The United Nations University

GEOTHERMAL TRAINING PROGRAMME
Orkustofnun, Grensásvegur 9,
IS-108 Reykjavík, Iceland

Reports 1999
Number 3

GEOTHERMAL WATER IN GREENHOUSES IN TUNISIA: USE OF COMPUTERS TO CONTROL CLIMATE AND FERTIGATION WITH COOLED GEOTHERMAL WATER

Mohamed Ammar Gandouzi
Ministry of Agriculture,
Regional Commissariat for Agricultural Development - CRDA Kebili,
Kebili 4200
TUNISIA

ABSTRACT

In Tunisia, geothermal water is used for heating and for irrigation when cooled to appropriate temperatures. The greenhouse sector is developing rapidly albeit under severe climatic conditions. Yield is still far from optimal. The use of climate computers would greatly facilitate further development of the sector. A brief description of the constituents of climate control systems is given and the advantages and disadvantages are discussed. The need of reliable, yet flexible systems is stressed. Climate computers can also be used to control fertigation in greenhouses and tunnels. The high content of some undesireable salts must be dealt with and inexpensive, reliable fertiliser blenders are suggested. An account of the chemical composition, especially macro-nutrients, of some wells in Kebili region in Tunisia is given and discussed with reference to the literature in order to facilitate solutions to the problems associated with usage of cooled geothermal water for irrigation.

1. INTRODUCTION

In Tunisia geothermal water is used for agriculture and bathing. Sources have been identified in eight regions and three regions have been selected and maintained for developing greenhouses: Kebili, Tozeur and Gabes. In agriculture, geothermal water is used for oasis irrigation and heating, irrigation, and soil disinfection in greenhouses. The total area of greenhouses in Tunisia is more than 85 hectares, 31 ha in the Kebili region. The first greenhouse project was started in the Kebili region (1 ha) in 1986 as an experiment and the results were very encouraging, earlier production, high yield and good quality compared to normal greenhouses (unheated).

The greenhouse areas have expanded more and more and are developed under adverse climatic conditions. Two main problems exist which inhibit the expansion of the sector. They are (a) to master optimal climate control and (b) poor water quality. These are the main challenges which farmers have to face. This paper aims to introduce the advantages and possibilities with climate and fertigation control in greenhouses and tunnels in Tunisia, heated with geothermal water in order to increase productivity, through a brief introduction of the potential of climate computer control, description of each constituent, and the use of computer control to cope with the climate and fertigation. The potential dangers in using cooled geothermal water for irrigation will be examined through water analysis from 8 wells situated in the Kebili region, with reference to the literature. Attention is also given to micronutrients as important and essential parts of fertilisation.

2. GREENHOUSE PRODUCTION IN S-TUNISIA: CASE STUDY OF KEBILI REGION

2.1 Climate

South Tunisian climate is characterised by a hot summer exceeding 45˚C and a relatively cold winter reaching 0 to -1˚C. The coldest month average minimum temperature (Θ_e) (outdoor temperature in South Tunisian regions) is given in Table 1.

TABLE 1: Coldest month average minimum temperature

Regions	**Θ_e (˚C)**
Tozeur	5.5
Kebili	4.5
Gabes	6.5
Hamma of Gabes	6
Elborma	2.8

South Tunisia is an arid and desert region known for its lack of rain. In the Kebili region, the rain average is about 80 mm per year, hard wind (sirocco) is very frequent, or about 50 to 60 days per year. Sandy wind has a long duration, from the middle of March to late April. Evapotranspiration is considerable; it can reach 7 mm per day.

