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Proceedings of the Seminar on closed production systems

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Preface

On the occasion of a visit by a delegation of Japanese scientists, IMAG-DLO in cooperation with the Research Station for Floriculture and Glasshouse Vegetables in Naaldwijk organized a seminar on closed production systems on September 11th, 1995.

Both, Japan and the Netherlands have common problems in glasshouse horticulture. In these densely populated countries, emissions of nutrients and chemical pesticides lead to pollution of the environment. Closed production systems may be one of the solutions to decrease environmental pollution by glasshouse horticulture.

In the seminar several aspects of closed production systems were orally presented. Discussion between the participants led to a better understanding of one another's problems and their visions on the future developments.

This report contains the written contributions of the participants and can be seen as the proceedings of the seminar.

I hope that publication of these proceedings will lead to a fruitful cooperation between the participants, not only on a level of exchanging ideas but also on a level of cooperative execution of research projects.

Ir. A.A. Jongebreur
director

Contents

Introduction

Both Japan and the Netherlands have large areas with protected cultivation, which have many similarities, but also many differences. In Japan, there is more than 50,000 ha of greenhouses (glass as well as plastic covering). However, mainly plastic (48,000 ha) is used as covering material because of the frequently attacking typhoons and, related to this, the low costs of investment for renewal. In the Netherlands, on the other hand, 99% of the covering material is glass, because of light transmission and climatic conditions. Another difference is the size of a holding. In Japan, the size of a holding varies between 1000 and 2000 m^2. In the Netherlands the overall average size has increased to more than 1 ha for vegetable production. This figure is expected to increase further. Newly built holdings have a size of at least 2 ha.

Whilst in Japan the vegetable production under glass and plastic (35,000 ha) is far more important than floriculture, flower production in the Netherlands occupies the same area (4500 ha) as vegetable production. Besides, the production of pot plants is very important in the Netherlands, while Japan has an important area with fruit trees.

For production and quality reasons a change can be noticed from soil towards soilless production methods in the Netherlands. Additionally, for environmental reasons a change from open systems towards closed systems can be seen. At the moment the area with soilless cultures is approx. 5000 ha (of which 3500 ha is vegetables). A change to soilless growing systems is highly feasible for crops with only a few plants per m^2, by which an increase in yield can be expected. Tomatoes, sweet peppers, eggplants and cucumbers are the main vegetable crops, while roses, gerbera, anthuriums and orchids are the main flower crops. Lettuce, radishes and chrysanthemums are still grown in soil, because the high number of plants per m^2 and the low prospects for an increasing yield make it hardly feasible to change to soilless growing systems.

Solid substrates, such as rockwool, perlite and polyurethane foam, are mostly used (95%) for vegetable and flower production in the Netherlands. One of the reasons is the buffer capacity of the solid substrates. Making mistakes is not immediately a disaster. In Japan there is 500 ha with soilless growing systems, of which approx. 75% uses a system with water as substrate: nutrient film technique (NFT) and deep flow technique (DFT). The crops grown also vary: not only tomatoes, but also lettuce, mitsuba, strawberry and Welsh onion.

In the Netherlands there is a great concern about the risks of spreading pathogens all over the nursery in closed growing systems, and related to this there is the question of how to disinfect the nutrient solution. In Japan this concern does not seem to exist. There is hardly any grower who has disinfection equipment at his nursery. One of the reasons is the high investment necessary to buy this equipment, which make it more difficult for small (Japanese) nurseries, than for bigger (Dutch) nurseries. This may also be an explanation for the different growing systems in the two countries. In the Netherlands, NFT demands a much higher water use, which has to be disinfected (50 m^3/h). This is a reason for the Dutch grower to choose solid substrates, with which only 30% of the supply water has to be disinfected (2.5 m^3/h).

Both countries have to face similar problems for the near future: how to get well skilled labour. In Japan there is a lack of successors to the present generation: the status of work is low, and outside the horticultural sector one can earn more money. This is a reason to look for more automation and to have robots do the work. Also in the Netherlands, the status of work is rather low, but work force for glasshouse horticulture can be achieved in the coming years. Here, reasons for automation and introduction of robots are the decrease of costs. Closed production systems may be a help to find solutions.

The seminar on closed production systems with participation of Japanese and Dutch scientists was a good occasion to exchange recent ideas and developments in this field. The presentations by the participants were divided into the following subject areas: the use of environmental friendly materials, the control of the recirculating solution and new production systems.

I would like to thank all speakers for working out their papers into a written contribution. Furthermore I also hope that the proceedings of this seminar may lead to a better understanding of each other and to a fruitful cooperation and execution of joint projects.

Erik van Os
convener

New design for greenhouses for low environmental impact

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1 Introduction

Greenhouse production is becoming more important in Japan. In 1993 the area was about 50,000 ha, 1% of the cultivated area in Japan. In spite of the small ratio, greenhouse production has its important role in Japanese agriculture. Currently, there are several vegetables that are mainly grown in greenhouses. For example, 66% of tomatoes, 60% of cucumbers and 60% of bell peppers are grown in greenhouses (Table 1). Greenhouse production is becoming more important for the food production in Japan.
Growers are most interested in profitable crops. On the other hand, the ageing of growers and the shortage of farm successors is a serious problem in Japan. It is necessary to reduce labour requirement and the costs of greenhouse construction. In addition, the greenhouses should be labour-friendly and have a low environmental impact. Low environmental impact in greenhouse cultivation is necessary, not only to achieve an improved productivity but also for the preservation of living and agricultural production environment.

2 Greenhouse design considered for low environmental impact

Several structural components for low environmental impact are considered in this study, which include:

1. Greenhouse size
   A larger sized greenhouse is desirable, which may justify the investment of equipment for recirculation systems of drainage water, fertilizer, etc.
2. Disposal of covering film
   In Japan, waste plastic film in agriculture amounts to 189,494 ton per year, of which 47% comes from greenhouses. Recycling of used film, however, is limited; only 27% of waste plastic film is recycled. For example, PVC film is most used for greenhouses (85% of all greenhouses) and amounts to 56% of waste plastic film. Only 45% of waste PVC film is recycled for PVC production. Incineration of waste PVC film amounts to 23% of waste PVC film. It is necessary to establish a collection and recycling system for waste plastics to lower the environmental impact.
3. Improvement of covering material
   Development of long-life film contributes to a reduction of waste film. Use of biodegradable plastics also reduces the environmental impact.
4. Greenhouse site selection and construction design
   Construction, location and arrangement of greenhouses have to be considered at the planning stage. For example, application of natural energy (geothermal, hot spring, etc.) for greenhouse heating reduces fossil fuel consumption. Energy saving is important. In addition, saving material in constructing greenhouses leads to a saving of natural resources and to low costs.

3 Study of air-supported (bubble) greenhouse

In order to realize the above-described conditions for designing a greenhouse, the feasibility of using an air-supported greenhouse for agricultural production was studied.
The advantages of this type of structure include:

1. possibility of making a long span and a light structure;
2. increase solar radiation transmission due to less structural components;
3. possibility of using a larger tractor in the greenhouse to compensate for the labour shortage problem, due to the ageing of farmers and shortage of farm successors.

As a first step of this study, the environmental characteristics of the air-supported greenhouse (referred to as air-house in this paper) such as solar radiation, temperature, humidity, heat transfer, air pressure in air-house, and ventilation were investigated.
The investigated air-house is located at Tsukuba, Japan. The floor space is 900 m^2 and the maximum height is about 8 m. The air pressure in the air-house was by about 5 mm H_2O higher than the atmospheric pressure. The PVC film is used as covering material, and it is held by a 13 cm mesh net from the outside. Cucumber is the major crop in the house.

4 Results

The transmittance of solar radiation is observed to be about 70% for both summer and winter days. This value is the same for the PVC film after one year of use. This shows that the air-house has a better solar radiation transmission, compared with a conventional greenhouse, due to less structural components.
The temperature in the air-house has extremely high variations due to the fluctuations in solar radiation. In summer, the peak difference of the inside and outside temperatures is about 30 °C on sunny days, while the inside temperature rises to 60 °C.
The relative humidity in the air-house is lower than outside. On the other hand, absolute humidity in the air-house is higher than outside. This is caused by the very high temperatures in the air-house.
The high temperature gradient was caused by poor ventilation. It has been calculated that the air renewal was only 5-6 times an hour, which is much less than that of an ordinary greenhouse, there it is only 0.1 or less.
Therefore, the daytime heat balance is considered for different times of the year. The heat due to solar radiation in summer is twice of the one in winter, but the contribution (in percentage) of heat dissipated through various means is almost the same. The ratio caused by ventilation is about 45%, that caused by transmission through the covered film is about 35% whereas the ratio caused by heat transfer to the ground is about 20%.
It was found that the ratio of heat dissipated due to ventilation is too little to control the high temperatures in the air-house. One approach to improve the high temperature situation in the air-house, may be the use of sun shades as an effective way to reduce the solar radiation load. Therefore, one of the important problems of the air-house is to increase the ventilation rate, while the shape of the air-house is maintained.

5 Conclusions

The results from this investigation are summarized as follows:

1. very high temperatures were observed in the air-house on sunny days in summer;
2. by calculating the daytime heat balance, it was found that the ratio of heat dissipated because of ventilation, is too little to control high temperatures in the air-house. Therefore, it is necessary to increase the ventilation or to use sun screens for the improvement of the environment in the air-house.

In spite of some environmental engineering problems that were observed, the air-house should be further investigated for its apparent advantages: less quantity of construction material, more efficient use of solar radiation, more economical recycling system, and easier access to machinery. The air-house has a potential in meeting Japanese agriculture needs: lowering labour requirement and lowering environmental impact.

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Table 1: Major vegetable crops in greenhouses; planted area and production

Crop	Planted area			Production		
	1. Total (ha)	2. Greenhouses (ha)	3. Ratio 2./1. (%)	4. Total (hundred tons)	5. Greenhouses (hundred tons)	6. Ratio 5./4. (%)
Eggplant	16,000	1,694	11	5,194	1,524	29
Tomato	14,000	7,041	50	7,717	5,079	66
Cucumber	19,000	7,182	38	8,989	5,334	60
Sweet pepper	4,460	1,491	33	1,665	1,006	60
Strawberry	9,350	7,377	79	2,086	1,919	92
Water melon	21,400	3,652	17	7,367	1,446	20
Outdoor melon	16,400	8,303	51	3,577	2,090	58
Greenhouse melon	1,340	1,340	100	395	395	100

Ventilation of screened greenhouses for insect control

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1 Introduction

Alternatives to the use of chemical pesticides in greenhouses must be found, to realize a sustainable greenhouse industry in the near future. Environmental considerations are expected to be a dominant consideration in greenhouse technology in the coming decade. The potential of discharging any chemicals into the environment and the occupational exposure of workers shall be reduced or eliminated, if possible. The control of insects will be substantially simplified if the entry of insects can be reduced. It is important to avoid the entry of insects via the ventilation.

Screening to keep insects out of the incoming air during ventilation is one measure. However, screening affects the greenhouse environment during ventilation, because the screens increase the resistance to the airflow through the ventilator openings. The effect of screening on the airflow shall be known and this effect shall be accounted for the design and management of the ventilation system.

This paper describes an overview of the studies with engineering aspects on screening greenhouses by Sase and Christianson (1990), and Huang et al. (1992). A number of screen materials proposed for use in greenhouse applications were tested to determine the discharge coefficients; these parameters are presented. A procedure for utilizing the screen discharge coefficient to calculate the area of screened ventilation opening required for a given forced ventilation system is proposed. For natural ventilation systems, a simulation model was used to study the effect of screening on ventilation rate and internal temperature increase for a single-span greenhouse. The same model was used to investigate ventilation improvements that can be achieved by increasing the screened inlet areas in a conventional natural ventilation system. Field tests were carried out to investigate the effects of screening on the internal temperature under natural ventilation.

2 Methods

Eight screen materials were tested in the Bioenvironmental and Structural Systems Laboratory fan test chamber at the University of Illinois. All materials tested were new and clean except for a sample. Screens were mounted, tautly stretched into a plywood frame with an open face area of approximately 0.9 m on a side. The exact face area was measured for each screen tested, and that area was used to compute the approached air velocity. Then, each plywood-framed screen sample was clamped to the test face of the fan test chamber. The approach velocity was varied, using a variable pitch supply fan, and then the static pressure across the screen was measured. The discharge coefficient for relating the approach velocity to the square root of the imposed pressure was determined statistically.

