Structures and Climate Control for Protected Agriculture in Arid Environments

Structure and Covering Materials for Greenhouses in Arid, Hot Climates

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Abstract

To check the suitability of a region for protected agriculture, the climate data should be compared with those for other regions and with the main requirements of the plants. The choice of greenhouse structure and covering material depends on the main problems of plant production at the location, the requirements of the plants, the general design criteria for the region and on the available construction materials. Greenhouses should be built less in accordance with national traditions and more with regard to general cropping needs and conditions of the climatic zone where they are located.

Greenhouses for arid zones should have the following characteristics: good light transmission; effective ventilation; sufficient tightness (resistance) to sand, dust and loss of moisture; wind-proof construction; low-cost construction; evaporative cooling if necessary and possible; avoidance of heat loss at night; simple but efficient solar desalination system; low operating cost.

Besides conventional constructions, special closed-system greenhouses have been developed for desert regions, which have good energy balance and water-saving operation. Incoming heat energy during the daytime can be reduced by the shape of the greenhouse and by specific covering materials, which reduce the transmission of near-infrared radiation (above 600 nm).

If the outside air humidity is not too high, evaporative cooling may be necessary. Fan-and-pad cooling systems are sensitive to sandstorms and direct solar radiation. Operation with brackish or saline water is essential, but the pads tend to clog with salt and sand. A simple spray cooling system has been developed which is more resistant to desert conditions, and is highly efficient.

Greenhouse Climate Control in Arid, Warm Countries: State of the Art and Prospective

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Abstract

Protected agriculture has expanded markedly in the Mediterranean region over the past 20 years to help improve agricultural productivity. However, the plastic houses commonly used are designed for temperate or moderately warm regions and need upgraded climate control to overcome overheating in summer and overcooling in winter when used in warm, arid regions. The greenhouse climate is dictated by: the soil inside the greenhouse, which constitutes the major thermal mass; the 'greenhouse' effect itself, which can be controlled mainly by ventilation in most greenhouses; the crop's transpiration, which has a dominant effect on temperature and vapor-pressure deficit. Structures commonly used in the region are small (low and small volume) and have inappropriate roof-slopes (reducing light transmission); taller structures with appropriate roofs would improve light transmission, ventilation, inertia against external climatic variations, and drainage of condensation. Few greenhouses in the region are heated, and the economic benefit of heating has yet to be proven. Cooling is, however, essential and several methods are available—static or forced ventilation; evaporative cooling (pads, misting, sprinkling); shading (screens, white-washing). Roof ventilators are efficient, but present practical problems because of their location. Evaporation is the most efficient cooling mechanism, especially if the outside air is dry, but many systems require good-quality water. Shading has good prospects, but requires further research. Information (real-time data) is required for adequate climate control—this is generally lacking in the region; however, the cost of sensory equipment is likely to fall to affordable levels. Modeling and simulating crop-responses to management decisions in greenhouses also have potential for improving climate control, coupled with questions of economics, technology adaptation, and suitability of different crops. Overall, technology is not the main constraint to efficient climate control of greenhouses in the warm and arid regions, rather the need is for adapting the technologies developed for temperate climates, and training the farmers in the proper management of improved structures and equipment.

Summary of Major Issues Arising and Discussion

Greenhouse Design and Structure

The prevailing greenhouse structure in the region is still the single-span, round-arched tunnel covered with a single-layer polyethylene (PE) film of 200 µm. The disadvantages of this type of greenhouse were underscored by several speakers. This design should be improved in order to avoid problems encountered with ventilation requirements, insect-proofing, useful cultivated area and climate control. It is also necessary to arrange for gutters in order to collect rainwater in a reservoir. Therefore, there is a need for guidance on a suitable greenhouse type for the region as well as norms and standards for construction parts and covering materials. During the lectures and discussions, the following recommendations were made on possible improvements.

- The roof shape and inclination should allow water condensation droplets to slide down and the greenhouse volume should be increased (multi-span greenhouses are more suitable).
- The recommended greenhouse orientation for a single-span round-arched greenhouse is east–west when light is the limiting factor during the winter months; however, the greenhouse may be oriented differently according to light interception, wind resistance and ventilation requirements. It was recommended that a technical leaflet be prepared to assist growers in orienting greenhouses according to local conditions.

There are a certain number of large-scale greenhouses in the region run by commercial companies. These companies are pressured by sales agents and do not have easy access to specialized services from experts with a technical background from whom they can get pertinent unbiased technical advice on investment or general crop management. To fill this gap, it might be useful to establish a technical advisory committee (composed of national focal points) at the national or regional level from which commercial growers can seek advice and technical assessment.

