Towards a More Sustainable, Water Efficient Protected Cultivation in Arid Regions

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Abstract

The first step towards a more sustainable, water efficient greenhouse is made through the application of soilless culture. Numerous studies have shown that separating the root zone from the ground increases water efficiency up to 5 times since the process of irrigation is well controlled. Monitoring of the irrigation water and the drain water is an important aspect when applying this method. The ultimate system in terms of water saving is a closed greenhouse. No air exchange between the greenhouse air and the ambient is needed so no water is lost. Using a dynamic simulation model which acts as a virtual greenhouse, the operation of the Pad & Fan system and the closed greenhouse is evaluated under climate conditions in Riyadh. Water consumption is reduced by 95% and biomass production is increased by 75% due to the increased carbon dioxide level and the optimal climate. Almost 4 GJ of cooling is needed annually with a maximum cooling capacity of 650 W for the closed greenhouse.

INTRODUCTION

Water scarcity is becoming a major problem all-round the world. Specially in the Gulf region where rainfall is minimal (Wikipedia) and current agriculture relies on deep water resources. As these resources are depleting, alternative resources have to be exploited and the remaining water has to be used more efficiently. The main source of water in Saudi Arabia for example is coming from groundwater (Fig. 1). This source is especially used for agriculture en forestry. Domestic water is produced mainly from sea water using reverse osmosis. At the same time there is a need of food production in the Gulf area, countries want to be more self-supporting in their food production. With an increasing population this increases the strain on agriculture. Furthermore consumers are tending to become more demanding in terms of food safety and quality which leads to more sophisticated production methods.

SOILLESS CULTURE

Water is used for agriculture in Saudi Arabia to irrigate the crop and to cool the greenhouse by evaporative cooling. Still a lot of production is done in the soil which increases the water use since the water supply is not related to the water consumption of the crop and the fact that the soil is usually sand which does not hold water very well. Increasing water efficiency can be done through the application of soilless culture (Van Os, 1999). The water demand of the crop can be related to the drain measurement so the water is used more efficiently. This water saving measure should be simulated since it is very effective and is investment costs are low. State of the art irrigation systems (Fig. 2) use the water most efficiently but the investment costs are higher and proper management of these system is crucial.

CLOSED GREENHOUSE

Cooling of greenhouse in arid regions is done by evaporative cooling. The transpiration of the crop forms an important part of the cooling usually in combination with a mechanical system such as pad and fan. The evaporated water is not reclaimed for the air and is therefore lost. As a result the water use for agriculture in arid regions is high. The only alternative method of cooling is convective cooling where a cold surface is used. Through the application of this method the greenhouse can be closed meaning no air exchange between the greenhouse and the outside is needed. The heat and moisture is removed for the greenhouse air using a heat exchanger through which cold water is pumped (Fig. 3). The water is reclaimed using this method and can be reused.

Closed greenhouses are the ultimate production systems since the greenhouse climate can be regulated optimally independent of the outside climate. Furthermore all the water used will be recycled in the system, drastically increasing the water efficiency. Carbon dioxide enrichment can be applied in these greenhouses which can increase production by 40% (Nederhoff, 1994) given the proper climate. A production of more than 100 kg of tomato per square meter of greenhouse is possible given the amount of solar radiation available in the Kingdom of Saudi Arabia and the reference cases in the Netherlands (Groenten en Fruit, 2010). Carbon dioxide can be supplied by pure CO_2 or by burning natural gas. Finally pesticide use is decreased as insects are kept outside, which increases food safety.

MATERIALS AND METHODS

The cooling need depends on the solar heat load inside the greenhouse and the convective heat load as the outside temperature is higher than the greenhouse temperature. The heat released in the greenhouse is transformed into sensible heat which increases temperature as well as latent heat through the transpiration of the crop. Both forms of heat have to be removed by the coolers in the greenhouses. The fluxes described are used in a model which acts as a virtual greenhouse providing all relevant information on the greenhouse climate based on the greenhouse design and the climatic conditions. The model has been validated using experimental data (De Zwart, 1996). The pad and fan system has be modelled by added water vapour to the greenhouse air and extracting the latent heat of this vapour at the same time combined with air exchange between outside air. The heat exchanger used in the closed greenhouse is modelled as a cold surface with a heat capacity from which heat is being extracted to reduce the temperature. The heat and mass flux between the heat exchanger and the greenhouse air is modelled.

RESULTS

Table 1 and 2 show the main results from a dynamic simulation model which was used to simulate the Pad & Fan system and the closed greenhouse using the climatic data of Riyadh. These results are directly calculated from the fluxes in the model. The water loss (Table 1) for the Pad & Fan system is high since all the water being evaporated by the crop and the pad is lost. The water loss for the closed greenhouse results from air leakage of the greenhouse and dehumidification with outside air.

Other relevant parameters are shown in Table 2. The maximum temperature in the closed greenhouse depends on the amount of cooling capacity available. Calculations showed that a conventional greenhouse needs a maximum of 650 W of cooling capacity per square meter of greenhouse. Far less that the maximum solar radiation of 1100 W since not all the radiation is entering the greenhouse and a large part is being reflected. On an annual base 4 GJ of heat has to be removed from the total of 7 GJ of solar energy. Assuming the heat pump which generates the cold water operates with a coefficient of performance of 3, the electricity consumption is 361 kWh per square meter of greenhouse on an annual base. These numbers together with the other numbers mentioned in Table 2 are used for the economic evaluation of the closed greenhouse which is presented in the paper “Is a Sustainable Protected Horticulture in Arid Regions Economically Feasible?” (Campen, 2012).