For natural ventilation systems, the computational procedures developed at the National Research Institute of Agricultural Engineering in Tsukuba was used to estimate the ventilation rate and the temperature rise (temperature difference between internal and external air) under a steady state condition. The simulation of natural ventilation was conducted on a typical single-span greenhouse equipped with continuous hinged ventilation windows on side walls and ridge. The internal net radiation above the plant canopy, the wind velocity at a height of 10 m, the wind direction and the external air temperature are input weather conditions. The internal net radiation of 500 W/m2 above the plant canopy was assumed as a value under high solar radiation. Half of the internal net radiation was assumed to be transported as sensible heat.

Two side-by-side plastic greenhouses were constructed for the screening experiments. One was screened with a commercial screen with 26 threads/inch in either direction. As the other one was used as a reference, no screen was installed.

3 RESULTS

3.1 Determination of discharge coefficients

For all materials tested, the pressure drop was found to vary linearly with the square of the approach velocity. The discharge coefficients of the screen materials tested ranged from 0.07 to 0.48. The value for the Vispore screen with 400 holes/inch^2 was the smallest. The Vispore screens have male and female sides. The insects are less likely to pass from the male side to the female side, although the discharge coefficient for this direction was slightly smaller than for the other way. For a dirty screen, which had been in service for three years, a reduction by about 20% of the discharge coefficient was found.

3.2 Design considerations for forced ventilation systems

For forced ventilation systems, a common criterion for greenhouse air inlets is to design ventilator opening control systems, so that the pressure drop across the ventilator is about 2.5 mm of water pressure. At the maximum ventilation rate the ventilator should open at least wide enough, so that this velocity and pressure drop across the ventilator are not exceeded. The designed approach velocities were calculated for the materials using the following assumptions:

- the ventilator opening can be adjusted so, that for the window alone the pressure drop across the window at the maximum ventilation will be 0.8 mm w.g. (water gauge);
- the inlet area of the screen is designed so that the pressure drop across the screen alone will be 0.8 mm w.g.;
- the screen will be cleaned when the pressure drop across the screen and the ventilator passes a total 2.5 mm w.g.

The inlet opening area can be given by the required ventilation rate divided by the designed approach velocity. The designed approach velocity ranged from 0.25 m/s to 1.71 m/s.

3.3 Simulation studies on effects of screening on natural ventilation systems

For the simulation of the natural ventilation, the results showed that the ventilation rate (and the temperature rise) did not vary significantly at a wind velocity lower than approx. 2 m/s for every screen discharge coefficient. Wind direction had little effect. As the natural ventilation at a low wind velocity is most important under high solar radiation, all discussions below were made at a wind velocity of 1 m/s.

The temperature rise increased rapidly with a decrease in the discharge coefficient of the screen, when the discharge coefficient of the screen was less than 0.2 to 0.3. For example, the temperature rise for the discharge coefficient of the screen of 0.05 was approx. 10 °C, while without screening it was 6.1 °C at an angle of ventilator opening of 10°, and 2.8 °C at an angle of the ventilator opening of 50°. On the other hand, the temperature rise did not significantly vary for a higher discharge coefficient of the screen. This is due to the fact that the overall discharge coefficient of the ventilator opening with screening depends dominantly on the smaller discharge coefficient among the discharge coefficients of the ventilator opening and the screen if the difference of discharge coefficient between them is large.

The ventilator area requirement to achieve the same ventilation rate as that without screening was calculated under the condition of the same screen area as the window area. It was shown that 145% of the original area was needed to achieve the discharge coefficient of the screen of 0.5, 202% for 0.3 and 536% for 0.1.

The third calculation was carried out for the design of the screening. If the ventilators are fixed and have no possibility of being reconstructed wider for the installation of screens, an increase in the screen area itself is a practical alternative to reduce the airflow resistance and increase the ventilation rate. It was shown that the ratio of the ventilation rate with screening to that without screening increased logarithmically with an increase in the area ratio of the screen to ventilator. For example, when the discharge coefficient of screen is 0.5, the ventilation rates were 0.78, 0.92 and 0.96 for the area ratios of the screen of 1, 2, 3, respectively. With the discharge coefficient of screen of 0.1, the ventilation rates are only 0.30, 0.49 and 0.62 for the area ratio of the screen of 1, 2, 3, respectively. To achieve 80% of the ventilation rate without screening, it was shown that the screen area of 1.1 times as wide as the ventilator area was required for the screen with a discharge coefficient of 0.5, 1.8 times for 0.3, and 2.7 times for 0.2.

From the temperature rise point of view, the area ratios of the screen of 0.78, 1.29 and 1.94 were realized for the screens with discharge coefficients of 0.5, 0.3 and 0.2, respectively. A temperature increase of 1 °C compared to no screening could be acceptable. If the screens with discharge coefficient of 0.1 or less are required to keep the insects out, the greater temperature increase may be unavoidable. For example, the temperature increases by 1.4 °C and 3.1 °C over the temperature without screening was shown for the screens for discharge coefficients of 0.1 and 0.05, respectively, even if the screen area was up to 3 times as wide as the ventilator area. However, the installation of a wide screen may cause the decrease of sunlight transmitted and structural difficulties. This shall be taken into account in the design of the screening as well.

3.4 Field experiments

The field experiments showed that the internal temperature difference between screening and no screening was 2-3 °C on a sunny day, although the screen installed was not very fine. The difference depended on external wind velocity and solar radiation. The vertical temperature difference in the greenhouse with screening was higher than that of the greenhouse without screening. Particularly, the top region below the roof cover was warmer than that without screening. The screen material on the ridge ventilators seemed to reduce the outflow of air through the ridge opening.

4 CONCLUSIONS

Coefficients of discharge were determined for a number of screening materials for greenhouse use. More information is needed on the effects of the accumulation of dirt on the discharge coefficient. A design recommendation was proposed for forced ventilation systems, based on an initial pressure drop across clean screen material and a fully open window of 0.8 mm w.g. each at full ventilation. Simulation studies showed that the discharge coefficient of the screen can be the dominant parameter in the ventilation rate of natural systems. With a discharge coefficient of 0.05, a screened greenhouse will have about 1/3 the ventilation rate of an unscreened greenhouse when there is no wind.

Based upon the results, it is clear that the use of screening on greenhouses will have significant effects on the design and performance of the ventilation system. Maintaining the required ventilation rate will be especially difficult when very fine screening is required to keep the insects out of concern to the grower.

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Materials for sustainable production systems

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1 Introduction

The Dutch government has defined the environmental aims for future production systems. The major goals to be achieved are:

- reduction of emissions to water and air;
- reduction of non-recyclable waste materials;
- reduction of the use of non-renewable resources.

The sustainable encapsulated production system is considered to meet these requirements. In the research programme "Development and Evaluation of closed production systems", the Research Station for Floriculture and Glasshouse Vegetables has used these considerations as a starting point.

2 Considerations for the design of a production system

Sustainability of a production system can be defined as a minimized pollution and minimized consumption of non-renewable materials during the entire lifecycle from raw materials to destruction. Sustainability of a system can be obtained with the following measures:

- a long life span;
- use of materials with a low energy requirement for their production, transport and recycling;
- systems with low energy requirements during their use;
- use of renewable or recyclable materials.

2.1 A long life span

The life span usually ends before the technical life ends, because of technical, social or market developments. This means that a long life can only be achieved if a system is prepared for future developments. A modular construction method can improve the flexibility of a system to be modified against low costs. Flexibility is also required in the possibilities to move to other types of products. Automation of all kinds of tasks is a sure development in the coming 10-20 years. The system should also be prepared for that. Technical life depends on the defined functions of the system. Examples are: absence of leakage, production level, costs. If the maintenance costs to keep the system functioning within the predefined requirements, rise too much, this will lead to the removal of the system. Maintenance should be scheduled and incorporated in the system's design. For closed production systems, the substrate plays an important role for the production level. It should be possible to keep the characteristics of the substrate within narrow limits. Measures such as steam sterilization, filtering and washing etc. should be possible at low costs to extend the life span of a substrate. The system's design shall be adjusted to allow for these operations. Requirements are: temperature resistance, optimum drainage of water, mechanical strength.

2.2 Materials with low energy requirements

There is much difference in the amount of energy required to produce, transport and recycle various kinds of materials. These differences can be due to geographical, technical or organizational factors. In general, materials shall be preferred that are produced in bulk and suitable for multiple purposes, because such materials usually are low-cost, largely available and produced nearby. Sometimes the energy required to produce a material is many times more than the energy required to recycle it. Aluminium is a good example. In that case the material should be chosen only if a good recycling programme has been organized and the characteristics of the material after many cycles of recycling do not deteriorate too much.

2.3 Systems with low energy requirements

Control of the substrate temperature becomes more difficult in above-ground production systems. Heating and cooling become important and can easily lead to extra energy consumption compared with production in the greenhouse soil.
Insulation measures and, if possible, thermal contact with the greenhouse soil are important measures to reduce this extra energy consumption.

2.4 Use of renewable and recyclable materials

Renewable materials such as agricultural products or energy from wind or sunlight should be preferred, unless a good recycling programme has been established. A grower should never buy a material that can only be removed by dumping or burning, because future removal of such materials will become a financial risk. Recycling should where possible lead to as little as possible deterioration of the material properties to obtain a high economic value.
Costs for removal, cleaning and transport of the material should be in relation with the value of the raw material. This means, for instance, that the use of thin plastic liners with a short life cycle will automatically lead to a financial problem for the recycling phase. A thick material with a long life reduces the recycling costs.

3 Results

Simulation studies have indicated that the emission, energy consumption, exhaustion of non-renewable resources and some other environmental effects per unit of marketable product can be estimated and used to compare production systems. The life cycle analysis method of the University of Leiden in the Netherlands is a suitable tool for this purpose, since it translates the effects of all kinds of substances into the effect of an equivalent in kilograms of a substance with well-known effects.
A case study of various open and closed production systems for roses and tomatoes have indicated that the energy needed to heat the glasshouse is responsible for the major part of the emission and consumption of non-renewable resources (gas). The energy contents of the glasshouse and everything in it, equals only a couple of months of heating energy, which makes it relatively unimportant to try to reduce that. The same is true for waste materials. If a non-recyclable substrate is being used and the production cycles are much shorter than the expected life of the glasshouse system, the volume of waste materials is usually very high. In that case trying to reduce the amount of dismantling waste has a lower priority than trying to reduce the amount of substrate residues, unless there is a difference in toxicity or other non-desirable effects.

4 Conclusion

Future plant production systems have to meet new requirements in the fields of energy consumption, the use of non-renewable resources and the emissions.
The LCA method in combination with a database for construction materials, developed by the Technical University of Delft in the Netherlands will be the future tool to develop sustainable production systems.

Diurnal control of the nutrient concentration of the nutrient solution in hydroponics

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Abstract

We investigated the effect of a diurnal control of the nutrient concentrations on the growth and yield of tomatoes in a hydroponic culture. Plants of the tomato cultivar "Kyoryoku beijyu 2go" were raised in a water culture. The plants were transplanted in the solution control system that was able to vary the nutrient concentrations of the solution in a short time using a computer. There were two experiments:

1. Tomatoes were sown on September 14, 1994, and transplanted on October 31. Fourteen plants were planted in each treatment;
2. Tomatoes were sown on November 4, 1994, and transplanted on December 21. Nine plants were planted in each treatment.

In the two experiments, three treatments were set and diurnally changed in concentrations of nitrate, potassium and phosphate. Equal amounts of nutrient elements and water were given to the plants in each treatment. A half strength "Enshishoho" culture solution was given to the plants as a reference. In the two experiments there were two treatments and a reference:

1. NKp-nkP, the nitrate and potassium concentrations were high and the phosphate concentration was low during the daytime, while the nitrate and potassium concentrations were low and the phosphate concentration was high during the night;
2. nkP-NKp, the nitrate and potassium concentrations were low and the phosphate concentration was high during the daytime, while the nitrate and potassium concentrations were high and the phosphate concentration was low during the night;
3. Reference

Supply of the amount of nutrient solution per day was decreased after December 21.
Results:

- Experiment 1: the plant dry weight of both the NKp-nkP and the nkP-NKp treatments were higher than that of the reference. The yield of the nkP-NKp was the lowest. The yield of the NKp-nkP was equal to that of the reference;
- Experiment 2: the yield of the NKp-nkP was the lowest. The yield of the nkP-NKp was equal to that of the reference.

These results show that diurnal changes in the nutrient concentrations affect growth and yield of tomatoes. However, the effects of diurnal changes were different between experiment 1 and experiment 2. It is suggested that the effect is influenced by the quantity of the solution supply, the nutrient concentrations, the plant growth stage and the climatic conditions.