2.2 Greenhouses in Kebili

The total greenhouse area has increased considerably, particularly during 1986-1991 (Figure 1), because the government initiated drilling of many deep wells to exploit geothermal resources identified in the late seventies and during the eighties for irrigation of oases, where the date palm is the most dominant crop. This water is cooled by ventilated atmospheric towers. Early production and good quality of production for export need greenhouse heating. Therefore, the concept of using geothermal water for heating greenhouses has been introduced. The government and the private sector are both involved in the capital investment of the greenhouse projects. After this period the sector stagnated until 1998, and now a new expansion is

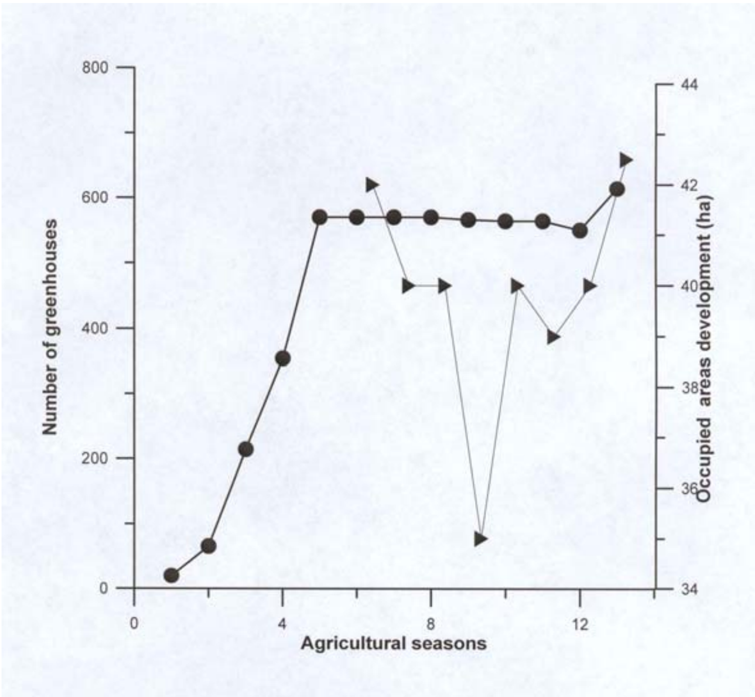

FIGURE 1: Development of greenhouse area in the Kebili region; the numbers on the x-axis designate growing seasons with 86/87 as a starting year and 14 referring to 98/99

observed in 1999. Production within the Kebili region has also increased (Figure 2).

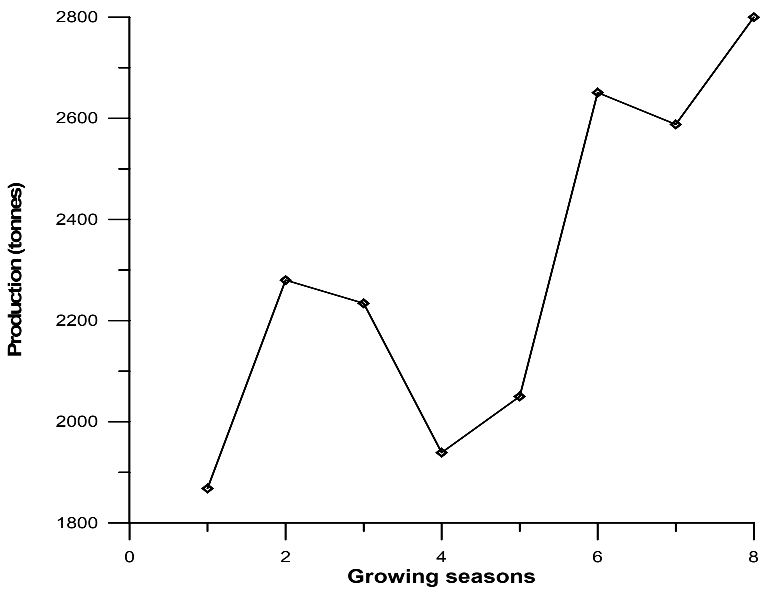

FIGURE 2: Production in the Kebili region; the numbers on the x-axis designate growing seasons with 91/92 as a starting year and 8 referring to 98/99

Utilisation of greenhouses is based on two types of utilisation; two consecutive seasons or one continuous. The first season is from late August to December, second season (continuous) is from late August to June, and the third season is from December to June. Utilisation is more than once a year, which explains why the occupied area is more important than the real area (e.g. in 1999, the total area is only 31 hectares, however the occupied area is more than 42 ha). Growing season includes the three seasons, it starts in late summer or early autumn, and should be finished by early summer in the next year. So the same greenhouse can be used once if the grower adopts a continuous culture, or twice if he adopts two cultures, one in the first season followed by another culture in the second season.

