Hydroponic Green Farming Initiative

Increasing water use efficiency by use of hydroponic cultivation methods in Jordan
Final report

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Referaat

Hydroponic Green Farming Initiative is een project dat in Jordanië is uitgevoerd. Wageningen UR Glastuinbouw heeft de huidige stand van zaken bij telers met substraat geanalyseerd met als doel het productiesysteem te verbeteren en om kennis te verspreiden middels trainingen. Door veel zonlicht heeft Jordanië grote productie mogelijkheden. Daar tegenover staat een gebrek aan (goed) water. Substraatteelt kan een hulpmiddel zijn om water te besparen, hiervoor is echter een hoog kennis niveau nodig. Trainingen zijn gegeven voor groepen (3x) en via discussies met individuele telers. Kleine stappen die te nemen zijn, zijn het verhogen van de ventilatiecapaciteit van bestaande kassen en, zeker in de Highlands, het opvangen van regenwater. Alleen hierdoor is al veel water te besparen. Training aan tuinders en samenwerken van tuinders met elkaar, met overheidsinstanties en toeleveringsbedrijven kan verder verbeterd worden.

Abstract

Hydroponic Green Farming Initiative was executed in Jordan. Wageningen UR Greenhouse Horticulture analysed the present situation at hydroponic farmers with the aim to adapt and to improve where possible and to disseminate results and knowledge to other farmers in training sessions. With large amounts of light the potential yield in protected cultivation is huge. Lack of water might stimulate the use of hydroponics. For this more knowledge is required. Small steps forward can be easily taken by increasing the ventilation rate of traditional tunnels and to collect rainwater to improve the water quality given to the plants (especially in the Highlands) and to save water by using hydroponics. Training of farmers and cooperation between farmers and governmental bodies (research, consultancy) and suppliers are more challenging aspects.

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Summary

The goal of Hydroponic Green Farming Initiative programme (HGFI) was to investigate and to implement different hydroponic farming systems in Jordan to increase the water use efficiency, the profitability for farmers and advance livelihoods. The project was executed by ECO Consult and funded by USAID. Wageningen UR Greenhouse Horticulture was asked to analyse the present situation at hydroponic farmers, to improve where possible and to disseminate results and knowledge to other farmers in training sessions. The project was carried out from 2015 to 2017. For this, three missions to Jordan were executed and a training for staff of ECO Consult and Jordan consultants was executed in The Netherlands. For dissemination 9 fact sheets and 5 monographs were written about specific topics. All results (lessons learned) are reported and discussed, a summary is presented in the report below.

Concerning horticulture, Jordan can be characterized in two different climatic zones, the Jordan Valley, where cropping takes place in winter while summer is too hot, and the Highlands, where in winter it is too cold and cropping continuous during summer. In both regions, light is sufficient, so the potential yields are high. Other factors have to be further optimised: greenhouse ventilation, water quality, soilless cultivation and growers' skills.

The traditional greenhouse single tunnel lacks ventilation capacity, which can be cheaply improved by making a slit of 20 cm after each strip of covering foil. Next steps would be a rolling-up sidewall ventilation with insect netting or a ventilation in the top of the tunnel (butterfly type).

In greenhouse horticulture, a rather poor water quality is used with too much salt and often other harmful elements. As being one of the driest countries in the world there are hardly alternative water sources. However, for changing the traditional growing system in the soil towards hydroponics water quality needs to be improved. First step to get good irrigation water is to harvest rainwater. In Jordan Valley only 250 mm of rain is available on a yearly base, but in the Highlands a substantial amount of 300-600 mm is accessible. Also the use of reverse osmosis water seems to be economical. If a hydroponic growing system is introduced, it can be advised to start with an open system in order to learn all details, after a few years recirculation of used water can be introduced as well. Even in an open system 10-20% water and fertilizers can be saved, while production and quality can be improved. A challenge will be the upgrade of current knowledge of growers. A hydroponic growing system has little water and nutrient buffer, therefore, small mistakes can rapidly lead to large consequences. Especially in the field of fertilizing the crop farmers has to gain new knowledge, especially on the field of chemistry. Frequent trainings could help them.

Another important aspect of hydroponic cultivation is measuring and analysing. EC, pH, temperature, relative humidity, water consumption of the crop by measuring supply and drain are important factors to register.

With this knowledge the crop can be controlled which will lead to higher yields (30-50% is possible), certainly compared to a grower in a traditional soil-grown system suffers from soil-borne diseases.

To bring the knowledge and skills of all growers at a higher level cooperation between growers, consultants and research is a necessity. A hydroponic experimental farm for demonstration of new cultivation methods and training of farmers could be an excellent next step to achieve new skills, higher yields and better quality of their produce. Working together, solving farmers problems funded by governmental bodies and private supplying companies will help to increase the production level.

1 Project overview

ECO Consult executed the Hydroponic Green Farming Initiative programme (HGFI) which was funded by USAID. The main goal was to investigate and to implement different hydroponic farming systems in Jordan to increase the water efficiency, the profitability for farmers and advance livelihoods.
Wageningen UR Greenhouse Horticulture was asked, as leader in hydroponic farming, to carry out the following activities:

- Visit growers and to help them to improve hydroponic cultivation.
- Disseminate results and experiences.
- Assess water sources and their quality issues.
- Deliver fertilizer recommendation schemes and calculation programme instructions.
- Analyse yield responses recorded by growers as well as water savings and feedback measures.
- Discuss the set-up of the hydroponic infrastructure (including the importance of measuring and analysing the nutrient composition by a laboratory).
- Meeting with USAID to discuss progress and future developments.
- Participate in workshops and training sessions conducted by the project.