1 Introduction

In hydroponics, it is possible to realize a positive control of the nutrient solution, corresponding with the climatic conditions and growth. By control of the solution, it is possible to control the plant growth by an efficient supply of the nutrient solution to the plants. There are some examples about a plant growth control by controlling the solution. Shimaji et al. (1994) investigated the water uptake of the plants by a simulation model. They succeeded in feed-back control of the stem diameter growth of the tomato plant grown in the spray culture by using the model and a computer.

Efficient supply of the solution may decrease the waste solution and may decrease the uptake which is not necessary to produce fruits. As a consequence, the costs of fertilizers may be reduced. Moreover, this would be important in closed production systems, where the solution cannot be discarded.
A solution control system in spray culture was made. The system can vary the nutrient concentrations of the solution in a short time using a computer. The effects of the diurnal control of the nutrient concentrations on the growth and yield of tomatoes were researched.

2 Materials and methods

2.1 The solution control system

The solution control system was made, in which quantitative pumps take a fixed quantity of solution from each element stock tank filled with a highly concentrated solution to a mixing tank. In the mixing tank, the nutrient elements and water are mixed and adjusted to setpoint level. The solution is supplied to tanks of each cultivation bed by supplying pumps. The beds are made of polystyrene foam and approx. 10 cm deep. Drain sheets and water-permeable sheets cover the beds to keep the solution inside. The plants are planted on the sheets; as a consequence the roots are often suspended in the air. Spraying pumps supply a mist of nutrient solution every 10 minutes. For spraying, nozzles are used, which are normally used for cooling the air by fog. A computer (YOKOGAWA: YEWMAC500) and a controller (YOKOGAWA: FA500) control the input and output of the quantitative pump, the supply pump, the spray pump, the electric valve and the level sensors in the tanks.

2.2 Experiments

Plants of the tomato cultivar "Kyoryoku beijyu 2go" were raised in a water culture and hereafter transplanted into the solution control system. The plants were topped at the leaf above the 4th truss. The cultivation was executed in the acrylic greenhouse. Heating was used, when temperatures drop below 12 °C. The experiments were practiced twice:

1. Tomatoes were sown on September 14, 1994, and transplanted on October 31. Fourteen plants were planted in each treatment. Plant height and number of leaves were measured every week. Fifty days after sowing, fresh weight and dry weight were measured in seven plants for each treatment. After that, the yield of the other plants was measured;
2. Tomatoes were sown on November 4, 1994, and transplanted on December 21. Nine plants were planted in each treatment. Plant height and number of leaves were measured every week as well as the yield.

2.3 Diurnal changes in the nutrient concentrations

In both experiments, three treatments were set, at which the concentrations of nitrate, potassium and phosphate changed diurnally. A half-strength "Enshishoho" culture solution was given to the plants as a reference. It consisted of 4 meq/l KNO_3, 4 meq/l $Ca(NO_3)_2$, 2 meq/l $MgSO_4$, 2 meq/l NaH_2PO_4, 3 ppm Fe added as Fe-EDTA, and full strength micro-elements of "Enshishoho" (0.05 ppm Mn, 0.5 ppm B, 0.005 ppm Zn, 0.02 ppm Cu, 0.01 ppm Mo). Although usually phosphate was given as $NH_4H_2PO_4$ in an "Enshishoho" culture solution, in these experiments phosphate was given as NaH_2PO_4 to avoid effects of ammonium.
Except for the reference, the changes in the nutrient concentrations were executed stepwise (Tables 1 and 2). During daytime in the NKp-nkP treatment the nitrate (max. 8.8 meq/l) and potassium (max. 4.8 meq/l) concentrations were moderately and the phosphate concentration (min. 1 meq/l) was low. During the night, nitrate (min. 5.6 meq/l) and potassium (min. 1.6 meq/l) concentrations were low and phosphate concentration (max. 4.4 meq/l) was high. For

the nkP-NKp treatment, nitrate (min. 6 meq/l) and potassium (min. 2 meq/l) concentrations were low and phosphate concentration (max. 2.4 meq/l) was moderately during daytime. During the night the nitrate (max. 12.8 meq/l) and potassium (max. 8.8 meq/l) concentrations were high and the phosphate concentration (min. 0.8 meq/l) was low. Equal amounts of nutrient elements and water were given to the plants in each treatment. After December 21, the supply of the nutrient solution per day was halved.

Table 1: Diurnal change in nutrient concentrations before December 21.

	NKp-nkP				nkP-NKp				
	N	K	P	EC	N	K	P	EC	Water
time	me/l	me/l	me/l	mS/m	me/l	me/l	me/l	mS/m	ml/nozzle/h
6:00	5.6	1.6	4.4	112	12.8	8.8	0.8	199	92
7:00	8.0	4.0	2.0	141	8.0	4.0	2.0	141	183
8:00	8.0	4.0	2.0	141	8.0	4.0	2.0	141	183
9:00	8.0	4.0	2.0	141	8.0	4.0	2.0	141	367
10:00	8.0	4.0	2.0	141	8.0	4.0	2.0	141	550
11:00	8.4	4.4	1.0	142	6.0	2.0	2.2	113	733
12:00	8.8	4.8	1.0	147	6.0	2.0	2.4	113	733
13:00	8.8	4.8	1.0	147	6.0	2.0	2.4	113	733
14:00	8.4	4.4	2.0	147	8.0	4.0	2.2	140	733
15:00	8.0	4.0	2.0	141	8.0	4.0	2.0	141	550
16:00	8.0	4.0	2.0	141	8.0	4.0	2.0	141	367
17:00	8.0	4.0	4.4	143	12.8	8.8	2.0	202	183
18:00	5.6	1.6	4.4	112	12.8	8.8	0.8	199	183
19:00	5.6	1.6	4.4	112	12.8	8.8	0.8	199	92
20:00 | 5:00	5.6	1.6	4.4	112	12.8	8.8	0.8	199	37

Table 2: Diurnal change in nutrient concentrations after December 21.

	NKp-nkP				nkP-NKp				
	N	K	P	EC	N	K	P	EC	Water
time	me/l	me/l	me/l	mS/m	me/l	me/l	me/l	mS/m	ml/nozzle/h
6:00	5.6	1.6	4.0	110	12.0	8.0	0.8	199	92
7:00	8.0	4.0	2.0	141	8.0	4.0	2.0	141	92
8:00	8.0	4.0	2.0	141	8.0	4.0	2.0	141	183
9:00	8.4	4.4	2.0	147	8.0	4.0	2.2	140	275
10:00	8.4	4.4	1.0	142	6.0	2.0	2.2	113	275
11:00	8.8	4.8	1.0	147	6.0	2.0	2.4	113	367
12:00	8.8	4.8	1.0	147	6.0	2.0	2.4	113	367
13:00	8.8	4.8	1.0	147	6.0	2.0	2.4	113	367
14:00	8.8	4.8	1.0	147	6.0	2.0	2.4	113	275
15:00	8.4	4.4	2.0	147	8.0	4.0	2.2	140	275
16:00	8.4	4.4	2.0	147	8.0	4.0	2.2	140	183
17:00	8.4	4.4	4.0	149	12.0	8.0	2.2	193	92
18:00	5.6	1.6	4.0	110	12.0	8.0	0.8	190	92
19:00	5.6	1.6	4.4	112	12.8	8.8	0.8	199	92
20:00 | 5:00	5.6	1.6	4.4	112	12.8	8.8	0.8	199	37

3 Results

Experiment 1
At 50 days after sowing, the dry weight of both the NKp-nkP (133.3 g/plant) and the nkP-NKp (136.2 g/plant) were higher than that of the reference (112.6 g/plant). The plant height and the top weight ratio of the nkP-NKp were the highest (table 3).

Table 3: Effect of a diurnal change in the nutrient concentration on growth in experiment 1 at 50 days after sowing.

treatment	height(cm) top	root	dry weight (g/plant)	T/R ratio
Control	132.17	88.07	24.56	3.59
NKp-nkP	131.67	103.61	29.68	3.49
nkP-Nkp	137.71	109.54	26.64	4.11

The yield of the nkP-NKp was the lowest (2935 g/plant). The yield of the NKp-nkP (3655 g/plant) was nearly equal to that of the reference (3618 g/plant; table 4). This point is different from growth at 50 days after sowing.

Table 4: Effect of a diurnal change in the nutrient concentration on the yield in experiment 1.

treatment	yield (g/plant)	fruit weight in g	number of fruits per plant
Control	3655	218.7	16.7
NKp-nkP	3618	241.2	15.0
nkP-Nkp	2935	188.5	15.6

Experiment 2
The plant height of the NKp-nkP was slightly higher than that of the other treatments. The yield (table 5) of the NKp-nkP was the lowest (1995 g/plant). The yield of the nkP-NKp (3748 g/plant) was nearly equal to that of the reference (3714 g/plant). This point is different from experiment 1.

Table 5: Effect of a diurnal change in the nutrient concentration on the yield in experiment 2.

treatment	yield (g/plant)	fruit weight in g	number of fruits per plant
Control	3714	178.8	20.8
NKp-nkP	1995	138.8	14.4
nkP-Nkp	3748	185.1	20.3

4 Discussion

These results show that diurnal changes in the nutrient concentrations affected tomato growth and yield. Why is there a difference in growth, caused by a diurnal change of the solution ? Two reasons are considered. First of all, it might be caused by differences in nutrient uptake. Secondly, it might be caused by differences in the distribution of photosynthetic products.

Here, the nutrient concentration of the solution immediately influenced the root growth and the T/R ratio; as a result, the growth rate is influenced.
The nutrient absorption volume relies on the nutrient concentration of the solution and the quantity of water uptake. Some reports showed diurnal changes in nutrient absorption (Masuda et al., 1990; Terabayashi et al., 1991). These reports showed that the uptake ratios for nutrients and water were higher during the night, and that they differed for each element. For example, phosphate uptake during the night compared with the uptake of 24 h was the highest. Diurnal change in the nutrient concentration of xylem were reported (Masuda and Shimada, 1993). They reported that the nutrient concentration of the xylem exudates changed diurnally, and changed with the light intensity. They showed that the nitrate concentration increased slightly from early morning, the phosphate concentration rose during the night, and the potassium concentration rose during the daytime. It may be considered that these diurnal changes in the nutrient concentration of xylem cause the diurnal changes in the nutrient uptake as described above. Tachibana and Suzuki reported (1980), that even if the phosphate level of a culture solution rose, the phosphate concentration of xylem exudates did not rise. We have to measure the nutrient uptake and make that clear.
The effects of a diurnal change in the nutrient concentration were different between experiment 1 and experiment 2. Besides, the effects were also different between plant growth and yield. It is suggested that the effects were influenced by the quantity of solution supply, the nutrient concentrations, the plant growth stage and the climatic conditions. The authors would like to investigate on further details.

5 Conclusion

If the same quantity of nutrient solution is supplied to tomato plants, the diurnal changes in nutrient concentration cause differences in growth and yield. This shows that it is necessary to carry out diurnal control of the solution in closed production systems.

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Disinfection of recirculation water from closed production systems

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Abstract

The development from growing in border soil to closed production systems has not resulted in the disappearance of soil-borne diseases. Most root-infecting pathogens also occur in these new cultivation systems. Some pathogens such as *Pythium*, *Phytophthora*, cucumber green mottle mosaic virus and tomato mosaic virus are easily transmitted in recirculation water as is Olpidium, the vector of several viruses. To exclude any risk of dispersal of plant pathogens, the water has to be disinfected before reuse.
Disinfection methods investigated in the Netherlands are heat treatment, ozonization, ultraviolet (UV) radiation, membrane filtration, slow sand filtration and iodination. Currently, water disinfection by heat treatment, ozonization or UV radiation is applied on more than 500 nurseries. These methods are effective against fungi, bacteria and viruses. Membrane filtration is not used due to clogging of the pores and unreliability. Selective disinfection against *Phytophthora* and *Pythium* spp. can be accomplished with slow sand filtration. Iodination is not effective against viruses at concentrations below 15 ppm, but is very effective against fungi at a concentration of 0.7 ppm.