2.3 Season 1998/1999

The main crops were cucumber (37% of area), tomato (33%), and melon (16%). Only 8% were used for watermelon and 4% for peppers. The yield and production per cultivation are given in Table 2.

TABLE 2: Growing seasons 98/99

Season	**Vegetable crop**	**Area (Ha)**	**Yield (kg/m^2)**	**Production (tonnes)**
First season	melon	0.075	2.5	2
(August- December)	cucumber	13.375	3.5	468
Total		**13.45**		**470**
Second season	Tomato	9.4	14	1316
(continuous)	Pepper	1.375	3	41
(August- June)				
Total		**10.775**		**1357**
Third season	Tomato	4.675	7	327
(December- June)	Pepper	0.525	3	16
	Melon	6.925	5	346
	Cucumber	2.575	3.5	90
	Watermelon	3.45	6	207
	Others	0.1	4	4
Total		**18.25**		**990**
Grand total		**42.475**		**2817**

Plastic greenhouses, irrigated and heated with geothermal water, have developed rapidly during the last few years. However, many problems must be solved to achieve expansion of this sector. The main problems are:

- Lack of climate control;
- Salinity;
- Nematodes;
- Wind (tearing of plastic);
- Lack of export, partly due to absence of farmer organisations such as a service co-operative company.

In this paper emphasis will be given to the two first problems (climate control and salinity).

3. GREENHOUSE FERTIGATION IN S-TUNISIA HEATED AND IRRIGATED WITH GEOTHERMAL WATER

In S-Tunisia cooled geothermal water, after heating greenhouses, is used for irrigation. In the following sections a short description of soils and water quality is given, because fertigation adaptation is related to the characteristics and constraints of this media.

3.1 Growing media

3.1.1 Physical quality and hydrodynamic characteristics

The growing media that is primarily used in Tunisia is soil. The majority of soils in the southern part of Tunisia have a sandy muddy texture with the important presence of fine sand and coarse ooze. Coarse sand, fine ooze and clay are generally present in low proportions.

In dry state, soil water potential ranges between 5 and 20%. Thus, at critical point (moisture stress), available moisture is 2.5 to 10%. So for growing using a thin layer of soil, and at 2.5-3 plants per m^2, there is storage of water of 4-15 l/m^2 and it can be used for 1 to 4 days. The hydraulic conductivity is generally important. The horizontal permeability value ranges generally between 3.6 and 36 cm/hr, thus, these conditions exclude the dispersion formation at irrigation times, when flow rate is near 8 l/m^2 hr.

3.1.2 Chemical characteristics and water quality

The pH of the geothermal water is normally quite high. The value is generally between 7.5 and 8.5, seldom 7.2-7.5 or strongly (>8.5) alkaline. The presence of alkaline pH constitutes a chlorosis risk due to high calcium content of the water. These soils are calcareous, the proportion of $CaCO_3$ is higher than 50 g/kg, and can reach 300 g/kg. In some cases, high calcium content inhibits the absorption of iron (Fe) and manganese (Mn). Gypsum ($CaSO_4$) is present in many cases and can form a crust or nodules. The total salinity (g/kg) is important. Soil EC is over the normal value of 1.5 to 2 mS/cm, and can reach 4 mS/cm. Organic material is very low (< 0.5%). Chemical composition of the water is represented in Table 3.

The geothermal water is characterised by a high SO_4^{2-}, Ca, Mg, Na, Cl and bicarbonate content but small or no content of N, P and K. The geothermal water contains an excess of many elements, such as:

- 188-425 mg/l Ca, only at Djedidi: 82 mg/l;
- 53-126 mg/l Mg, in Tozeur region it is only 15-25 mg/l;
- 265-588 mg/l Na, except for Borma and Douz which are higher;
- 96-168 mg/l SO4 except for Hamma, Nefta, and Tozeur which can reach 1355-1516 mg/l;
- 355-887 mg/l Cl excpet for Borma and Douz , which can reach 1435-1595 mg/l;
- 85-293 mg/l bicarbonate (Djedidi 482 mg/l);