Additional to HGFI a training for Jordanian specialists was organised in The Netherlands. Furthermore an extension of the project with additional activities was granted. Both activities were funded by USAID.

Time schedule:

- Preparation of the project: 2014.
- Start in early 2015 with a tentative report on the prospects of hydroponic cultivation in Jordan.
- Mission of two WUR specialists in May 2015, August 2015 and April 2016.
- Training course in The Netherlands in January 2016.
- Extension of HGFI included writing dissemination papers in 2nd half of 2016 and a final visit in April 2017.

HGFI worked as a catalyser. In 2016 there was considerable interest in hydroponic farming in Jordan. This was also witnessed by:

- A project called "Investment order" funded by the Dutch Government and private companies to make growers aware of the most profitable investments for their specific climate/price/technology/yield level (2016 – 2018).
- A project of the Dutch embassy to help Syrian refugees to work in Jordan in protected cultivation while strengthening the Jordanian infrastructure by constructing Mid-Tech greenhouses producing for the export market (2017-2019). This project will be coordinated by ECO Consult with participation of WUR Greenhouse Horticulture and other Dutch partners.

In the next chapters, an overview will be given of the most important results (missions, training, dissemination papers), followed by a discussion about experiences and conclusions.

2 Missions to Jordan

2.1 Mission May 3-8, 2015

2.1.1 Activities

As an introduction to WUR specialists, all HGFI participating farms were visited during the first mission in May 2015. In addition, several other companies were visited, too. A wide diversity of crops was shown on hydroponics and in soil: tomato, sweet pepper, cucumber, lettuce, strawberry, basil and roses. For each farm improvements or adaptations were suggested and extensively discussed.

Figure 1 *Banner of HGFI at one of the participating farms.*

2.1.2 Selected lessons learned

1. Many growers were not yet focused on elemental analysis as a tool to understand their crops and cultivation systems. The advice is simply to always start with a supply water analysis to know the required basic corrections of water quality.

2. Some hydroponic systems required almost daily preparation of nutrient solutions. In an open system, without recirculation, it is enough to prepare a nutrient solution every two weeks. This could also be a concentrated (stock) solution in an A and B tank. This will reduce the time required for preparation and will not affect the composition of the solution in a negative way. Adaptations according growing stage can be made every 14 days which is sufficient.

3. Drain analyses were not common. As elements like Na, Cl, Mg, SO_4, and B tend to concentrate it is advised to do a drain analysis every 3 weeks in recirculation and every 6 weeks in open drain systems.

4. As there is no lab for hydroponic nutrient analyses, sending samples to The Netherlands is probably a quick and reasonable cheap option. It is necessary that one organisation takes the lead to prepare the paperwork with an import agent after which packages with multiple samples can pass customs without delay.

5. Greenhouse climate control in single tunnels can be improved by more ventilation to lower the maximum temperature. It seems to be possible to create better tunnels or simple multi-spans without high investments.

6. Light in the greenhouse was often rather poor despite the abundance of sun outside of the greenhouses. Permanent screening resulted from applying a sand/mud mixture, partly by sand/dust blown over the tunnels. A reason for the apparent over-screening was the idea that the temperature can be lowered while ventilation is poor.

7. Substrates to be used should be analysed first, which is not the case. The effect of an irrigation strategy depending on the substrate is unknown. A better dissemination of knowledge on irrigation strategies will help some growers to immediately realise extra yield without any extra cost.

8. More attention should be paid to feedback: measuring and analysing the results in order to understand what the crop needs. For example, know how much water you supply to the plants with a certain EC, pH and how much drain returns with certain, other EC, pH.

9. Use of compound fertilizers is quite popular, but single fertilizers are preferred. Single fertilizers are cheaper and do not contain urea (which can damage a hydroponic crop quite easily).

10. With an adequate irrigation strategy, there is more control over growth, and even steering the plant balance (ratio between leaves and fruit yield) is quite well possible.

Figure 2 *Left: basil in bed with solid substrate; middle: discussion at Al Nimer; right: strawberries in double layer system in coir.*

2.1.3 Output

Blok, C., E.A. van Os, R. Daoud, L. Waked, May 2015.
Jordan hydroponic green farming project; Potentials of hydroponics in Jordan, after 1st visit. Deliverable 2, presentation pdf.

Blok, C., E.A. van Os, 2015.
The Jordan Hydroponic Green Farming project, experiences from first field trips. Wageningen, Report GTB 5084, 52p deliverable 2.

Blok, C., E.A. van Os.
Developing greenhouse horticulture. Wageningen, GTB 5085, 54p, deliverable 1.

2.2 Mission August 16-21, 2015

2.2.1 Activities and lessons on the farms

The trip was characterized by visits to participating farmers. The general theme was: lessons learned. From this point on detailed improvements could be proposed. A few examples:

1. Adaptations for recommended EC (mS/cm) for Jordan compared to The Netherlands:
   a. Tomato: NL = 3.5; Jordan = 2.5 (excluding EC of the raw water);
      - Sweet pepper: NL = 2.4; Jo = 1.7 (excluding EC of the raw water).
   b. Cucumber: NL = 2.8, Jo = 2.0 (excluding EC of the raw water).