1 Introduction

By the year 2000 all glasshouse crops in the Netherlands must be grown in closed production systems to stop the leakage of nutrients and other chemicals to ground and surface water. This implies the reuse of excess nutrient solution. This drainwater can be infested with pathogens. To exclude any risk of dispersal of pathogens via recirculation water it has to be disinfected before reuse.
Several disinfection methods were tested for efficacy against plant pathogens: heat treatment, ozonization, UV radiation, membrane filtration, slow sand filtration and iodination. As test pathogens a member of the group of tobacco mosaic (TOBAMO) viruses and a *Fusarium oxysporum* species are always used. Sometimes other plant pathogens are involved. Elimination of the test pathogens mentioned also supposes a reliable disinfection against other plant pathogenic viruses and fungi. This article presents a review of possibilities for disinfection of recirculation water.

2 Heat treatment

Heat exchangers are widely used for the pasteurization of milk. The existing data on temperature-time exposures that are lethal to plant pathogens are mainly based on their survival during heat treatment of infested soil by means of steam.
A heating installation on the basis of heat exchangers was constructed by the Institute of Environmental and Agricultural Engineering in Wageningen. Drainwater returning from the plants is collected in a recatchment tank. After filtering out (an)organic particles the drainwater is pumped from the tank into the first heat exchanger, where it is preheated to a certain temperature by heat recovery from disinfected water. In the second heat exchanger the water is heated to the disinfection temperature, using an external heat source. The disinfected water flows back to the first heat exchanger to be cooled down and subsequently be stored in a

seperate reservoir. From this reservoir it is pumped to the central mixture tank where it is mixed with the standard nutrient solution (Van Os et al., 1988).
The disinfection apparatus tested, heated the drainwater in about 2 s to the temperature required. The exposure time was about 10 s. Tomato mosaic virus (ToMV) was eliminated at 95 °C for 10 s. Spores of *Verticillium dahliae* were killed at 90 °C. In the trials with *Fusarium oxysporum* f.sp.*melongenae*, some spores survived the heat treatment (Runia et al., 1988).
On nurseries a temperature of 95 °C for at least 30 s is recommended.

3 Ozonization

Ozone is the most powerful oxidizing agent. Ozone is applied for the disinfection of drinking water and industrial and municipal waste waters. Ozone reacts rapidly and has no residual power. As a donor of electrons (oxidation) to other substances, ozone itself is reduced to oxygen. The possibility of the interaction between reduction and oxidation is determined by the concept of redox potential, which is expressed in volts (Bernard et al., 1991a).
In all trials the water was treated in batches. Water was pumped via the ozone injector into a treatment tank. At the same time nitric acid was dosed to achieve a pH of 4. When the treatment tank was full, recirculation of the water along the ozone injector started. The exposure time to ozone is the filling time plus the recirculation time.
The maximum ozone concentration in water is achieved with a redox value of 754 mV. This redox value was reached in 80 min. with an installation which produced 6 g ozone h^{-1}. Cucumber green mottle mosaic virus (CGMMV) was eliminated after 75 min. of ozonization. Consequently, it was concluded that disinfection was complete when the redox reached 754 mV.
In some situations, however, the redox value of 754 mV was never reached although disinfection was achieved. Apart from micro-organisms also root cells, root exudates, humic acids, pesticides and some micro-nutrients are oxidized in the water by ozone causing a low redox value. Therefore, instead of the redox value, a certain exposure time is used as an indicator for effective disinfection. The elimination of tomato mosaic virus (ToMV) appeared to run parallel with the reduction of the number of non-pathogenic bacteria and fungi. The exposure time is regarded sufficient when the total count of bacteria and fungi is reduced by 99.9 %. Bacterial tests on commercial ozone installations indicated that treating 1 m^3 drainwater with 10 g ozone for 1 h was sufficient to achieve the required disinfection (Runia, 1994a).

4 Ultraviolet radiation

Ultraviolet is electromagnetic radiation of a wavelength between 100 and 400 nm. In this area UV-rays with a wavelength of 200 to 280 nm (short wave) have a strong germicidal effect with an optimum at 253.7 nm (Gelzhäuser et al., 1985). These are called UV-C rays and destroy micro-organisms by photochemical reaction. For the disinfection of drinking water in general terms 20-25 $mJ.cm^{-2}$ is thought to be sufficient, although a dose of 150 $mJ.cm^{-2}$ is required to inhibit *Giardia* cysts (Bernard et al., 1991b).
Two types of lamps were studied for efficacy against plant pathogens: a high-pressure and a low-pressure mercury vapour lamp. High-pressure lamps emit UV-C radiation of a wavelength between 200 and 280 nm, whereas low-pressure lamps emit UV-C rays predominantly of a wavelength of 253.7 nm (Gelzhäuser et al., 1985). High-pressure lamps are less energy-efficient (about 10 % of the power consumption is converted into UV-C) than low-pressure lamps (about 40 % UV-C).
Both installations were equipped with a sand filter, containing 0.4-0.8 mm sand particles, to remove organic material before the water was treated with UV-C radiation.
Trials with the high-pressure lamp resulted in a 90 % reduction in infectivity of conidia of *Fusarium oxysporum* f. sp. *lycopersici* after a UV dose of 28 $mJ.cm^{-2}$. To achieve 99.9 % reduction a dose of 84 $mJ.cm^{-2}$ is required. Infectivity of ToMV was reduced by 99% after a UV

dose of about 100 mJ.cm^{-2} and by 99.99 % after a dose of 277 mJ.cm^{-2}.
When the low-pressure lamp was tested, 70 mJ.cm^{-2} was adequate to eliminate conidia of *Fusarium oxysporum* f.sp. *melongenae*. A dose of 100 mJ.cm^{-2} reduced the infectivity of ToMV by 99 % and a dose of 150 - 175 mJ.cm^{-2} eliminated the virus by 99.9 %. Both high- and low-pressure lamps can disinfect recirculation water providing the required UV dose is achieved.
For commercial installations a UV dose of 100 mJ.cm^{-2} is advised to eliminate pathogenic fungi. For complete water disinfection, including viruses, 250 mJ.cm^{-2} is recommended. These doses are higher than those in this study for a reduction of 99.9%. A margin of safety is necessary because the composition of the drainwater changes throughout the cultivation season and pathogen inoculum levels in the water are unknown (Runia, 1994b).

5 Membrane filtration

In the Netherlands the concept of membrane filtration is well-known in glasshouse horticulture due to the application of hyperfiltration (reverse osmosis, RO) membranes for desalinization of irrigation water. This type of membrane is not suitable for water disinfection because reuse of fertilizers is also desirable. Ultrafiltration (UF) membranes possess a slacker structure than RO membranes and let fertilizers pass. They are usually characterized by their removal threshold, i.e., the size of the lowest molecular weight protein rejected by the membrane. The removal threshold ranges between 2 x 10^3 and 10^5 daltons. Microfiltration (MF) membranes do not change the composition of the solution; only suspended solids, colloids, bacteria etc., are rejected (Bernard et al, 1991c).
Three polymeric cross-flow UF membranes were tested for efficacy against ToMV. The removal threshold amounted to 1 x 10^4, 5 x 10^4 and 8 x 10^4 daltons. The molecular weight of a ToMV particle is about 4 x 10^7 daltons. The purified virus was filtered out by all the membranes tested (Runia, 1989).
Five cross-flow MF membranes were tested for efficacy against *Fusarium oxysporum* f. sp. *lycopersici* and *Verticillium* spp. Two carbon and one polyetherimide membranes of a maximum pore size of 0.5 um only partially rejected both fungi (Runia, 1990). A ceramic membrane with a maximum pore size of 0.1 um filtered out *Fusarium* partially and *Verticillium* completely (Runia, 1991). A polyether sulphono membrane of a maximum pore size of 0.05 um rejected both fungi completely (Runia, 1990).
On account of the unreliability of the MF membranes and the clogging of the pores of both the UF and MF membranes, membrane filtration is not recommended.

6 Slow sand filtration

Slow sand filtration has been applied as part of the purification process for the production of drinking water for more than a century. Wohanka tested this method for efficacy against plant pathogenic fungi. Water passed through a 90 cm layer of quartz sand with a flow of 3-7 m^3.day^{-1}. Mechanical and biological factors are supposed to be responsible for the effectiveness. *Phytophthora* was filtered out completely, but the relatively small microconidia of *Fusarium oxysporum* partly passed the filter. When ceramic material was used *Fusarium*, at a flow of 4 m^3.day^{-1}, was also rejected by 100 % (Wohanka, 1991).
According to the instructions by Dr. Wohanka a slow sand filter was installed in the Netherlands. At a flow of approximately 5 m^3.day^{-1} 17 % of the added ToMV could be traced after one passage through the filter, after two passages 10 % infectivity was left and after five passages 3 %. In a similar experiment with *Fusarium oxysporum* f.sp. *dianthi* in four out of six water samples after filtration the fungus could be detected (Runia, 1993). In all trials the grain size was 0.2-2 mm.
The efficacy of the sand filter improved when a grain size of 0.15-0.30 mm was used; the fungi *Fusarium oxysporum* f.sp. *pisi*, *Verticillium dahliae*, *Thielaviopsis basicola* and *Cylindrocladium scoparium* were completely filtered out and the concentration of the bacterium *Xanthomonas campestris* pv. *pelargonii* was reduced by 99 % (Wohanka, 1992).

At the moment 12 sand filters are tested in the Netherlands. The items to be studied are grain size, flow rate, height of sand layer, effect of temperature and pesticides, and the basic principles of slow sand filtration. This study should reveal the conditions for an adequate water disinfection.

7 Iodination

The greater stability and general utility of iodine, compared with chlorine, are probably responsible for the use of iodine for the disinfection of drinking water. Although human viruses were eliminated with iodine, tobacco mosaic virus proved to be resistant to iodine (HSU, 1964).
This is in agreement with results in the Netherlands about the efficacy of iodine for the disinfection of recirculation water. Initially CGMMV and ToMV were added to drainwater. Suspensions of 50 ml made contact with an artificial resin loaded with 2.3 gram iodine on a shaking machine for at most 30 min. The infectivity of both viruses was not affected by iodine (Runia, 1988). Later on drainwater infested with ToMV passed through a cartridge with iodine loaded resin. A concentration of about 14 ppm had no viricidal effect. A similar trial with *Fusarium oxysporum* f. sp. *lycopersici* proved that conidia of the fungus were completely killed at concentrations of 0.7 ppm (Runia, 1994c).
For nurseries a concentration of 0.8 ppm of iodine is recommended.

8 Conclusions

In closed cultivation systems recirculation water can be disinfected against viruses and fungi. Summarized, the options for water disinfection against both fungi and viruses are heat treatment at 95 °C for 30 s, ozonization with 10 g ozone per m^3 drainwater for 1 h or UV radiation with a dose of 250 $mJ.cm^{-2}$. When the water may be infested with plant pathogenic fungi only, apart from heat treatment and ozonization with the same conditions as indicated for virus disinfection also UV radiation with a dose of 100 $mJ.cm^{-2}$ can be applied or iodine at a concentration of 0.8 ppm. At the moment slow sand filtration is known to be sufficiently effective against *Phytophthora* and *Pythium* species only.

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Application of nanofiltration membranes to control the chemical components of the nutrient solution

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ABSTRACT

The basic performances of thirteen different nanofiltration (NF) membranes for the separation of chemical components in the nutrient solution were studied. It was shown that the NF membrane can be used to change the ionic balance in the nutrient solution fundamentally. General information of the NF membrane and a possibillity of membrane technology for the hydroponics were also described.

1 Introduction

Regulations for fertilizer and pesticide emissions to the groundwater will be established in the near future in many countries. In greenhouse production systems, especially hydroponics, the discharge of a very concentrated nutrient solution will be restricted and it should be recycled. To maintain the quality of the nutrient solution during recirculation, a new system using a nanofiltraition (NF) membrane is supposed. The NF membrane can be used to separate ions which have a very close molecular weight. Different organic acids or amino-acids can also be separated from each other. The NF membrane will be applied for controlling the concentrations of nutrients.

The aim of this paper is to compare the basic performance of some different NF membranes. Before the discussion of the NF experiment, a summary is given about the possibilities of membrane technology for hydroponics and a brief explanation of membrane technology.

2 Membrane technology in hydroponics

Table 1 shows the several disinfection or separation methods of the nutrient solution, which are being investigated or commercially used in practice. The left column indicates substances in the nutrient solution arranged from large to small size. The right column are several methods. Separation of coarse substances, such as leaves, roots, algae, etc., is easily achieved by using a net or screen. Most of the research and development for recirculation of the nutrient solution has been focused on the removal of micro-organisms by using UV, ozone, heating, dissolving chemicals and filtering. But only a few studies are conducted on the removal of small substances, of a size smaller than 1 nm.

The methods which are under investigation now in several laboratories cannot even remove proteins. It is expected that further investigations are needed for precise control of the small substances in the nutrient solution during recirculation.

