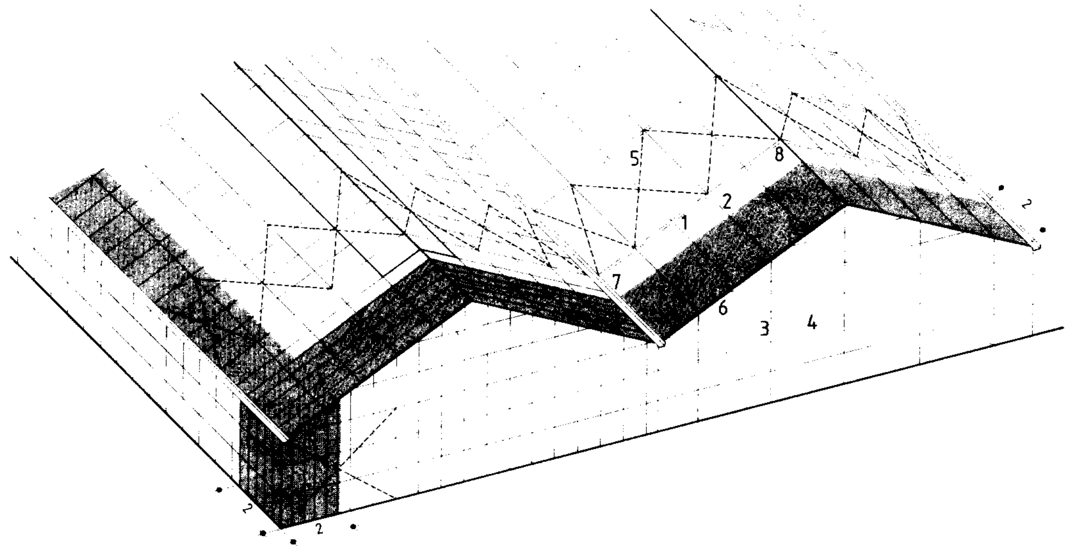

Fig. 1. Wide span greenhouse

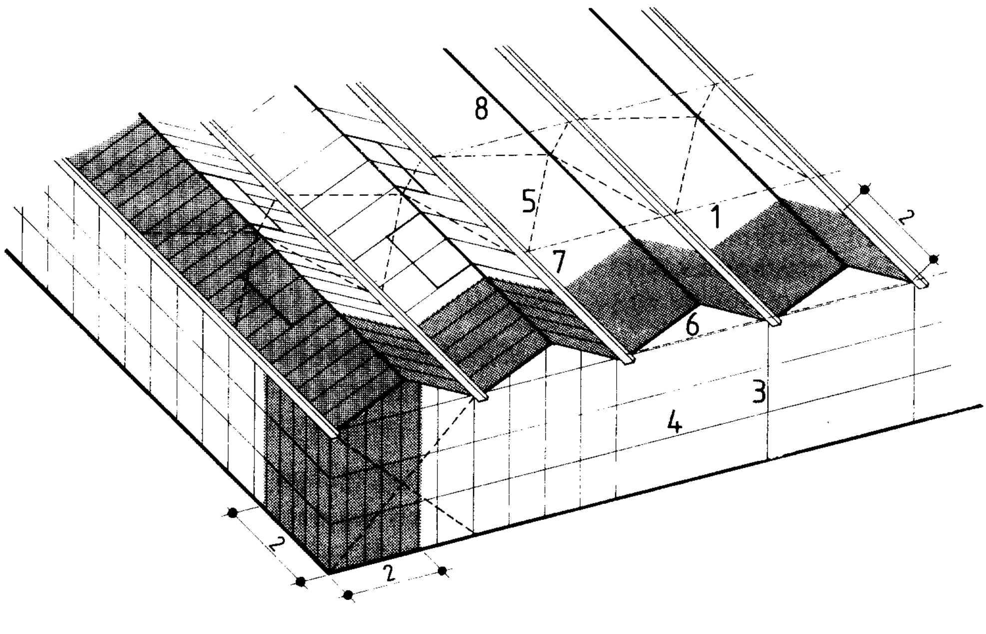

Fig. 2. Venlo-greenhouse

Legende

1. rafter
2. purlin
3. wall stanchion
4. clamping batten
5. stability bracing
6. top batten in front wall
7. gutter
8. ridge beam