Figure 3 *Al Nimr farm with mature tomato, young plants and lettuce on deep flow technique.*

2. Estimated feasible production in Jordan compared to NL:
   a. Tomato: NL = 70 kg/m^2; Jo = 48 (too high in first sight);
   b. Sweet pepper: NL = 35; Jo = 14 kg/m^2;
   c. Cucumber: NL = 80; Jo = 73 kg/m^2;
   d. Cherry tomato: NL = 25; Jo = 16 kg/m^2;
   e. Differences are caused by shorter seasons in Jo, no CO_2, no climate control, no optimised water and nutrient solution. However Jo has more light and higher temperatures. Therefore the potential for improvement is good.

3. A good quality tomato will not be paid in the market compared to traditional bulk quality. Marketing is required here and has to be developed.

4. The impact of not having a local laboratory for analysing hydroponic samples is clear. Often the reaction on a situation has to wait 14 days for the analyses resulta while a reaction within 1-2 days is called for. Steps have to be taken to set-up such a lab.

2.2.2 Activities and lessons at ECO Consult

A yield analysis was made by ECO Consult (Figure 4). Results achieved so far indicate that the average soil production is comparable with soil grown tomato in unheated plastic houses in Spain and similar water consumption. The soilless yield is much higher and comparable with modern Spanish greenhouses.It was concluded that production/quality results were good. Main problem for Jordan growers is how to finance the investments and how to mobilize enough knowledge to avoid the risks of hydroponic growing for many more seasons.

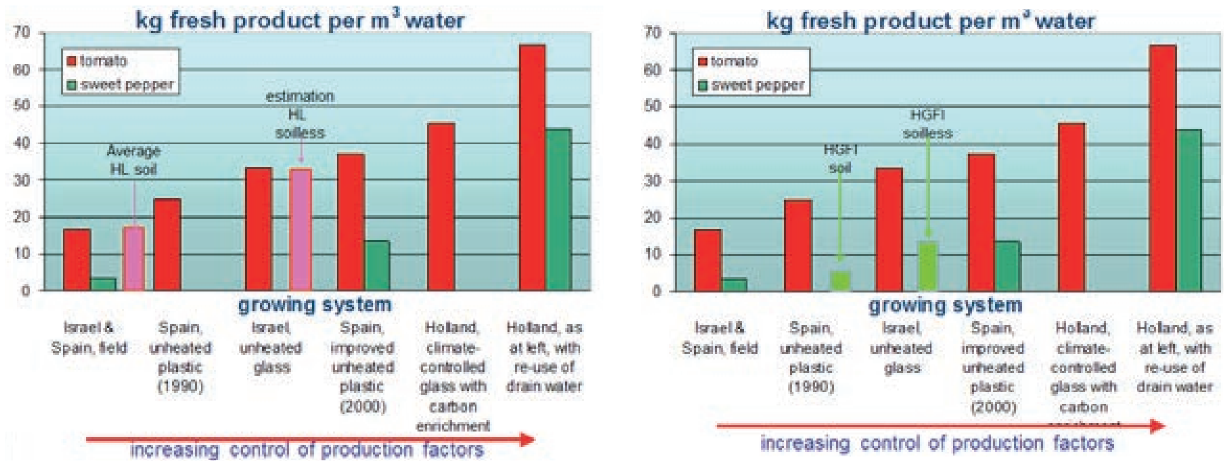

Figure 4 *Comparison of water use efficiency in Jordan (sweet pepper, left) and tomato (right) in various regions.*

At the office of ECO Consult much time was spent on training the staff about how to calculate a nutrient solution. Excel tools were provided. In principle the nutrient solution differs from soil growing. Based on standard recipes (tomato, cucumber, pepper, strawberry, lettuce) in required mmol/l per element, calculations are made toward A and B containers with concentrated fertilizers to be added.

Discussion highlights:

1. Calculations with EC were explained: EC varies linear, while composition keeps the same. Within the same EC, composition can be changed between cations or anions.

2. Use of compound fertilizers makes calculation difficult often impossible (when urea is present). Most recipes using compound fertilizers will have an excess or a shortage of one of the elements.

3. Calculation in mmol/l is preferred by the Dutch as this allows calculated checks on electro neutrality and EC. In most countries, not only in Jordan, people calculate in mg/l. The result is a lack of overview on the calculations and further best guess estimation to bring it to a recipe in kg/m^3.

4. Nitrogen can be given as ammonia (NH_4), nitrate (NO_3) and urea (NH_2). However it is not clear on all labels of fertilizer packing how much from each is inside. Besides urea has no part in EC and other element do. It is potentially very dangerous as urea and ammonia can damage and even kill hydroponic crops while being harmless for soil grown crops.

5. Ammonia fertilizer in soil is very much in use to give some acidity to the soil. In hydroponics at most 10% of nitrogen may be given by ammonia, the other part is nitrate and urea must be avoided. Overdosing of ammonia and urea can be easily done in hydroponics, but should be avoided.

6. All fertilizers should be analyzed before use in hydroponics to avoid potential mistakes.

2.2.3 Activities and lessons at Study Day Meeting

August 19th there was a study day for growers, consultants and others for about 70 participants. Presentations given are placed in output (2.2.1).

Figure 5 *Dr Raed Daoud from ECO Consult (left) and Dr Scott Christiansen from USAID (right) speak to the audience at the August 19 workshop.*

Conclusions from the workshop: hydroponic farming is one of the best techniques for Jordan to overcome local water shortages, while also maintaining a high quality crop standard. It provides a reliable, predictable, and consistent food production and has proven to be suitable for arid and semi-arid regions as it targets the two main growing concerns; including 1) diminishing soil quality and availability, and 2) water scarcity. Hydroponic farming has also shown to be economically and environmentally advantageous to traditional soil farming.