Membrane methods which are performed with pressure are summarized in Table 2. Substances in the solution are separated with the membrane by pressurizing the solution. The methods, except nanofiltration, have been investigated for a long time and have become the standard operation techniques in chemical engineering.

Recently, NF membranes which had intermediate performance of RO membranes and UF membranes were developed and commercialized[1,2]. The NF membranes have a high salt rejection ability as high as that of RO membranes and also have a flux rate at low pressure as high as that of UF membranes. The NF membrane has an ability to separate low-molecular weight substances which have a very close molecular weight.

For example, inorganic ions such as phosphate and nitrate, organic acids and amino-acids[3,4] will be separated from each other.

An idea of an application of the membrane technology for the nutrient recirculation system shows table 3. Using these membranes, it is possible to separate low molecular weight substances from the nutrient solution. Fundamentally, almost all substances which have a size larger than the membrane pore size, can be separated using an NF or RO membrane.
In practical use it is not easy to establish the recirculation system using the membrane only. In practice, the membrane technology cannot be used by itself. A combination of different methods such as heating, UV radiation, sand filtration, membranes, etc. is very much needed.

3 Control of the chemical components in the nutrient solution with an nf membrane[5,6]

3.1 Method

The membranes used in the experiment are shown in Table 4. Every membrane is more or less charged. For example, 7250 is cationic, UTC-60 is anionic and UTC-20 is an amphoterically charged membrane. Rejection data of sodium chloride supplied by the manufacturer were widely distributed from 10% to 99.5%. Before the experiment, sodium chloride rejection of these membranes was measured at the same conditions, indicated in table 4, because the catalogue data were taken under different conditions. The experimental data roughly agree with the catalogue data.
Flux and rejection of these membranes were measured during a concentration of the nutrient solution from 300 ml to 100 ml. The experiment was performed using a batch cell with a flat sheet membrane of 75 mm diameter at 0.5 MPa, 25 °C and 400 rpm (stirrer bar revolution). Potassium nitrate and di-ammonium hydrogen phosphate were the nutrients of reagent grade and were analysed by ion-exchange chromatography and atomic absorption analysis.

3.2 Results

The phosphate concentration (30 - 100 ppm) and the nitrate concentration (190 - 500 ppm) did not affect the performance of most of the NF membranes, except for a few membranes. All membranes had over 60% rejections of phosphate ions, and the maximum rejection was close to 100%. Rejections of the nitrate ions varied from 20% to 95%. The maximum difference between rejection of phosphate ion and of nitrate ion in the above concentration limits was 55%. It suggests that an ion balance of the drainwater of the nutrient solution can be controlled by the NF membrane. The water flux through the membranes was nearly 30 l.m^{-2}. h^{-1}. The flux of an exceptional membrane, scoring 50% rejection of nitrate, was 5 times larger than usual.
From the point of view of the rejection, BW30 was the best membrane to separate the nitrate ion from the solution of phosphate, because the phosphate rejection of the BW30 membrane was close to 100%. But from the flux point view, UTC 60, UTC 20 and 7450 should be better. To change the ion balance of the nutrient solution slightly, 7410 membrane can possibly be used for this purpose.

3.3 Conclusion

Fundamentally, it was shown primarily that the NF membrane system can be used to change the ionic balance in the nutrient solution. The authors will further evaluate the feasibility of using an NF membrane to separate growth inhibitors such as organic acid from the nutrient solution and remain the useful ions in the solution for plant growth.

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Table 1: Disinfection or separation methods on substances in the nutrient solution.

Substances	Size	Methods
leaf, root, algae	mm	net, screen
micro-organism (pathogen)	um	UV, ozone, heat, chemicals (iodine, H_2O_2,etc.), sand filtration, microfiltration
protein, enzyme, virus	nm	active carbon adsorption, diatomite filtration, membrane
amino-acid, organic acid (inhibitor)		sorption, ion exchange, membrane
organic compounds with low mol. weight (pesticide etc.)		adsorption, ion exchange, membrane
inorganic substance (fertilizer)	Å	membrane

Table 2: Pressure-driven membrane separation methods.

Method	Cut-off particle size or MW	Operation pressure (MPa)
Filtration	10 um -	suction - 0.2
Microfiltration (MF)	0.025 - 10 um	suction - 0.2
Ultrafiltration (UF)	MW. 1,000 - 300,000	suction - 0.5
Nanofiltration (NF)	350 - 1,000	0.5 - 3
Reverse osmosis (RO)	- 350	3 - 10

Table 3: Membrane separation methods of substances in the nutrient solution

Substances	Size	Methods
leaf, root, algae	mm	filtration
micro-organism (pathogen)	um	microfiltration (MF)
protein, enzyme, virus	nm	ultrafiltration (UF)
amino-acid, organic acid (inhibitor)		nanofiltration (NF), reverse osmosis (RO)
organic compounds with low mol. weight (pesticide etc.)		nanofiltration (NF), reverse osmosis (RO)
inorganic substance (fertilizer)		nanofiltration (NF), reverse osmosis (RO), ion exchange membrane (IE)

Table 4: Nanofiltration membranes (NF)

Manufacturer	Membrane	NaCl Rejection in %	
		Catalogue data	Experimental data *
Desalination	G10	30	41
	SH	95-96	97
Daicel	DRA80	80	87
FilmTec	NF45	55	39
	BW30	98	91
Nitto Denko	NTR-7410	10	10**
	NTR-7450	50	40
	NTR-7250	60	59
	NTR-769SR	97	96
	NTR-759HR	99.5	98
Toray	UTC-60	55	86
	UTC-20	60	-
	UTC-70	99.4	99

*) 3.5×10^{-3} mol.l^{-1} (= 200 ppm), 0.5 MPa, 25°C.

**) 3×10^{-3} mol.l^{1} (= 175 ppm).

Development and evaluation of closed production systems

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Abstract

To reduce the environmental pollution of water and soil by the glasshouse industry, closed production systems have been developed and studied for soil-grown crops.
The starting points for designing closed systems were: a leaktight and steamable system, recycable materials, cultivational demands and the integration of labour and mechanization. The testing factors were construction, substrate type and water supply system. The effects were studied in cultivational, technological, labour and economic terms. Moreover, the prospects of closed systems will be indicated in the relatively short term.
Pilot crops were lettuce, radish, chrysanthemum, carnation, freesia and Alstroemeria. The experiments were carried out on both a small and a semi-practical scale. The project was supported by commercial growers and the extension service.
The pilot crops could be cultivated in closed production systems with the same cultivational results as in a soil culture. The closed systems proved to be leakproof and the desinfestation of the system by steaming could be carried out more effectively. A higher production was obtained by shortening the crop cycle (lettuce) or improving the space utilization with mobile systems (lettuce, freesia and Alstroemeria). Although the drainwater was not disinfected, only in the case of lettuce a spread of disease caused a severe reduction in production and quality.
The economic results indicate that most closed production systems are (still) not profitable. Only for Alstroemeria a closed production system on rolling benches seems to have economic perspectives. In the other cases, the running costs of closed production systems are not paid back.

1 Introduction

To reduce the environmental pollution by the glasshouse industry, the Dutch government has issued several goals for the year 2000. One of these goals is to reduce the emissions of pesticides and fertilizers into soil and surface water. The cultivation detached from the soil could substantially contribute to this goal.
In 1993 the cultivation on substrate amounts to about 50% of the total glasshouse area (10,035 ha). The cultivation on substrate differs per sector; for vegetables, cut flowers and potted plants 3306 ha (70%), 765 ha (20%) and 1078 ha (100%), respectively. On 25-30% of the substrate area the nutrient solution is recirculated.
A project has started with the objective to develop, test and evaluate closed production systems for those glasshouse crops which are still being cultivated in the soil.

2 Set-up

The project is carried out by the research stations (Naaldwijk and Aalsmeer) in cooperation with the experimental stations (Horst, Klazienaveen and Westmaas). The period was 1991 - 1995. From different crop categories the following pilot crops were chosen: chrysanthemum (once-over harvested cut flowers), carnation (repeatedly harvested cut flowers), freesia and Alstroemeria (flowering tuberous/bulbous crops), radish and lettuce (once-over harvested vegetables).
A multi-disciplinary approach was chosen with involvement of expertise in the cultivational, technological, labour and economic fields. Besides that, the project was supported by

commercial growers and the extension service.

The starting points for designing closed systems were: system (leaktight, steam-sterilizable, long life span and recycable materials), substrate (quick drainage, reusable and steam-sterilizable), cultivational requirements (such as substrate temperature control and mechanized sowing) and integration of future mechanization in system design (Tas & Van Weel, 1994; Van Weel, 1994).

Closed production systems consist of a combination of three components, the following variants were studied: production system (container, box, gutter, bed and bench), water supply system (spraying, drip irrigation, ebb-and-flow, nutrient film technique (NFT) and aeroponics) and substrate type (peat, sand, pumice stone, lava, expanded clay granules, perlite, mat (polypropylene), substrate-less and soil). In a feasibility study a wider range of production systems had been evaluated (Ruijs & Van Os, 1992; Ruijs, 1994).

In the cultivational, technological, labour and economic fields several observations and measuments were done, such as production, product quality, substrate analysis, leakproofness, temperature control, steaming, labour need, working posture, investments and financial result. The basis for an evaluation on labour and economics has been a fictitious nursery of 1 ha.

3 Results

In this paper the preliminary results will be discussed per pilot crop. Nevertheless, the available figures will give a fairly good indication of the perspectives of the closed production systems. The results in the fields of cultivation, technology, labour and economics will be described seperately.

3.1 Chrysanthemum

The following production systems were studied: a substrate-less bed system in combination with ebb-and-flow, aeroponics, NFT or drip irrigation (on PP mats) and a bed system with peat, pumice stone, or clay granules in combination with drip irrigation.

Cultivation

The closed systems 'ebb-and-flow' and 'aeroponics' resulted in a 5-10% extra production in comparison with the soil culture, in particular during the summer. The other closed systems showed a similar (substrate beds) or lower (NFT and drip irrigation on PP mats) production level. In the NFT system the peat blocks stayed too wet and the roots were infected with Pythium. The hydroponic systems appeared to be more vulnerable, because of the risks of obstructions and faults. This is probably the reason why the good results with 'ebb-and-flow' could not be repeated on a (semi-)practical scale. Chrysanthemum is apparently very sensitive to oxygen deficiency.

With the crop Aster very good results were obtained, especially at higher water supply levels. Even a deep-water system (trial) showed good results.

Technology

The systems consisted of a polyethylene bed. Only for ebb-and-flow and aeroponics cuttings in plugs instead of peat blocks were used and supported by cover plates. The experience is that special attention should be paid to the installation. Especially the connection between the foils and the return pipes (drain outlets) is a weak point. Also the risk of clogging nozzles in the aeroponic system is evident. The system with PP mat and drip irrigation showed an irregular water distribution, so wet and dry spot occurred. It pointed out that the water supply frequency for clay granules (coarse material) is five times higher than for peat. With pumice stone the water supply strategy can be easily adjusted to the circumstances.

Labour

For the system with PP mat the labour need is 7% lower compared with the soil culture, due to easier planting and harvesting. The labour force for pulling out the stems is much lower and also the working condition improves. Harvesting at ebb-and-flow and aeroponics is easier for the same reason, but the total labour need does not differ because of the higher production level. The labour need for the systems with peat and pumice stone is 3-5% higher.

Economics
None of the closed production systems are yet an interesting alternative to soil culture. The 'best' results showed the systems with ebb-and-flow and pumice stone, but the financial result is still by 7 NLG/m^2 lower compared with that of the soil culture. A bed system with coarse substrate and ebb-and-flow seems to have the best prospects.

3.2 Carnation

The closed production systems were: bed and container in combination with drip irrigation and ebb-and-flow. As substrate perlite (coarse and fine fraction) and flugsand were chosen because of their physical characteristics.

Cultivation
The experiments showed varying production results. The bed system with ebb-and-flow and coarse perlite produced significantly better during the first year, but this could not be repeated in the second year. This was due to a system-independent Botrytis infection during winter, because at that time it had the greatest number of young shoots. The container systems showed the best product quality (stem length and weight). The production system with ebb-and-flow was not selected for a semi-practical scale experiment, because disinfestation of the recirculating nutrient solution was economically not feasable. Because of that, an experiment was set up, in which the different closed systems were infected with Fusarium. Eight months after planting no severe damage has occurred yet. Another experiment pointed out that planting of the containers can be postponed for 16 weeks in wintertime and for 8 weeks during summer by lengthening the propagation period. In the meanwhile, the old crop can be harvested.