TABLE 3: Composition of Tunisian geothermal water (given in mg/l) and pH

Regions	**Projects**	**Ca**	**Mg**	**Na**	**K**	**SO_4^{2-}**	**Cl**	**HCO_3^-**	**pH**
Kebili	Steftimi	250	95	312	39	613	674	107	7.5
	Kebili	270	85	345	33	670	650	115	7.5
	Fareth	282	108	340	36	725	733	113	7.6
	Limagu	276	93	342	36	822	639	120	7.96
	Jemna	240	80	517	33	736	887	101	7.5
	Douz	280	126	830	32	780	1435	110	7.5
	Menchia	250	86	312	27	654	710	101	7.6
	Saidane	400	48	386	37	1128	622	87	7.7
	Bouebd	209	97	375	13	677	667	122	7.9
	Om-som	188	105	389	55	562	567	293	8
	Debebc	228	145	265	28	816	568	123	8
Tozeur	Nefta	425	15	437	60	1440	532	114	8
	Tozeur	400	25	299	48	1355	355	93	8.8
	Hamma	304	19	588	39	1516	390	114	8.08
Gabes	Khebey	280	108	329	33	1008	674	85	7.89
	Chench	330	123	441	37	1168	781	132	7.75
	Bechim	335	60	497	39	952	671	113	7.69
Others	Borma	250	70	1074	39	1010	1595	170	7.3
	Djedidi	82	53	271	14	96	422	482	7.8

It's clear and admitted (Verlodt, 1991) that the following values have inauspicious effects for cultures:

- Ca > 240 mg/l - Carbonate and sulphate formation risk;
- Mg > 48 mg/l - Carbonate formation risk;
- Na > 92 mg/l - Toxic;
- SO_4 > 432 mg/l;
- HCO_3 > 480 mg/l - Carbonate, Ca and Mg precipitation risk, thus pH increase in medium.

Water quality doesn't allow cultivation without danger of toxic salinity effects.

Transformation conditions of NH_4^+ to NO_3^- are not very favourable (Verlodt, 1991) due to low organic matter so the risk of NH_4^+ excess is obvious, creating a toxic environment.

3.2 Irrigation

Water requirement of a crop is a function of radiation, temperature, cultivated crop, stage of crop development and drainage rate. Daily water demand is calculated according to the global radiation received. The following formula is used (Verlodt, 1991):

$$W_{rg} = 0.00247 R_g - 0.8 \tag{1}$$

where W_{rg} = Water requirement related to radiation [l/m^2/day];
R_g = Global radiation [J/cm^2/day].

Thus, variation in water demand is calculated as a function of radiation, at different periods it is:

- Second half of December: 0.00158 l/m^2;
- Late January and late November: 0.00184 l/m^2;
- Late February and late October: 0.00195 l/m^2;
- Late March and late September: 0.00205 l/m^2;

- Late May: 0.00216 l/m^2.

The next equation is used to determinate the total water demand (Verlodt,1991)

$$W_r = W_{rg} \times C_c \times C_s \times C_d \times C_t \tag{2}$$

where W_r = Water demand;
C_c = Cultural coefficient of crop related to stage development, $0.4 \le C_c \le 1.1$;
C_s = Cloud of sky coefficient;
C_t = Temperature inside greenhouse;
C_d: = Drainage coefficient.

From Equation 1, the potential water demand according to global radiation is determined for each day when the global radiation is known. Experimental work in south Tunisia has determined the global radiation through the year, in order to facilitate the tasks for the growers who haven't the necessary instruments to measure global radiation. But, the total water demand isn't only a function of radiation. Thus an efficient method was developed and all the parameters were taken into consideration using Equation 2.

3.3 Fertilisation

Plants require minerals for their growth in large (macroelements) or small quantities (microelements). Geothermal water in Tunisia contains some minerals, sometimes more than the plant in question needs, so the fertigation water can not be perfectly in equilibrium with plant demand. Thus N, P, K are equilibrated but other elements are not (Table 3). Microelements need more management and emphasis will be given to this topic in this report.