2.2.4 Output

Van Os, E.A., C. Blok, 2015.
Jordan hydroponic green farming project. Experiences from 2nd field trip. Lessons learned and recommendations for improvements. Internal report, deliverable 3, 8p.

Blok, C., E.A. van Os, R. Daoud, L. Waked, August 2015.
Jordan hydroponic green farming project. Workshop modules 2015 08 19 and how to control risks when recirculating water and nutrients, 50 participants, deliverable 4.

2.3 Mission April 3-8, 2016

2.3.1 Activities and lessons on the farms

The farms visited showed great interest again. It was good to see that one of the farms visited for 3rd time did implement the advice given in previous visits (Al Nimer, Al Taji). He also said that because of his water savings he was able to maintain his full area with tunnels instead of closing tunnels because of lack of water.

Figure 6 *Visiting Al Ordan, Al Nimer, Hisham Al Taji.*

Some general remarks:

1. Ventilation in tunnels was poor resulting in higher risks of Botrytis fungi. In general report on system improvements the tunnel itself should not be forgotten (see output, report GTB 5130).

2. Irrigation takes place during day and night, this also favours botrytis (stem botrytis in tomato) which decreases the life of plants resulting in less and poorer yield.

3. Cultivation measures such as pruning of leaves, trusses can be improved by better execution and better timing both.

4. Fertilization is, similar to Dutch farms, a complex topic and not always handled appropriately. Especially the lack of analyses feedback prevents taking the right action at the proper moment. The subsequent losses can amount to 30% yield i.e. all the potential advantage of hydroponic growing.

5. Short time costs are more important than long term profits (coming days against next few months). As fertilizers are expensive, we encountered several growers who decreased the nutrient supply to zero. The lowered ECs result in less quantity and very poor quality of fruits. Unlike in soil growing, the quality loss affects all future results. Growers who need to cut back in fertilizer costs cannot use hydroponics. Hydroponic growers must learn to cut back but not abandon the supply of fertilisers based on analysis data rather than price levels.

6. Water and substrate samples were taken at nearly each farmer and analysed at a Dutch laboratory. Results were discussed with ECO Consult and the specific growers.

2.3.2 Activities and lessons at Study Day Meeting

At April 5 there was a study day for growers, consultants and others. Presentations given are placed in output (2.3.1), there were about 50 participants. The presentations resulted in extensive discussions between participants and speakers about the prospects of hydroponic cultivation for the individual grower and the needs after finishing this project.

Further the extension of HGFI project was discussed between ECO Consult and WUR. The topics mentioned in the contract (visiting nurseries, yield analysis) were similar as in HGFI contract not fully up-to-date anymore. Jointly it was decided to write:

- Factsheets about technical topics, which should be delivered as a leaflet for growers about how to start a hydroponic cultivation (see also ch 4.1). Each factsheet has a length of 1-4 pages with a fixed lay-out. 7 topics were identified;
- Monographs: a more extensive description of a topic which can be used as a background document by researchers, consultants and suppliers. Each monograph has a length of 5-10 pages. 5 topics were identified here.

2.3.3 Output

Van Os, E.A., C. Blok.
Wageningen UR Greenhouse Horticulture trip to Jordan, April 2016; internal report, 16p., deliverable 5.
Blok, C., E.A. van Os, W. Voogt, April 2016.
Substrate growing: basic concepts, pdf presentation, 14p.
Van Os, E.A., C. Blok, April 2016.
Soilless cultivation; system development, crop approach, pdf presentation, 8p.
Voogt, W., C. Blok, E.A. van Os, April 2016.
Fertilisation, nutrient solutions and calculations of recipes. Pdf of presentation, 10p.
Van Os, E.A., C. Blok, L. Waked, A. Hasan, 2016.
System improvements for hydroponic cultivation in Jordan, deliverable 6. Wageningen, GTB report 5130, 28p.

2.4 Mission March, 18-23 2017

2.4.1 Activities and lessons learned at a Hydroponics Course

Between 18 and 23 March 2017 Geerten van der Lugt and Chris Blok visited the JUST University in Irbid, Jordan. They delivered a series of lessons on operating hydroponics. Lessons consisted of 20 modules of 1.5 hours each of which two thirds were held in the class room and one third in the greenhouse. Lessons included the basics of plant nutrition, calculating a nutrient scheme by hand and by using an on line model, and designing and controlling a hydroponic system by using measurements in the greenhouse. The greenhouse was used to practise recognition and treatment of adverse circumstances and the use of EC and pH meters. Alongside there were discussions with project leader ECO Consult about a follow up project, the HAED project, which already started. There were also talks with the Dean of Agriculture and some larger growers/exporters.

The course was very successful for all three subgroups of trainees: students, staff and growers. The group was enthusiastic about the level of hands on experience brought to them and also about the level of interaction brought by the teachers. The accent on dialogue and interaction with the group proved a very good tool including direct questions, educational questions and calculation examples. Students were encouraged to deal with problems in front of the class and to do calculations with the help of the others in the class.

The visits to the greenhouses were very valuable and delivered:

1. First-hand knowledge of what the lessons were about.

2. Learning to detect and diagnose deviations from the normal situation. What do you see? What does that mean? What is the cause? When did it start? How can you act upon this?

3. Learning to sample, measure and evaluate in a practical situation.

Figure 7 *Practical explanation during the training sessions.*

Most topics were easily absorbed by the group but the nutrient recipe and its use proved to be the most difficult part of the course. It was greatly appreciated that a web based tool was introduced which could help the users. Even so the concept of using a standard nutrient solution and then adapt this to a specific nutrient solution to stabilise the desired slab conditions was not properly mastered. Future lessons should have a separate session on the difference and connection between standard irrigation solution, standard slab solution, slab analysis and adapted irrigation solution. It is also advocated to use additional examples to make clear what the absence of proper analysis of drain and raw water can mean.