Covering Materials

The predominant covering material , because it is the cheapest is UV-stabilized 200 µm PE film. Other types of film should be tested, including anti-drop and infrared-opaque films as well as other new films. (such as a recently imported multi-layer film from India to Qatar). Films with IR-opaque properties could be recommended for inland sites to decrease the high radiative heat losses during clear nights in winter and increase greenhouse and plant temperature.

It may be worthwhile to make an agronomic and economic assessment of cheaper 100–120 µm films which have a life of only one year. It was emphasized that it is of utmost importance to have the film properly fixed to ensure that the greenhouse is tight, and to avoid direct contact with the steel pipes, which have to be protected against overheating.

There are already some positive results on the use of photo-selective films. However, additional research and validation are still required before they can be recommended to the growers. Their effect on the behavior of insects inside the greenhouse needs further study.

There is no advantage in using double films if the film is not well fixed and the greenhouse is not perfectly tight. Good results can be obtained using single-layer covers which are properly fixed.

Climate Control

The temperature inside the greenhouse should be adjusted in relation to the requirements of the species grown and not necessarily with respect to the temperature difference between outside and inside. The temperature inside the greenhouse should be monitored in relation to the vapor-pressure deficit (VPD).

Heating

Some countries have reported frost damage, which has sometimes destroyed the crop. Supplemental heating using simple low-cost (gas or oil) burners with hot-air blower or hot-air-distribution plastic sleeves is recommended.

Consideration could be given to the potential for the use of a passive solar heating system; however, this system only allows heating by a few degrees (3–5°C) above the outside temperature. Its effectiveness, particularly when the air temperature goes below zero, is not well established. Furthermore, the efficiency of the system diminishes as the plants grow and cast shade on the solar water-tubes inside the greenhouse.

Cooling

In order to extend the growing period (i.e. from May to September), cooling is needed. Where fan-and-pad cooling is available, the farmers need advice on proper operation of the system. Some simple recommendations are, for example, that pads need to be protected from direct sunshine and must never dry out, implying that water has to be applied in excess. In addition, brackish water can be used. Horizontal pads using water in excess can work perfectly well, and may be preferable to vertical pads. Commercial pads, which become clogged, should be replaced. To provide the growers with this type of basic information on fan-and-pad management, simple extension leaflets could be prepared and disseminated.

Experiments should be conducted on improved cooling systems (evaporative cooling). Preference should be given to technology that can be locally manufactured and maintained with nozzles adapted for use with brackish water.

Positive-pressure cooling systems need further study, including economic comparison with negative-pressure cooling systems.

Positive-pressure evaporative cooling system at the Research Station of PAAAFR, Kuwait

For evaporative cooling systems, the instructions provided by the manufacturer are to be carefully observed when mounting and operating the system.

Evaporative cooling depends on outside humidity and its efficiency has to be calculated. The use of air-conditioners is too expensive for greenhouses. In order to improve the efficiency of cooling systems, lowering the humidity of the incoming air before it enters the greenhouse would be very expensive.

For solar desalination of water for cooling or irrigation, active desalination systems are more efficient than passive ones. The energy required for pumping can be obtained from photovoltaic panels (probably only economic in remote areas). Technical details were given of an experimental solar desalination unit studied at the Technical University of Hanover. Its capacity was 4–5 L/m² for an average radiation of 5.8 kW/m² day. The actual capacity will be dependent on the solar radiation prevailing at the site where the unit is used. Eventually this technology could also recycle the drainage water.

Shading
In late spring and summer, high temperature prevails in the region. In order to reduce the requirements for cooling, some type of shading could be used. The most appropriate combination of shading with ventilation and/or cooling needs to be investigated further. A preliminary assessment could be made through modeling based on available climate data.

Ventilation
The type of ventilation required is linked to the height and the volume of the greenhouse. In static ventilation, the higher the greenhouse, the better the chimney effect. When forced ventilation and cooling are applied, the height of the greenhouse can be more restricted (3.2–3.5 m).

Forced ventilation can be recommended for climate control. It is more efficient than static ventilation and can be easily automated. The efficiency of forced ventilation is limited by the distance between the fan and the pad (about 35 m). The system should be properly calibrated in order not to exceed an air velocity of 0.5 m/s in the greenhouse. Precautions should be taken to avoid sucking insects entering the greenhouse—adequate insect-proofing is needed.