CONCLUSIONS

Technology is the key to increase water use efficiency for agriculture in arid regions. The water is used more efficiently since less water is used and the production is increased. Aside of this the quality of the production will also increase and the use of pesticides will decrease making the food more healthy. Technology comes at a price though and it has not been tested in practice under the arid conditions. The practical and economical feasibility of these technologies have to be demonstrated and introduced so protected agriculture in arid regions will be possible in the future.

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Tables

Table 1. Annual water consumption of the pad and fan system and the closed greenhouse.

	Pad and fan	Closed greenhouse
Transpiration (L)	1200	1063
Evaporative cooling (L)	3260	6
Total water loss (L)	4460	180

Table 2. Parameters to compare the pad and fan system with the closed greenhouse.

	Pad and fan	Closed greenhouse
Maximum temperature (°C)	34.8	30.5
Biomass production (kg)	11.4	19.9
Carbon dioxide supply (kg)	-	34
Cooling need (MJ)	-	3900

Figures

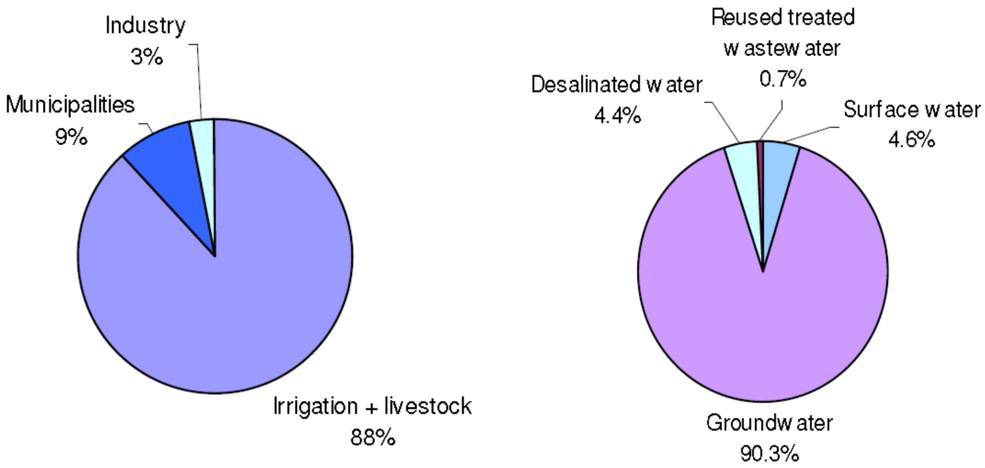

Fig. 1. Water consumption by sector and water sources in Saudi Arabia (source: FAO Water report 34, 2009).

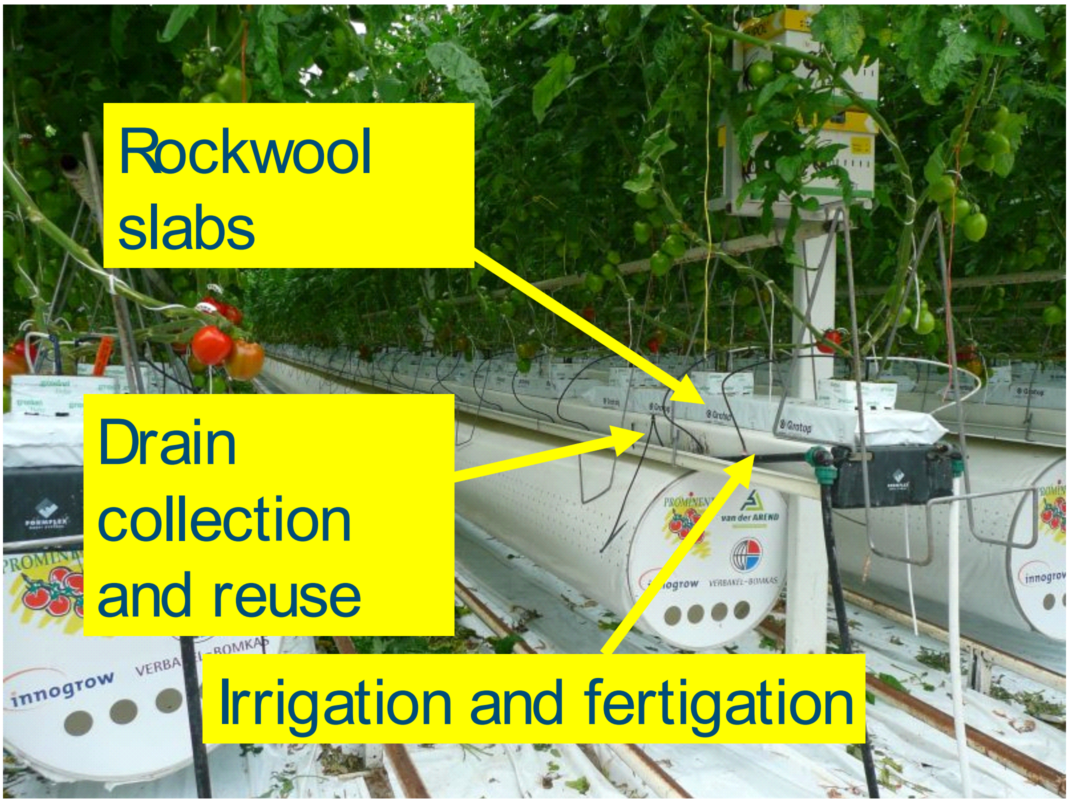

Fig. 2. State of the art irrigation system with drain water collection.

Fig. 3. Heat exchanging units hanging above the crop in the closed greenhouse.