3 Training course, January 25-29, 2016

3.1 Activities at the Training Course

Additional to HGFI a USAID funded training was organized in The Netherlands for 9 researchers and consultants from 25-29 January 2016. This five-day course enabled participants to discover and explore new and advanced hydroponic techniques that achieve high production of vegetables with a minimum of water and fertilizer use. The main topics tackled were:

1. Introduction, growing systems, water.
2. Basics of plant nutrition.
3. Fertilizers.
4. Nutrient solution recipe and calculations.
5. Growing media and their properties.
6. Water and media sampling, by Aat van Winkel; interpretation and analysing the data, by Geerten van der Lugt.
7. Feedback from analysis and how to make adjustments by Geerten van der Lugt.
8. Salinity and its effect on plant growth.

In addition to these lectures, several field visits were conducted to show the commercial farming systems in The Netherlands and how farmers are controlling and managing their farms. Details of the visits and photos are placed in output (3.1.1).

Figure 8 *Practical and theoretical training aspects.*

After this training course, many issues were clarified. Visiting real farmers and growers at their farms increased the level of understanding of many issues. The HGFI team is now able to give advice and recommendations more deeply and scientifically than before. HGFI will disseminate the gained knowledge to farmers in different areas through field days, workshops, and printed materials. This will enhance the adoption of hydroponic farming, save more water and increase farmers' profits.

3.2 Concluding remarks Training Course

1. The farmer/grower is the main success factor of hydroponic farming systems even with fully automated systems.

2. Greenhouse design, weather control requirements, and level of complexity are determined by the growers abilities and marketing strategies.

3. Fertilizers quality used in hydroponics is of a paramount importance and greatly affects production quantity and quality. Fertilisers for soil systems must not be used to avoid crop damage by salinity, ammonium/urea and trace element problems. Fertilisers especially made for hydroponics and soilless culture are advised. When recirculating, special fertilizers are available for systems with recirculation.

4. Water quality and nutrient solutions affect the quality, quantity, and taste of the product. The farmer himself can control this with on farm equipment.

5. Marginal water could be used for hydroponic farming but requires more attention and knowledge of salinity problems, the influence of salinity on production (production thresholds) and management strategies with salinity.

6. Production of tomato in the Netherlands is higher than in Jordan for many reasons including: better control of the greenhouse climate (optimised temperatures, relative humidity, CO_2, length of season), higher input of technology, more educated farmers, and coordinated (group wise) marketing to achieve reasonable selling prices.

7. Investment in greenhouse industry is very large in the Netherlands. For example, the pepper farm (80 dunums) cost was 8 million euro, 100 EU/m^2. But the revenue is also high due to high selling prices and high volumes of product. The total industry in Holland is 10,000 ha protected cultivation, mainly glass (95%) of which 7,000 ha are grown soilless (hydroponically) and 3,000 ha remaining with soil plantations.

8. Generally there is no just one fixed value or set-point for EC, pH, nutrient concentration, temperature, oxygen concentration etc. Values fluctuate around an optimum. Because the optimums change with the weather the grower has to “play” with the set-points. It is a similar situation for substrate, growing system and variety selection.

9. Record keeping of measurements during cultivation of a crop is very important: you know what you did and can improve in next crop. It is difficult for growers to start to trust the measurements more than the visual crop condition, but the “fly by wire” approach allows much earlier interventions i.e. corrections are made before the crop is in trouble.

10. A national plan should be started to increase the adoption of hydroponics tied with continuous support from government and the donor community:
    a. Improve present greenhouse/tunnel design: use better ventilation.
    b. Design better low-tech tunnels and mid-tech multi-span greenhouses adapted to Jordan’s climate zones.
    c. Create an investment environment that will help growers.
    d. Introduce training facilities and courses in mid tech hydroponic growing.
    e. Test hydroponic growing systems for various crops with different substrates, nutrient composition, temperatures, oxygen concentrations and varieties.
    f. Stimulate the start of a private nutrient analysis laboratory.

3.3 Output

Van Os, E.A., L. Waked, C. Blok, 2016.
Training Hydroponics. Wageningen, GTB report 5114, 120p. (confidential, including presentations)
Van Os, E.A., L. Waked, C. Blok, 2016.
Hydroponic Training Visit. Wageningen, GTB report 1400, 28p. (public)

4 Extension of HGFI

HGFI was in 2016 originally extended with a 6 months period to have additional visits to growers and analysing their progress. At the start of this extension it became clear that the profits of HGFI were in the field of further dissemination of results and experiences of WUR GH and EcoConsult in Jordan. Therefore, it was agreed to write a number of fact sheets (short technical information sheets of 1-4 pages and monographs (5-10p) covering special topics instead of frequent visiting growers. The papers could support ECO Consult in theoretical background and help to stimulate growers and consultants to think about and change to hydroponic cultivation.