Humidity control
Plant growth may be negatively affected by the reduction in air humidity due to excessive ventilation with incoming cool and dry air during the winter. Therefore, it may be necessary to regulate the fan speed and the number of air renewals to avoid water stress or increased water consumption. The control of humidity inside the greenhouse based on the adjustment of the air VPD could be a subject for applied research in the medium term. At VPD values exceeding 20 millibars, stomata begin to close and plants may suffer more or less severe water stress; here, applying intermittent cooling is a possibility, even in winter, spring and autumn, because it can be used to lower the VPD.

Carbon-dioxide enrichment
The need for CO_2 enrichment is not clearly established for greenhouses in the Arabian Peninsula in view of the prevailing high radiation during winter months. Furthermore, the need for prolonged ventilation periods during the day represents an obstacle to efficient CO_2 enrichment.

Automation
Simple automation for ventilation and heating, as well as for irrigation, is required.

Concern was expressed with regard to situations where high temperatures prevail combined with high humidity outside the greenhouse (RH>80%). This could be managed through more efficient ventilation, combined with shading.

Simple automation devices would be helpful to improve climate monitoring. This may require further investigation which could be undertaken through existing models using climatic parameters specific to a given region.

Site Selection

The region is endowed with very favorable climatic conditions for greenhouse crop production during winter. When compared for example with Almeria in Spain, it can be deduced that the Arabian Peninsula countries have the environmental and agronomic potential for producing high-quality vegetables, which could compete on export markets. The best regions for greenhouse crop production are located in the coastal zones. The humidity in winter should not be a handicap provided that ventilation is managed in a convenient way. In the continental areas with greater temperature amplitudes, the conditions are less favorable—because of cooler nights during winter, heating will be required, and because of very warm and dry weather in summer, cooling systems will be essential for growing crops during this period.

Therefore, it is recommended that the agro-climatic characterization that has already been initiated to identify the areas with the best potential for the greenhouse-crop sector (temperature, solar radiation, evapotranspiration potential (ETP), water availability and quality) be completed. This information could be processed and analyzed using geographic information systems (GIS) and the experience of the Central Laboratory for Agricultural Climates, Egypt (CLAC) in agrometeorology.

Agro-ecological characterization is of primary importance for the selection of the best sites for greenhouse establishment. Agricultural extension staff and growers should have this information available to enable them to select the most appropriate microclimates and areas. APRP is already collecting and processing agro-ecological information within the region.

Concern was expressed with regard to methodologies of technology transfer to the producers and farmers. The solution of establishing ‘model’ or ‘reference’ greenhouses was envisaged which would allow the farmers to see and compare the proposed improvements.

Future Activities and Research Priorities

Priority Target Area and Beneficiaries

Research and demonstration should concentrate on simple, low-cost technologies affordable by small- or medium-scale growers.

In general, the activities proposed belong to one of the following groups:

- Training and demonstration for technology transfer
- Technical guidelines and demonstrations
- Applied research and demonstration for investigation and validation
- Information management and databases.

Activities have been classified in three categories based on the time estimated for producing an impact or quantifiable output: short term (activities which could be initiated immediately), medium term (activities which could be initiated as soon as possible and should produce tangible results within three years), and long term (activities which could be initiated as soon as possible and should produce tangible results within five years or more).

Short Term

There are a certain number of technical improvements which could be immediately proposed to the growers and are expected to have a positive impact. It is therefore suggested that training activities for existing extension field officers and growers be undertaken.

Selected technical topics for immediate improvement at the farmers' field level are:

- Orientation of greenhouses
- Fitting of plastic films
- Proper installation, operation and maintenance of fan-and-pad cooling systems
- Shading of greenhouses.

S.1. Training

S.1.1. Training of trainers and government technicians (extension services) for interaction with farmers:

- Prepare technical booklets for training purposes
- Implement technical training seminars.

S.1.2. Training of growers (producers) and farm technicians:

- Prepare training materials and guidelines for growers (simple hands-on extension leaflets)
- Implement training of growers possibly using the farmers' field school approach (participatory training).

The participating countries rated this training component as high priority to be implemented as soon as possible.

S.2. Information

S.2.1. Country blueprints (detailed identification of country status and constraints).

Some countries consider that a more in-depth survey/study might be required to identify the needs and constraints of the greenhouse crop sector more precisely. It was also indicated that a technical document would be published on the ‘state of the art,’ compiling the information obtained through country case studies and missions carried out under the umbrella of the APRP.