Technology
In the systems with ebb-and-flow the sheets clogged, which was meant to prevent washing out of perlite into the drain pipe. The desired flood level could not always be reached. It also appeared that an extra drain pipe improves the drainage.

Labour
In general there is little difference in labour need. Nevertheless containers offer the possibility to improve the working conditions. The crop operations of planting and changing of plant material can be done in a shed. Based upon a lengthened propagation period, the labour effects will be calculated, while the old crop is being harvested.

Economics
An economic evaluation is premature, because insufficient figures are available. Nevertheless, it is expected that closed production systems will not be interesting economically. Even extending the propagation period will probably not give that benefit which makes the container system economic feasible.

3.3 Alstroemeria and freesia

The following closed systems were studied: bed, box and bench and water supply by drip irrigation (freesia) or spraying and ebb-and-flow (Alstroemeria). Perlite, pumice stone and clay granules were used as substrates.

Cultivation
Rolling benches increase the space utilization by 30% and proportionally increase the production level. For freesia the expected shortening of the cultivation period (4 weeks) in boxes could not be achieved inside the glasshouse, when sprouting and ripening of the corms took place in climate chambers. The systems with ebb-and- flow showed a higher production level than the ones with a spraying system (Alstroemeria); this is probably due to a lower substrate temperature. The experiments confirmed that cooling of the substrate layer is very important to flower induction. Temperature-sensitive Alstroemeria varieties showed a tremendous increase in flowers and a tremendous decrease in empty buds.

Technology
The substrate temperature followed exactly the pattern of the air temperature, but on a lower level. Cooling tubes near the corms or rhizomes improved the temperature control, but caused an irregular horizontal temperature distribution. The substrate temperature is 0.5 °C lower, when the production system has contact with the subsoil. In substrates with a higher water capacity the substrate temperature will vary less than in substrates with a lower water capacity; water is a transmitter of cold or heat. It also appeared that in production systems with ebb-and-flow the substrate temperature was almost 1 °C lower than in systems with sprayers (conduction). Insulating the production system has hardly any effect. Insulating the substrate surface by styrofoam or wooden chips has a large effect. In boxes the substrate temperature could hardly be controlled in warm/hot periods, because the box itself and the air space between box and tubes prevented a good conduction of cold.

Labour
For Alstroemeria, rolling benches (0.75 m width) improved the working posture. In a practical case crop shifting was carried out easier. For freesia, rolling benches (1.45 m width) appeared to be very unfavourable. The working posture was bad and the risk of damaging the stems in the outside rows was greater. Bed systems on the subsoil with inclined edges were jugded more positive, because the rows in the middle could be reached and harvested better.

Economics
Based upon the preliminary production results, rolling benches seem to have the best prospects, especially for Alstroemeria. For freesia rolling benches can give in the best case the same financial result as the soil culture. Important factor is the extra production caused by the extra space utilization.

3.4 Radish

A bed system with spraying and ebb-and-flow were studied. After a screening sandy substrates were taken further into research.

Cultivation
The first small-scale experiments showed a very poor product quality, especially the tuber colour and the root formation (too branched). Even experiments with sandy substrates resulted in an insufficient product quality. The root formation was still the problem and was taken care in another research project. On the basis of the experiences with lettuce in a substrate bed system on a semi-practical scale, eight experiments were carried out. It appeared that a good product quality can be obtained with an adjusted water supply strategy. Even with glasshouse soil (a sandy soil) the results were positive. Only after five experiments in glasshouse soil, problems occurred with structural deterioration and salty spots. Coarse sand showed the best results.

Technology
Spraying on glasshouse soil had to be carried out more carefully than on coarse sand. The risk of a saturized soil was great. On coarse sand the water supply was first being done by spraying (two weeks). Later on, the water supply was done by ebb-and-flow, and the flood level was

lowered in several steps. The thought was that the roots have to search for water. This strategy appeared to give the best results.
On coarse sand mechanized sowing required more attention with respect to the success of germination.

Labour
In general there is no difference in labour need between the production systems. A difference with the soil culture is that soil preparation in closed systems with coarse sand can be done easier.

Economics
The economic perspectives are negative, because no extra yield is to be expected while the yearly costs of investments increase by 5-6 NLG per m^2.

3.5 Lettuce

Two closed systems were studied: substrate beds (coarse sand, lava and pumice stone) with spraying or ebb-and-flow and gutters with NFT.

Cultivation
In substrate beds nearly the same quality (head weight) could be achieved as in the soil culture, especially in coarse sand with spraying and ebb-and-flow. With spraying, more Botrytis and Rhizoctonia occurred and also the head was somewhat smaller.
A big problem appeared to be the infection and spread of Lettuce vein virus by the fungus Olpidium. The disease was hardly to control and caused severe damage. Apparently the plant material was the source. To disinfect the nutrient solution by heating is only an option for spraying. For an ebb-and-flow system disinfestation is far too expensive.
In the experiments with gutters and NFT the main objective was to optimize the space utilization by shifting the gutters dependent on crop growth. In the beginning the gutters stand next to each other and at the end they stand at end distance. The gutters are transported in four/five steps in one direction. All crop stages occur, so on every day planting and harvesting will take place. It appeared that crop duration can be reduced by 10% compared with a soil culture. Based upon the results (plant date, head weight and crop duration) a planning schedule had been made to calculate the space utilization and production level for 200 g head weight on a practical scale. The results indicate that an increase in space utilization and production of approx. 60% can be realized.

Technology
In the substrate bed system ebb-and-flow required special attention to be paid to the installation. Transport of the gutters was now done by hand, for mechanized transport in practice, mechanisms are already available in Scandinavia (Swegro and Hannestad systems).

Labour
The substrate bed system requires more labour for planting and for cleaning. For gutters the labour handlings will change tremendously, because planting in gutters, placing the gutters on the production line and harvesting the crops will take place on a fixed spot and with a better working posture (standing). It is also possible to move the handlings into the shed. Calculations of the labour need have still to be carried out.

Economics
The bed system will not be an interesting alternative to the soil culture (analogous to radish). The perspectives for gutters with NFT depend on the difference between the extra yield and the extra costs. It is to be expected that the production system and transport mechanism has a (too) high capital input.

4 Conclusions

The results have shown that the pilot crops can be cultivated in closed production systems. Closed production systems - especially the hydroponic systems - appeared to be more complex and vulnerable. In some systems production could be increased by optimizing the space utilization (lettuce, Alstroemeria and freesia) and shortening the crop duration (lettuce and freesia). The closed systems proved to be leaktight and steam-sterilizable.
In general most closed production systems are not feasible economically, because the extra investments and running costs are not being paid back by an extra yield. Only for Alstroemeria rolling benches seem to have economic prospects.

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STUDIES ON A CLOSED HYDROPONIC SYSTEM FOR SINGLE-TRUSS CULTIVATION OF TOMATO

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1 Introduction

Recently, big problems on vegetable production occurred by the increase of aged farmers and a shortage of successors, severe working conditions, lack of environmental preservation techniques, damage by rhizosphere diseases, etc. Tomato production decreased by more than 20% within 10 years, in spite of increased yield during the winter/spring season (table 1). It is known that single-truss cultivation of tomato was adapted for labour saving. Experiments were carried out to clarify the relationship between the nutrient absorption rate and the growth rate of single-truss cultivation by a hydroponic method, and establish a new closed hydroponic system for tomato growing.

2 Methods and materials

Batches of 'Momotaro' (one of the most famous varieties in Japan) were sown into 7.5 cm rockwool pots every other week from September 28th 1990 to September 24th 1991. Four-week-old plants were placed in plastic containers on roller tracks, realizing a new closed growing system. The roller track for is used for transportation, as in an automobile factory. It was effective in the simplification of the cultivation technique. The system also consists of two nutrient solution tanks for recirculation and environmental preservation. Tank no. 1 was filled with a fresh nutrient solution and was used for non-circulated supply (open system). Tank no. 2 tank was filled with drained nutrient solution and was used for circulated supply. The minimum temperatures in an unheated glasshouse were measured, and it proved that these were going down to 4-5 °C during wintertime, while 0.1 mm transparant polyethylene film was covering the plants as a thermal screen (table 2).
Before flowering, all side shoots were removed and the top of the stem was pinched out at the next node order above the first flower cluster. After flowering, less than 5 fruits per plant were maintained by fruit thinning.

3 Results

The growing period of the single-truss tomato plants was about 85 days in the hot season and over 150 days in the cold season. Yields varied between 2.3 and 6.9 kg per m^2. Four cultivation cycles in the glasshouse could be successively realized per year, because the average growing period, including the four weeks in the seedling period, was estimated at 118 days (table 3). From another experiment during the cold season, when minimum temperatures in a heated glasshouse were kept above 12 °C, yield was more than twice as high compared with the unheated glasshouse.
To prevent root diseases, the solution from tank no. 1 was mainly used during the young stage of growth, and the solution from tank no. 2 was used after fruiting (table 4). It became evident that the absorption rate per day of a single-truss tomato plant was 220 ml on cold days and over 600 ml on hot days (table 5). The solution in tank no. 2 did not increase if the remnants of the nutrient solution of the first phase was reused in the second phase and limited to 10-20% of the fresh solution supplied. Higher quality fruits were obtained, when the solution from tank no. 2 was used after fruit colouring (table 6).

4 Conclusions

From the results it proved that the vegetation period of the single-truss cultivation was very short and could be clearly divided into three stages. The first stage was before flowering, the second was the fruit-enlarging stage and the last was the harvest stage. On the other hand, the growing period of the single-truss tomato plant could be divided into two phases looking to the nutrient uptake. The first phase was fixed at the first half of the second stage, this phase is very important for the uptake of the nutrient solution for vigorous growth. In the second phase, hereafter, uptake of the nutrient solution was less important. Here, growth control for high-quality tomatoes is important. It was supposed that the total amount of leached nutrient solution mainly originates from the first phase. If the uptake of the nutrient solution during the second phase is more than the leached nutrient solution from the first phase, a closed hydroponic system for single-truss cultivation is realized.

Table 1: Annual tomato production in Japan.

Year	Total area [w]	Total yield [x]	(*)	Yield /ha [x/w]	Summer autumn yield	Winter spring yield	Proces-sing tomato	Protected cultivation			
								Area [y]	Yield [z]	Yld/ha [z/y]	Ratio [z/x]
	ha	kt		t/ha	kt	kt	kt	ha	kt	t/ha	%
1980	19300	1014	(1.00)	52.5	713	300	285	4900	348	71.0	34.3
1981	18300	945	(0.93)	51.6	652	293	232	5050	355	70.5	37.6
1982	17000	891	(0.88)	52.4	586	305	197	5100	370	72.9	41.6
1983	15800	791	(0.78)	50.1	490	301	210	5350	382	71.3	48.4
1984	15300	804	(0.79)	52.6	504	301	223	5400	393	72.8	48.9
1985	15300	802	(0.79)	52.4	498	304	246	5550	404	72.6	50.4
1986	15200	816	(0.81)	53.7	507	309	251	5750	418	73.0	51.2
1987	15100	837	(0.83)	55.4	514	323	254	5950	443	74.7	52.9
1988	14900	776	(0.77)	52.0	445	331	248	6300	456	72.5	58.9
1989	14500	773	(0.76)	53.3	441	332	238	6650	480	72.5	62.1
1990	14200	767	(0.76)	54.0	425	342	238	6950	498	71.8	64.9
1991	14100	746	(0.74)	52.9	400	346	234	6950	486	70.2	65.2
1992	14000	772	(0.76)	55.1	421	350	240	7050	508	72.1	68.9
1993	14000	737	(0.73)	52.7	366	372	235	----	------	----	----

* ratio of yield, compared with 1980 (1.00).

Table 2: Average minimum temperature in greenhouse* per month between September 1990 and February 1992, measured in Anoh in Mie Prefecture.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1990									21.6	14.8	10.7	6.6	
1991	5.7	4.9	8.7	10.2	14.8	21.0	23.6	23.8	21.5	15.7	8.8	7.0	13.8
1992	6.0	5.1											

* Unheated greenhouse was covered by 0.1 mm polyethylene film for insulation at night.

Table 3: Seasonal changes of the growing period and yield in the single-truss tomato system between September 1990 and February 1992 (cultivated in Anoh in Mie Prefecture).