4.1 Fact sheets

A factsheet was defined as a short technical topics, which should be seen as a leaflet for growers about how to start a hydroponic cultivation. Each factsheet has a length of 1-4 pages with a fixed lay-out. Nine topics were identified:

1. Design of a hydroponic system: open system. C. Blok, E.A. van Os, L. Waked
2. Design of a hydroponic system: closed system. C. Blok, E.A. van Os, L. Waked
3. Substrate cultivation. C. Blok, E.A. van Os, L. Waked
4. Fertilization in hydroponic horticulture. C. Blok, E.A. van Os, L. Waked
5. Controlling the hydroponic system. C. Blok, E.A. van Os, L. Waked
6. Disinfection in hydroponic systems and hygiene. E.A. van Os, C. Blok, L. Waked
7. Deep Flow Technique (DFT) and Nutrient Film technique (NFT) for the cultivation of lettuce. E.A. van Os, C. Blok, L. Waked
8. Cultivation of tomato. C. Blok, E.A. van Os, L. Waked
9. Cultivation of cucumber. E.A. van Os, C. Blok, A. Kromwijk, L. Waked

4.2 Monographs

A monograph was defined as a more extensive description of a topic which can be used as a background document by researchers, consultants and suppliers. Each monograph has a length of 5-10 pages. 5 topics were identified:

Van Os, E.A., C. Blok, W. Voogt, L. Waked, 2016. **Water quality and salinity aspects in hydroponic cultivation.** November 2016 (7p.).

- Hydroponic cultivation requires an excellent water quality. If the supply water contains certain elements, some applications will not be possible without water treatment. It is recommended to analyse the supply water before starting a cultivation. In particularly high sodium and bicarbonate levels may disturb a smooth growth of plants. Crop specific threshold values indicate the salinity yield decrease. The EC (electric conductivity) is an easy parameter to measure and EC can be used to manage plant growth. Therefore, it is important to measure the EC of the root environment, which is controlling plant growth. To realise the proper EC along the roots, the supply-EC has to be lower than the EC measured in the drain.
  It is not just the quality, but also the quantity of irrigation water which is important. Various sources might be available: rainwater, surface water treated waste water, ground water. Rainwater is one of the best sources (quality). However the quantity in Jordan is limited due to limited precipitation in a short period. Even then it is worthwhile to collect and to use it. Higher yields may be expected. An overview of water sources is given. Depending on local quality and price one or the other source is chosen.

Blok, C., C. van der Salm, E.A. van Os, L. Waked, 2016. **Support document for improved infrastructure for water saving by hydroponics in Jordan** (4p.).

- An independent research centre for applied research on hydroponics is suggested to allow the demonstration of various crops and cultivation systems as well as substrates and fertilisers Results should be disseminated to growers. WUR GH can help to design such demo centres and can also assist in the design of experiments. As long as there is no recirculation of the nutrient solution (yet), experiments will be designed to re-use the discharged nutrient solution in open field cultivations. The realisation of a hydroponic cultivation oriented laboratory is another key activity. Finally, the centres should be organizing open days, inviting growers to see the experiments and the demo centres should publish in technical magazines.

Blok, C., E.A. van Os, W. Voogt, L. Waked, 2016. **Substrates for hydroponic cultivation.** Dec. 2016 (11p.).

- Advantages of using rooting media instead of soil are given together with the main differences in properties with soil. Much attention is given to the consequences of the differences for the application and management of water and fertilisers. In a table, a more detailed comparison between rooting materials is made while showing the properties of interest in various rooting media. The table also makes clear that different rooting material require different information on properties to allow the user to safely use the substrate. The properties have consequences for management, including irrigation and fertilisation strategies. In the second part of the monograph, attention is paid to the composition of the raw water used for irrigation and the influence of salinity on crop yield. It is argued that the yield loss caused by saline water is a monetary value which may be invested to acquire non-saline water either by buying or treating the raw water.

Van Os, E.A., C. Blok, 2016. **Greenhouse construction and light.** Dec. 2016 (7 p.).

- The presently used single tunnel (9x3.5x45m) is not the best option for the local climate either in the highlands or in the Valley. Due to high radiation levels, more ventilation is needed to keep temperatures at a lower level, which will result in a longer growing season and a higher production and quality. A number of measures can be taken to increase production in a present tunnel, such as slits between the plastic covering, more opening and closing of the doors at the top end, application of the sand/mud screen in several steps to utilize light in a better way. In new to build tunnels another design should be considered: shorter, insect nets, movable shadow/energy screen. Constructing multispan greenhouses is a more investment requiring option, but especially in the Highlands it could be competitive.

Van Os, E.A., C. Blok, 2016. **Crop specific hydroponic systems.** December 2016 (9p).

- It is possible to use more than just one system or one substrate for one crop. It is therefore important to know the properties of the substrate and the demands of the crop to construct an optimal system. Tomato, sweet pepper, cucumber, rose and gerbera are world-wide the most important crops hydroponically grown. They have 2-10 plants per m^2 which make it economic to use substrate slabs. Strawberries are mainly growing on racks to increase productivity and quality. Crops with 10-30 plants/m^2 are mainly grown on NFT or DFT, avoiding the use of substrate. In such water-based systems, only nutrient solution is circulating which is excellent for a short-term crop like lettuce. Labour intensive pot plants are grown on tables and are irrigated by ebb/flood. Labour extensive pot plants grow often on a concrete floor. Other cut flowers (chrysanthemum, lisianthus, aster) and vegetables (radish, spinach) with more than 30 plants per m^2 are still mainly grown in soil.

5 Concluding discussion and recommendations

5.1 Jordan climate

The two climate zones with most of the protected cultivation (the Jordan Valley and the Highlands) require a different approach. In the Jordan Valley cropping takes place in winter while it stops in summer. In the Highlands cropping takes place in summer, while in winter it is too cold without heating, reason to stop cultivation. Potentials for a good production are high as there is abundant light. It is the challenge to convert this energy in high production levels. To realise the production potential other factors have to be optimised, such as water, greenhouse ventilation, skills and most probably the introduction of large scale soilless or hydroponic cultivation.