S.2.2. Set up national and regional technical advisory committees to assist private commercial growers in decision-making.

The country representatives considered this proposal useful. It was considered that, although it could be established in the short term, it would need to be maintained on a long-term basis. It was therefore suggested to consider it as part of the networking activities. It was clarified that the technical advisory committee is expected to give an independent opinion on investment and crop management decisions to be taken by large-scale commercial growers. The committee would be composed at the national level of one or more knowledgeable persons. The national committee members would join into a regional technical advisory committee, which could operate as a network. The committee, through its professional contacts, would be able to seek advice from abroad whenever required. It would serve as a buffer and technical reference for growers who need an independent opinion to compare and evaluate the advice and recommendations received from commercial sales agents.

Medium Term

M.1. Training

M.1.1. Continue training program for growers and national extension staff initiated under S.1.

M.1.2. Develop a national/regional capability and the resources to design and assemble greenhouses and fill a local advisory capacity for maintenance.

M.2. Guidelines and demonstration—Greenhouse design and modeling: Design a model greenhouse to be established in each country in cooperation with a pilot private grower. This would be compared with the prevailing local model (conventional single-span tunnel) within the context of an overall integrated production and protection approach (physical measurements—light, humidity and temperature—as well as crop response). This would also include experimenting with new films, including anti-drop and IR-opaque films, as well as other commercial films of interest (e.g. the recently imported multi-layer film from India in Qatar). It would also be useful to make an agronomic and economic assessment of cheaper 100–120 µm films which have a life of one year.

> **The idea of conceiving and establishing 'model' or 'reference' greenhouses, targeted for the small- and medium-scale farmers was rated as high priority.** The country representatives considered that this would be a live demonstration of what could or should be done. They felt that it would be easier to convince the farmers to adopt a new greenhouse model if they could see it for themselves and verify that good crop results could be obtained. It was stressed that the study of improved greenhouse types would be undertaken based on the specific requirements of the individual countries and their climatic conditions. This program component would therefore be implemented as an application of the overall climate characterization initiated by APRP.

M.3. Applied research

M.3.1. Automation: Develop simple automation devices for ventilation, humidity control and irrigation management.

M.3.2. Climate control

> Experiments should be conducted on improved cooling systems (evaporative cooling) which can be locally manufactured and maintained with nozzles and pads adapted for use with brackish water.
> The most appropriate combination of shading, ventilation and cooling needs further investigation. A preliminary assessment could be made through existing greenhouse climate models available in EU countries (France, The Netherlands, Belgium) and by using specific climate data (radiation, temperature, humidity) available in the Arabian Peninsula.
> The control of humidity inside the greenhouse and more specifically the VPD needs to be investigated as part of the ventilation management. Excessive ventilation may induce high evapotranspiration rates and growth stress due to high VPD (>20 mbars).

M.4. Information management and databases

M.4.1. Continue with the agro-ecological characterization, which will be required to identify the areas (sites) with the best potential for the greenhouse-crop sector (temperature, radiation, ETP, water availability and quality). Integrate this information using CLAC and GIS experience and data.

> **This activity is considered of high importance for the AP countries and should serve as a powerful tool for the selection of areas (sites) which have the highest agro-ecological potential for the development of the greenhouse-crop sector**. The countries emphasized that it should be linked to GIS whenever this was already available in the country.

M.4.2. Write and publish a technical handbook on greenhouse management in the Arabian Peninsula.

The participants showed a high level of interest in this activity—the region is lacking scientific and technical documentation specific to the Arabian Peninsula.

M.4.3. Make an agro-economic assessment to evaluate greenhouse crop production in winter only (with ventilation only), versus year-round cultivation (including cooling). An 'input–output' approach should be adopted to substantiate the study economically.

It was indicated that this assessment should be made with due consideration for the climatic zones in individual countries.

Long Term

L.1. Training

L.1.1. Training of scientific staff at Masters and PhD degree level.

L.2. Applied research

L.2.1. Investigate the potential for the use of passive solar heating systems.

Networking Activities

Networking involves the active and voluntary participation and contribution of members in selected countries with some additional funding from outside. These activities are in addition to those mentioned in the chapter on Networking.

A. Training

Joint training courses and training workshops on selected topics (e.g. vegetable-seedling production; identification of insects and other pests; irrigation management; fan-and-pad cooling operation).

B. Joint applied research projects

Participation of a restricted number of countries in a well-defined project of interest to the region with a clearly defined objective, quantified outputs and a precise time-frame.