Crop no.	Sowing date	Flowering date	1st phase days	Min. tmp °C*	Harvest start date	finish date	2nd phase days	Min. tmp °C*	Total days	Fruit no / plant	weight g/pl	Sugar Brix. %
1	90' Sep.28	Nov.17	50	13.7	91'Feb.4	Feb.25	100	6.4	150	4.1	626	7.3
2	Oct.11	Dec. 3	53	12.0	Feb.25	Mar.14	101	6.1	154	4.6	541	6.3
3	Oct.24	Dec.25	62	9.5	Mar.14	Mar.28	93	6.4	155	4.4	407	6.2
4	Nov. 7	91'Jn.18	72	7.7	Apr. 1	Apr.15	87	7.3	159	3.8	337	6.0
5	Nov.21	Feb. 8	79	6.5	Apr.15	Apr.25	78	8.2	157	3.7	304	6.3
6	Dec. 5	Feb.27	84	5.7	Apr.24	May 4	66	9.7	150	3.1	218	6.6
7	Dec.19	Mar. 8	79	5.9	May 1	May 8	63	10.4	142	3.1	215	7.0
8	91'Jan.6	Mar.25	78	6.4	May 13	May 21	57	11.7	135	3.0	219	6.8
9	Jan.16	Mar.29	74	6.4	May 15	May 24	56	12.1	130	3.1	222	7.0
10	Jan.31	Apr. 9	68	7.3	May 22	May 31	52	12.9	120	3.2	242	7.0
11	Feb.13	Apr.17	63	8.2	May 28	June 5	49	14.2	112	3.5	251	6.7
12	Feb.27	Apr.27	59	9.3	June 7	June14	48	16.3	107	3.2	241	5.9
13	Mar.14	May 9	56	10.5	June17	June25	47	18.1	103	3.4	281	5.7
14	Mar.28	May 20	53	11.9	June24	July 2	43	19.5	96	3.5	322	5.5
15	Apr.10	May 27	47	12.8	July 1	July 9	43	21.0	90	3.8	350	5.2
16	Apr.24	June 8	45	14.0	July12	July19	41	22.2	86	3.6	336	4.9
17	May 9	June22	44	17.9	July26	Aug. 2	41	23.1	85	3.7	349	5.6
18	May 19	July 2	44	19.4	Aug. 5	Aug.13	42	23.7	86	3.6	387	5.7
19	June 4	July16	44	22.1	Aug.20	Aug.30	43	23.7	87	3.5	380	6.6
20	June17	July29	42	22.8	Sep. 4	Sep.14	46	23.1	88	3.3	367	6.2
21	July 5	Aug.14	40	23.7	Sep.20	Sep.30	47	22.3	87	3.2	401	5.7
22	July19	Aug.28	40	23.7	Oct. 5	Oct.21	49	19.7	89	3.4	409	5.0
23	Aug. 1	Sep.11	42	23.2	Oct.22	Nov. 6	52	17.6	94	3.4	401	5.3
24	Aug.13	Sep.25	43	22.5	Nov.10	Dec. 4	58	13.6	101	3.3	431	5.4
25	Aug.26	Oct.11	46	18.1	Dec. 7	Dec.28	74	10.1	120	3.3	504	5.5
26	Sep.10	Oct.28	48	14.7	92'Jan.9	Jan.31	95	7.5	143	3.4	558	5.9
27	Sep.24	Nov.12	49	13.5	Feb. 1	Feb.25	104	6.6	153	3.8	459	6.8
Average			55.7	13.9			62.0	14.6	117.7	3.5	361	6.1

* Minimum temperature in the unheated greenhouse are measured in each fase.

Table 4: Nutrient solution in the different plastic containers on July 28 1994.

	Number of plastic containers												Number of containers				
	(A)	1	2	3	4	5	6	7	8	9	10	11	{B}	12	13	14	15
	open system												closed system				
pH*	(6.6)	6.8	6.6	6.6	6.9	6.9	7.2	7.4	7.4	7.7	8.0	7.8	{5.7}	5.4	5.4	5.4	5.1
EC*	(1.2)	1.2	1.3	1.3	1.2	1.1	1.1	1.1	1.3	1.3	1.1	1.4	{5.0}	6.5	7.1	7.4	7.7
P**	(100)	119	113	86	61	99	42	76	61	46	4	21	{501}	703	698	651	702
K**	(100)	101	101	103	93	82	55	62	61	42	46	45	{701}	931	1009	1055	1134
Ca**	(100)	150	143	127	117	141	138	171	172	211	122	187	{454}	786	899	821	858
Mg**	(100)	136	135	125	114	130	116	129	153	144	116	166	{601}	963	1089	1057	1099

(A) First tank solution
{B} Second tank solution

* Reading value from pH and EC meter

** Relative value in % related to Tank A (100%) by ICP detector

Table 5: Growth rate at the various stages of the single-truss tomato growth (sowing date: March 14).

Growing Weeks	Stage	Stem Lgth cm	Wdth cm	Leaf Weight/plt fresh g	dry g	No.* /pl.	Lgth cm	Fruit Weight/plant fresh g	dry g	No./ pl.	weight/ fruit g
2	Raising seedling	5.1	0.20	0.1	0.0	2.0	3.1	0.2	0.0	-	-
4	Planting	19.5	0.52	2.7	0.3	6.2	19.6	4.5	0.6	-	-
6	Pollination	58.0	0.88	40.9	3.4	9.0	37.8	64.1	5.0	4.7	-
8	Fruit thinning	58.3	1.03	75.2	8.6	7.2	38.5	136.0	16.3	4.6	10.4
10	Immature	56.6	1.01	84.4	10.8	7.0	41.1	206.6	22.8	4.6	51.7
12	Pre-Harvest	60.3	1.05	95.6	10.5	7.0	46.4	299.8	31.3	4.8	122.0
14	Harvest	58.0	1.05	86.5	9.4	6.8	44.4	252.6	25.8	5.2	137.1

* Remained leaves

Table 6: Effect of a high concentrated nutrient solution on the fruit quality.

Period	Stem length cm	Leaf width cm	No.*	Length cm	Harvest fruits Date	No.	weight g	Sugar Brix %	Crack. %
Immature Harvest	59.0	1.05	7.0	43.8	June 27	4.8	119.8	6.2	0
Pre-Harvest Harvest	57.9	1.04	7.2	45.9	June 22	4.6	141.7	5.9	8
Control	58.3	1.06	7.0	46.6	June 21	4.6	139.4	5.4	34

* Remained leaves

TRANSPORTABLE BENCHES FOR THE CULTIVATION OF ROSES

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1 Introduction

The production of cut roses in the Netherlands is threatened by three phenomena: high labour costs, poor working conditions and competition from southern countries. Harvest and grading work is responsible for more than 60% of the total labour amount. Automation of these tasks should reduce the labour costs and improve the working conditions.

2 Starting-points for a plant factory

A strategy was developed to try to obtain the automation objective. The basis is the hypothesis that it must be possible to automate the harvest if the flowers are offered to a machine in a manner that the quality of the flower bud as well as the cutting point can be assessed with a sensor. Based on this principle, an imaginary system was designed and evaluated. The characteristics of the system are:

- intermittent single stem production instead of continuous production on a shrub;
- transplanting, harvest and crop maintenance tasks are executed in a central area, with the help of a transportable bench system;
- a limited amount of biodegradable or reusable substrate (e.g. water) is being used;
- the watering system is automatic, and is in principle the same for the rooting and the development stages and is no barrier to automatic transport and handling;
- integration of the existing equipment with a machine vision grading system.

3 Critical factors

An economic evaluation indicated that the chances for this system depend on the costs of the transplants and on the uniformity (in time and quality) of the harvestable product. A good economic result is within reach and is mainly caused by the extra production as a result of increased space utilization when using transportable benches. Based on these expectations, four major research tasks have been defined:

1. Investigate the chances for low-cost mass production of transplants;
2. What cultural treatments are needed to obtain maximum control over production;
3. What role can grading play for uniformity;
4. Design an inexpensive, non-polluting, automated production system.

4 The role of the transplant

The mass production of transplants may be the greatest challenge in this development project. A price reduction by more than 85% needs to be achieved compared with cuttings available on the market today, while uniformity and growth potential need to be guaranteed. Discussion continues about the choice between a system of stock plants to produce cuttings, or plant tissue to produce shoots. Both have their own problems and potentials. Stock plants are expensive and uniformity may be a problem. Right now, cuttings are mainly taken from marketable flower stems, which means that the price of a cutting depends very much on the auction price for a stem and the number of usable cuttings (usually 3-5) that can be made out of it. It was proven that the growth potential depends on the position on the stem. This means that each cutting needs to be graded, which causes extra work and more grades to deal with, which makes the goal of a uniform end-product more complicated. The new stock plant preferably produces one class of cuttings. Development of plant shoots on agar is very slow, probably due to the immobility of nutrients and gases. Production on a flowing liquid medium needs to be developed.

If all plants on a bench are in the same development stage and benches can be moved to other production areas, stage-dependent treatments can be given. Crop reaction to these treatments are much easier to interpret, so optimization of production can be expected. Production on water offers chances for optimum nutrient control and minimum problems in the connection between rooting and production stages.

Grading of the cuttings has shown a positive effect on the development rate and the quality of the flower stem. Further improvement of uniformity to obtain a once-over harvest may be needed. The transportable bench system allows a grading action during the production process.

5 Automation of harvest

If possible, harvest automation should concentrate on the development of a device, that can mow rows of flowers and transport the flowers directly into the grading machine. A robot that harvests one flower at a time may be an alternative, but the cost/capacity rate shall be investigated before actual development starts. The robot may have multiple tasks like planting, grading and harvest.

6 Conclusion

Critical factors for the automation of the harvest of roses are the costs of transplants and the uniformity of the harvestable product. Transportable benches offer a good basis for improved crop quality management as well as automation of harvest.

Conditions and demands for automatic picking of tomatoes depending on the production system

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Abstract

The feasibility of using robots for picking tomatoes in greenhouse crop production is investigated. A traditional production system in a 2-ha greenhouse is compared with simulated systems with transportable benches and a mobile row system. Conditions and demands for inserting picking robots are studied from the management point of view: working hours (6, 12, 24 h), picking speed per fruit (1.5, 3, 6 s), driving speed, handling of picked fruits and economical feasibility.

It should be aspired that a picking robot for tomatoes should work for at least 12 h at a picking speed of at most 3.0 s per tomato, having a driving speed of at least 3.4 m/min. Then, for a nursery of 2 ha, eight robots are necessary, while the space for investment amounts to approx. *ƒ* 89,000.- per robot.

At the time, mobile production systems, such as mobile rows and transportable benches are too expensive. If they are introduced, these systems have advantages (economic, cultural) over the traditional systems. The introduction of mobile systems is not justified by robots performing more efficiently. The feasibility of a picking robot for tomatoes will be realized in the traditional production system much sooner.

1 Introduction

Labour is one of the biggest costs for running a modern greenhouse holding. More than 30% of the total costs are spent on wages for the grower and his employees. Within the various operations crop maintenance (40%), harvesting (32%) and grading (13%) are the biggest in tomato production. For other fruit vegetables there are similar figures. Therefore, it is not strange that people are looking for possibillities to decrease the amount of labour. Automation started many years ago. Now, robots may be introduced to take over the most tedious and repetitive tasks in horticulture (Tillet, 1993), both outside and inside the greenhouse.

From a technical point of view, the harvesting of tomato fruits is one of the most interesting tasks. In the Netherlands, tomatoes are harvested from the same plants during a period of 10 months. The growing area is large (approx. 1200 ha), while the area per nursery is more than 1 ha. The layout of the nursery is rather uniform. Mostly there is a main path in the middle in combination with rather long aisles of 20 to 60 m. In these aisles heating pipes can be used as rails for transport. Summarized it can be said that there is a fairly good technical infrastructure for operating a picking robot.

Tomatoes to be harvested have a different colour. The whole fruit is orange or red and can be distinguished from the others, while the moment of picking is sharply fixed for quality reasons. This demands a high frequency of picking. Besides, the fruits are not hidden behind the leaves of the plant. These factors make detection easier, especially compared with the harvest of green cucumbers of an undefined length and thickness or sweet peppers which are hanging hidden behind leaves and start colouring partly.

From a labour point of view, working in a greenhouse is heavy and is done under poor climatic conditions, while earnings and status of work are low. These are reasons why it is getting more and more difficult to acquire adequate staff. A further automation will be welcomed.

From a management point of view, a picking robot replaces men, but the robot has to work at a certain speed and for a certain quality. Besides the robot has to fit in the total management system. Questions arise whether the robot should move along the plants or whether the plants should move along the robot standing under optimized working conditions. Other questions deal with the economics of the robot (investment and annual costs) and working time and picking speed.