5.2 Greenhouses

The most common greenhouses are single tunnels in which tomato, cucumber, sweet pepper, aubergine, strawberry or lettuce are grown. The 45 m long tunnels appear to be too long for the present climate, resulting in a ventilation rate of about 10% whereas more than 30% is required. There is too little ventilation when using just the top-ends of the tunnel. Other smart and cheap solutions might be to make slits of 20cm after each strip of foil (increasing the ventilation rate up to 15-20%). Next steps would be to make a new design for tunnels with rolling-up sidewalls for ventilation or, more expensive, design greenhouses with top ventilation.
Ventilation improvements are the first step to control temperature, a related next step is to reduce the light entering the greenhouse. In the common single tunnels this is done by spreading a sand/mud mixture over the tunnel. This reduces the light level significantly during all days (light or dark), but temperature reduction is still limited. Higher multi-tunnel greenhouses may use white wash or screens to reduce the temperature increase caused by the light.
A disadvantage of the single tunnels is that insects can often enter the tunnels freely. It is possible to use insect netting to stop them from entering but this decreases the already poor ventilation capacity quite severely (50%). For higher tunnels or multi tunnels, if there is ample sidewall ventilation it is also possible to introduce insect nettings to avoid them to fly into the tunnel.

5.3 Water

As one of the driest countries in the world Jordan should in theory be as efficient as possible with the use of water. In Jordan Valley water shortage of good quality is evident. Growers are dependent on reused water from Amman rather than the water delivered directly from the mountains in the north. Because of the re-use the water is often polluted or too salt. In many locations, the collection and storage of rainwater might be a solution. In Jordan Valley it is problematic with a precipitation of less than 250 mm. In many places, well water is used but this water source is finite and again the quality is often poor, usually containing Na, Cl, and B in too high quantities. The use of reverse osmosis (RO) might be expensive. However, for good productions in hydroponics excellent water quality is required and, consequently, supply water without sodium. In the Highlands, there is more rainfall (300 – 600 mm), here collection and storage might be useful. It decreases the required amounts of other sources of less quality. It is possible to calculate the monetary benefit of using high quality water i.e. the extra yield generated by using this quality. This calculation then shows if buying better water or applying RO are feasible solutions.

The close cooperation between ECO Consult and Wageningen UR Greenhouse Horticulture has led to a broadened understanding of each other’s way of working, methodology and cultural differences.

5.4 Hydroponic cultivation

To change from soil to soilless cultivation means investments resulting in higher yields and more profits. Often the soil is diseased, giving lower yields as potentially possible. Investing in hydroponic systems means caring for an excellent water quality, substrates, irrigation system, drain water collection materials and also increasing labourers' skills. A hydroponic crop is much more sensitive for mistakes as there is hardly any buffer. So, it requires much more alertness of the managers during cropping. Besides a farmer has to learn to work with the new system, the cultivation and the management. Despite all the efforts described hydroponics remain a very appealing solution for the Jordanian circumstances: not only can much more yield and profits be achieved but this is possible with a considerable reduction in water use and fertilisers.

5.5 Fertilisers

Most major international fertiliser industries are present in Jordan. This means that high grade fertilisers are sufficiently available. However, this does not mean it is easy for an individual grower to benefit from this situation. Several issues need to be addressed before growers can confidently find their way between competing brands:

- The availability of crop and crop phase specific fertiliser recipes suitable to calculate with all brands.
- The availability of cheap but robust EC, pH and drain measure equipment.
- Information on fertiliser quality:
  - Maximum allowable amount of ammonium and urea in hydroponics (to limit the possible acidifying potentially different from in soil growing).
  - Maximum amount of sodium which needs to be extremely low for recirculation.
  - Maximum amounts of metals, fluoride to protect the public.
- The availability of fast and reliable routine laboratories to check nutrient solutions.

The largest international fertiliser producers are capable of organising most of the issues above. To stimulate them to do so they could be:

- Invited to regularly visit the demo sites.
- Asked to perform some tasks related to the issues above.
- Invited to speak on grower meetings.

5.6 Feedback/grower skills

One of the most difficult changes for the growers seems to be the meaningful use of measurements and registration. These activities serve to bring feedback information to the grower on the condition of the plants and the functioning of the technical equipment. The whole idea is to get the feedback before problems can be seen on the plant and before they influence production. Feedback is the information you get from the plant or the system with which you can see what is happening and after that you can adapt you set points based on the given/measured data. Some basics are: twice a week measuring the EC, pH of the supply and the drainwater, daily measuring of volume given to the plants and drain retuning from the plants and fresh water input. Registration of yield (kg/m^2) and quality.

5.7 Experimental centre

It is useful to have an experimental centre to disseminate reliable information, to train horticultural workers and to do applied research for growers. To ensure research is focussed on problems growers several safeguards can be applied:

- Establish grower supervision (3-6 per project) of each and every research project separately.
- Scientists are obliged to communicate their plans, progress and results with growers in technical magazine.
- We suggest the facility head is an experienced grower.
- The management team is 1-4 times a year evaluated by a board. In this board growers and supply industry should have an important influence. The board decides on budgets, program focus and organisation.
- Regularly (2-6 times a year) special events are organised showing research experiments and results to interested parties.
- Research is performed and communicated to growers in facilities in the middle of the horticultural industry.
- Nurseries and active growing experiments are visited as part of every meeting; no meeting will be a pure theoretical practise.

The role of the government is to strengthen the education level of people in the agricultural business.

5.8 Future perspectives

Applying hydroponic techniques will bring Jordanian horticulture important strategic advantages on both farm level and the regional / national level:

- Saving of 50% on water input per unit area.
- Saving of 60% on fertilizer input per unit area.
- Safer and healthier crops allowing certification allowing export of Jordanian product.
- Improved greenhouse construction becomes viable allowing growth of a technical infrastructure:
  - Growth of the technical supply industry.
  - Higher yields of better quality in combination with improved post-harvest and transport facilities.
  - More challenging job offers (computerised climate control vs tomato picking).
- It becomes feasible to invest in improved fertilisation and climate knowledge allowing the growth of a knowledge infrastructure:
  - National horticultural education.
  - National and private extension (e.g. NEMA and ECO Consult).
  - National and private research/demonstration centres.

Dutch Horticulture heavily relied and relies on cooperation between growers, research, advice and education. Jordanian horticulture has the opportunity to use the same approach to capitalise on their impressive production potential: there is so much radiation (light) year-round that it is certain yields can be increased dramatically. To do so asks for interrelated actions:
supplying plants at the right time with water and nutrients and at a later stage also CO_2;
controlling temperature and humidity inside an improved greenhouse;
cooperation of farmers, researchers and officials.

5.8.1 At national level

In one of the monographs (see 4.2) a description is given about the improvements required for a water saving infrastructure based on hydroponics (see also 5.3). Water savings of 50% are common when converting from soil to recirculating hydroponics (per m^2 per year of cultivation). As the production will eventually rise to about double the amount now, the increase in water use efficiency (water used per kg product) will be even higher. The government has the opportunity to encourage these developments by using subsidy or tax instruments to stimulate growers to make investments in hydroponics and greenhouse improvements.

The further introduction of hydroponics depends on demonstration and trial centres in which there is a close cooperation between researchers and growers. Farmer-researcher cooperation is Dutch model strategy which starts with an enquiry among growers about their most urgent problems to be solved. A selection is made between crop specific (tomato, cucumber, strawberry) and more general problems (water, crop protection or technical issues as cooling the produce after harvest) followed by a ranking based on urgency (i.e. a specific disease appeared in tomato cultivation last year) and political wishes of the Government (i.e. more efficient use of water and fertilizers or more biological control to decrease pesticide application).

Together, researchers and growers formulate a project approach to solve a specific problem. In joint discussions commitment is created: it is essential that growers are convinced that with the discussed approach the problem can be solved. A project proposal with detailed description is the result.

The project proposal is followed by a funding process. Not all project proposals will be able to find funding. Funding sources are governmental bodies, by a mix of governmental bodies and commercial companies (growers, suppliers, consultancy) or by private companies on their own.

The approved and funded project proposals will start with a kick-off meeting in which growers who want to participate become members of a guidance committee. Those growers in the guidance committee will often meet every 2-4 weeks to discuss progress and results and to adapt the project actions if required. Growers participate because they are the first who can apply the result on their own farm. The guidance committee might be complemented with consultancy or supply specialists. Each member has personal interest, but will also work for advantages for the horticultural sector as a whole.

The close relation with growers also provides information on more fundamental research needs. The close relation with growers also for better and more practical prioritisation. If farmers want to solve a problem in the structure described here, they will have to become active and cooperate with other entrepreneurs to solve their specific problems.

Governmental bodies may influence the direction of research directly with money for funding certain research proposals, but also indirectly by funding open days or other specialized events around a certain topic.
For a more fundamental approach universities can be brought in. In close cooperation with applied research, students can do a master or PhD at the applied level to help to solve practical problems of growers.

5.8.2 At regional/national level

It must become “cool” again to work in horticulture, the image should be improved to attract people to work in the greenhouse industry. It is no longer about hot and dirty work but about applying practical technology and electronic data use. When growers invest in hydroponics and greenhouse technology, more specialists are required (technicians for hydroponic installations, specialist for recognizing diseases and to execute pest management, for post-harvest aspects, administrative workers). When such more skilled people are required, capacity building by vocational and mid-level technical education is very important. The Jordanian general and technical educational system is good but the agricultural educational system needs to be thoroughly adapted.

Another way to further local activities is to stimulate partnerships between local and international suppliers. Such partnerships make sense on several levels:
- The turnover of suppliers is equally large as the turnover of the growers.
- Supply industry technicians are the most frequent input of knowledge and information for most growers.
- Foreign partners can bring high level information and training to Jordanian technicians as well as access to international practical and research information (knowledge back up).

5.8.3 At farm level

The farmers decide on investing in hydroponic technology and greenhouse technology. These steps have important consequences:

- The grower and his staff need high level training to deal with the new technology.
- Yield and yield quality levels have to increase enough to pay for the investments.
- To improve market performance, products need to be certified for selected markets which includes investing in post-harvest and transport systems.

This will deeply change the existing horticulture in cheap seasonal half tunnels. It is however the only way to maintain a viable horticultural export sector in Jordan.

To explore
the potential
of nature to
improve the
quality of life

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Wageningen University & Research, BU Greenhouse Horticulture initiates and stimulates innovations for a sustainable protected horticulture and a better quality of life. This is achieved by partnering with primary producers, the supply sector, plant breeding companies, the scientific community and governments in applied research.

The mission of Wageningen University & Research is 'To explore the potential of nature to improve the quality of life'. Within WUR, nine specialised research institutes of the DLO Foundation have joined forces with WUR to help answer the most important questions in the domain of healthy food and living environment. With approximately 30 locations, 6,000 members of staff and 9,000 students, WUR is one of the leading organisations in its domain worldwide. The integral approach to problems and the cooperation between the various disciplines are at the heart of the unique Wageningen Approach.