In this presentation, results of a desk study will be presented in which the management side of applying a picking robot for tomatoes is analysed.

2 Methods

Three closed production systems were compared in a simulation study (Ruijs, 1994; Van Os et al., 1991). To have a basis for comparison, a reference holding was chosen in which tomatoes were grown in rockwool lying in long-shaped containers placed in troughs. The nutrient solution was recirculated and disinfected by a heat treatment. Liquid fertilizers were added in the substrate unit, which controls EC and pH.

The alternative production systems were transportable benches with an ebb-and-flow watering system and a mobile row system (Van Os et al., 1993). The transportable benches are 6.2 m long and fits in a traditional 6.4 m span. For transport, pushing lorries push the benches out of a span to the main path. Here, crop maintenance and picking can take place. Afterwards the benches are pushed by another lorry into the adjacent span. Per two spans there is a continuous system. Each bench consists of two troughs in which plants in rockwool can be placed. The nutrient solution is added from a central point to fill the troughs, after a certain time the solution is drained away and recirculated. The plants are grown using the high wire training system.

The mobile row system consists of long-shaped containers, filled with rockwool slabs, which are suspended by wires and connected to a conveyor belt. The belt is driven by an electric motor and fitted above each pair of rows that is continuous around the ends. The system should turn continuously or intermittently at variable speed to allow crop maintenance or harvesting to be performed at a central place, in this case the central main path.

Other differences, essential for introducing a picking robot, between the systems are the number of plants per m^2 and, as a consequence, the yield and the labour demand (table 1).

Table 1: Characteristics of three production systems.

	Plants per m^2	Yield per m^2	Labour demand total h/1000 m^2	picking in % of total
Reference nursery	2.5	50.1	965	27
Mobile rows	3.1	56.3	972	23
Transportable benches	3.4	60.8	1027	23

Although the number of plants per m^2 rises by 25% for mobile rows and by 34% for transportable benches compared with the reference nursery, the yields increase by 15% and 24%, respectively. Since the mobile systems move, a reduction in yield may be expected due to these movements. This reduction is estimated at 10%.

On this basis the financial results were calculated for the three production systems for a 2 ha nursery. The financial result is the difference between the balance (financial output (yield) minus variable costs) and labour costs, overhead and capital goods. Most of the necessary data come from a statitical database (KWIN, 1994).

Knowing the amount of labour necessary for picking tomatoes in the three production systems, the consequences can be calculated if a picking robot replaces human labour. Besides, something can be said about the working time and speed of the robot, the number of robots per nursery, the space for investment and several other problems the picking robot has to overcome. For this the working time of the robot is set at 6, 12 or 24 h. A working time of 6 h

is comparable with the present practice of yielding. At a working time of 12 h the robot is not only working longer and as a consequence cheaper, but there are always people present for control. Working for 24 h means that the grower has to come back at night for control purposes, resulting in additional costs.
The picking speed is set at 1.5, 3 and 6 s for picking one tomato. These times look reasonable for the present time, and also for the near future.

3 Results

3.1 Financial results

First, the financial results are calculated for the three production systems described (Table 2). Only relative figures are given here, because the absolute values are highly dependent on the market price for tomatoes. Now, it is calculated at a market price of NLG 1.50 per kg, which is the average of the last three years (KWIN, 1994). The consequence of this price is a very negative financial result, even for the reference nursery. A market price of approx. NLG 1.70 per kg equalizes benefits and costs.

Table 2: Financial results of two movable production systems compared with a traditional system used as a reference (= 100%).

	Balance	Labour	Capital goods	Financial result
Reference nursery	100	100	100	100
Mobile rows	119	100	133	90
Transportable benches	132	103	125	170

Although higher yields are obtained, labour costs hardly increase, due to the fact that plants come to the workers in the main path. The additional investment for the mobile systems make them very expensive, especially for the mobile row system. The extra yield of 15% does not compensate for the extra costs. For the transportable benches additional investments are quite well compensated for the extra yield of 24%. It has to be said that prices for capital goods are partly estimated; variations may be expected.

3.2 Picking speed and working hours of a picking robot

Using a picking robot for harvesting means that it should be known in what periods and frequencies it has to be used. From KWIN (1994) it is known how many tomatoes per 4-week period should be harvested, and also the necessary frequency of picking. From these figures it can be calculated how many tomatoes should be harvested per time and per plant, and how many seconds one robot needs to pick all tomato fruits within a working time of 6, 12 or 24 h (table 3). For the reference nursery the data are presented in table 3. The production of the other systems is higher, resulting in other picking times per tomato for robot picking.
No big differences can be distuinguished between transportable benches and the mobile row system for the demanded picking time of the robot. The demanded picking time per tomato varies between 0.13 and 0.22 s working 6 h and increases to 0.35 - 0.44 s and to 0.50 - 0.88 s for working 12 or 24 h, respectively. Compared with the reference nursery the difference is caused by a higher yield.
Now, picking of one tomato fruit in less than 1 s seems hardly possible. In other words, at this simulated nursery of 2 ha one picking robot is not sufficient, more robots are needed. Therefore, it is calculated how many robots are necessary when the picking speed per tomato varies: 1.5, 3 and 6 s per fruit, while the total picking work has to be done within 6, 12 or 24 h a day. These working speeds are more realistic for the near future. For the reference nursery the number of robots needed is presented in table 4. The use of robots can be approached

from different sides. There is a minimum number of robots necessary to be used continuously during picking from periods 3 to 12 (table 3). Above that, hand picking is necessary.
A maximum number of robots is necessary if one likes to pick all tomatoes even during the busiest period (5 and 6, table 3). The consequence is that robots are not working for rather large parts of the year. Between minimum and maximum, there is an optimum at which all picking is done by robots for most of the year. Only in periods 5, 6 and 7, extra labour is necessary for hand picking.

Table 3: Demanded picking times per tomato for one picking robot divided over the year and related to production.

Period 4-wks	Yield kg/m^2	Freq. picking	Average fruit weight	Picked toms per plant per harvest	Total toms per harvest	Demanded picking time in s per fruit 6h	12h	24h
	A	B	AFW	C=(A/AFW*B*pl/m^2)	D=C*area*pl/m^2	E=WH*3600/D		
1	0	0	--	--	--	--	--	--
2	0	0	--	--	--	--	--	--
3	1.5	4	50	3.00	149000	0.15	0.29	0.58
4	3.9	10	53	2.94	146000	0.15	0.30	0.59
5	6.2	12	59	3.50	174000	0.12	0.25	0.50
6	7.8	12	67	3.88	192000	0.11	0.22	0.45
7	7.9	12	77	3.42	170000	0.13	0.25	0.51
8	7.3	12	77	3.16	157000	0.14	0.28	0.55
9	5.4	12	67	2.69	133000	0.16	0.32	0.65
10	4.8	12	59	2.71	135000	0.16	0.32	0.64
11	3.9	10	56	2.79	138000	0.16	0.31	0.63
12	1.4	6	50	1.87	93000	0.23	0.47	0.93
13	0	0	--	--	--	--	--	--
Total	50.1	102						

Calculation: In period 4 there are 3.9 kg/m^2 (A) to be picked and it should be done 10 times (B); A divided by the average fruit weight (AFW), by B and by the *number of plants per m^2 (here 2.5) gives the number of picked tomatoes per plant per harvest (C). C multiplied by the greenhouse area (here 19840 m^2)* and the number of plants per m^2 gives the total amount of fruits to be picked per harvest (D). The working time of the robot (WH) divided by D gives the demanded time per tomato a robot should pick.

Table 4: Demanded number of robots and the maximum acquisition value for one robot at a 2-ha nursery for different working hours and working speeds.

Working hours	Picking speed s/tom.	Number of robots minimum	optimum	maximum	Max. acquisition in NLG 1000 minimum	optimum	maximum
6	1.5	6	8	10	98	89	77
	3.0	12	16	20	49	45	38
	6.0	24	32	40	25	23	20
12	1.5	3	4	5	202	179	154
	3.0	6	8	10	98	89	77
	6.0	12	16	20	49	45	38
24	1.5	2	2	3	358	485	257
	3.0	3	4	5	202	179	154
	6.0	6	8	10	98	79	77

It is quite clear that if a robot is working for a longer period (24 h instead of 6 h) or faster (1.5 s instead of 6 s) less robots are necessary and as a consequence the maximum acquisition value increases. A realistic option is to let the robot work for 12 h a day at a working speed of 3 s per fruit. In that case a number between 6 and 10 picking robots are necessary for the simulated 2-ha nursery.

For the same options the maximum acquisition value is calculated. This figure depends on the amount of labour that can be saved. From task times (Hendrix, 1993) it proved that approx. 32 min are necessary to pick 100 kg. That means that the picking time per fruit is 1.2 s. The picking costs amount to NLG 0.0094 per tomato or NLG 147,000 in total for 2 ha for the reference nursery. Picking costs for mobile rows and tranportable benches are higher, because of a higher production and amount to NLG 160,000 and NLG 174,000 respectively. The life span of a picking robot is estimated at 6 years, while maintenance is 1% and interest 3% per year. On this basis the maximum acquisition value for one robot is calculated (table 4). At a working time of 24 h, no adjustment is made for extra labour for control at night. The amounts for investment should be lowered somewhat in that case.

Now, working 12 for h a day at a working speed of 3 s looks like the most realistic option for a picking robot. Table 4 shows that for investment NLG 77,000 to NLG 98,000 per robot is available. Using a minimum number of 6 robots means that an additional sum of NLG 36,000 should be paid for hand picking. For the optimum situation of 8 robots, the additional sum for hand picking amounts to NLG 11,000.

Calculating the maximum acquisition value for one robot for the alternative systems, it proved that this figure was only slightly higher (varying between NLG 80,000 and NLG 100,000 for working 12 h and 3 s picking time per tomato).

3.3 Driving speed and handling

If a robot works for 24 h a day its driving speed may be less than if it has to work for 6 h. The necessary speed varies between 1.7 and 6.8 m/min. In the earlier stated case of 12 working hours and a picking speed of 3 s per tomato, a driving speed of 3.4 m/min is necessary.

The mentioned speeds are averages. From a technical point of view it has to be decided if a robot should move continuously or should stop at every plant at every 50 cm. In the latter case the demanded speed increases from 3.4 to 4.25 m/min. Besides, the robot has to move on the main path from aisle to aisle, which needs a further increase in speed.

In this study no calculations are made related to the way the robot is picking. If the robot has one picking arm, it may pick one side first and afterwards return for picking the other side. Another option is to execute the robot with two arms picking both sides at the same time and returning as fast as possible. To be sure that all tomatoes are picked it is another option to pick approx. 80% on the outward journey and the other 20% on the inward journey. Although tomatoes are not hidden by leaves, they may hang behind other tomatoes to make them invisible from one side.

The driving speed is also influenced by the picking itself. For the reference nursery of 2 ha there are side aisles of 60 m, at which there are 120 plants on either side. Every picking time the robot has to pick 2 or 3 fruits of 65 g per plant. This means that the robot is collecting between 31 and 47 kg per aisle if it transports the boxes. If the robot is only picking, it has to lay aside the picked tomatoes in a box which is transported in another way.

With a mobile production system plants are coming to the robot, but similar problems arise. The driving speed of the plants, or in other words of the mobile rows or transportable benches should match. The handling of the picked fruits can be realized in an easier way, the robot only needs to lay aside the fruits.

4 Conclusions

It should be aspired that a picking robot for tomatoes should work for at least 12 h at a picking speed of at most 3.0 s per tomato, having a driving speed of 3.4 m/min. In that case, eight robots are necessary at a nursery of 2 ha, while the maximum acquisition value amounts to NLG 89,000 per robot. Only at peaks in labour demand during the summer months human labour will still be needed to pick tomatoes.

If only one robot should pick all tomatoes on a 2-ha nursery, it should pick one tomato within 0.15 s while working for 6 h a day, within 0.31 and 0.62 s while working 12 or 24 h, respectively, in the busiest period.

Mobile production systems, such as mobile rows and transportable benches require high investments in capital goods which are partly equalized by higher yields. The use of a picking robot can be realized, but the maximum acquisition value is only slightly higher compared with the traditional production system.
The use of robots in movable systems has advantages above the traditional, stationary system. The picking place can be optimized, resulting in a higher efficiency. The financial space is less, not for the robots, but especially for the production system. The total infrastructure in the greenhouse has to be changed. This is only worthwhile if the production system is feasible.
The feasibility of a picking robot for tomatoes will be realized much sooner in the traditional production system.

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