3.4 Micronutrients

3.4.1 Introduction

Micronutrients are also called trace elements because they are required in low quantities by the plants. There are 8 micronutrients required by plants: iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), nickel (Ni), molybdenum (Mo), and chlorine (Cl). Chlorine is ubiquitous in nature and nickel is required in small quantities and they appear to be present in sufficient quantities. The concentration of micronutrients in dry plant tissues range from 1 (0.0001%) to 600 ppm (0.06%) (Hanan,1998). Values for tomatoes are given in Table 4.

TABLE 4: Micronutrients in mg/g of plant dry weight for the main crop (tomato) in Tunisia

Plant-species	Fe	Mn	B	Mo	Zn	Cu	References
Lycopersicum	155-193[a]	27-168[a]			48-66[a]		Smilde and Eysinga, 1968
Esculentum	94-819[b]	43-239[b]			201-458[b]		Smilde and Eysinga, 1968
(tomato)	90	350	35	0.5	80	15	Winsor, 1973
	20-100	50-100	20-40	1-5	20-200	5-25	Wittwer and Honma, 1979
					526-1489[c]		Chapman, 1960
			300-500				Brennan and Shive, 1948
					65-198		Chapman, 1960
		60-100	40-80		15-30	4-8	Geraldson et al., 1973

a) Value for plants growing in marine clay soils (The Netherlands);
b) Value for plants growing in river clay soils (The Netherlands);
c) Value represents toxicity levels.

Micronutrients are as essential as macronutrients but required in lesser quantities. Micronutrient deficiency or toxicity can cause devastating effects.

3.4.2 Microelement mobility and deficiency symptoms

Micronutrients are mobile or immobile within the plant. The key to micronutrient deficiency is given in Table 5 (Reed, 1993).

TABLE 5: Key to micronutrient deficiency (Reed, 1993)

Parts of plant affected	Plant deficient in
Young upper leaves affected first; may spread to older leaves when severe:	
Leaves only chlorotic with no necrotic spots; Veins remain green; overall yellowing to interveinal chlorosis:	Iron (Fe)
Necrotic or chlorotic spots small and interveinal; veins remain green, also possibly on older leaves:	Manganese (Mn)
Young leaves darkened or light green at base; leaves thick and brittle and die back from base or twisted; lateral branches grow, then die; flowers and fruits abort:	Boron (B)
Young leaves with chlorosis or necrotic spots; not wilted. Leaves with chlorotic or necrotic spots. Necrotic spots large or irregular; new growth rosetted and stunted:	Zinc (Zn)
Terminal buds remain alive but come chlorotic or wilted. Young leaves with chlorosis or necrotic spots; not wilted. Leaves with chlorotic or necrotic spot:	Copper (Cu)
Older, lower leaves affected first; may spread to younger leaves when severe:	
Leaves with localized motting; chlorosis or necrosis; leaf margins cupped. Lower leaves with large and general chlorosis to necrotic spots, which eventually involve veins; leaves thick; new growth rosetted and stunted:	Zinc (Zn)

Chlorotic: yellowing; necrotic: brown, dead area; interveinal: between the veins

The pH in the media strongly affects nutrient solubility. Iron, manganese, copper, zinc, and boron are more soluble at low pH (pH between 5.5 and 6). Thus they are available for absorption. According to Reed (1993), when pH is lower than 5, these micronutrients are more soluble and available to plants and they can become toxic. Other references do not agree (Mengel and Kirkby, 1987). Only for molybdenum is the solubility reduced. At high pH (between 6.5 and 7), the reverse is observed. Maintaining optimum micronutrient nutrition can occur when pH balance of the growing media is maintained.

A micronutrient nutrition programme will be coupled with control of the growing media. The target is to obtain an optimal state for plant microelement fertilisation.

3.4.3 Individual micro-nutrients

Iron is usually the most required and applied micronutrient, easily fixed and often unavailable in the soil. When the pH value is above 4.5, the soluble iron in the soil barely satisfies plant needs. Others conditions can cause iron deficiency or deficiency of other metals (Reed, 1993). High pH values induce the formation of insoluble iron oxides and hydroxides. High bicarbonate and carbonate in the soil cause interference with absorption of iron by plants. Soils in southern Tunisia are generally calcareous, thus, carbonates are high. Excessive phosphate fertilisation may cause phosphate-iron precipitate. Excessive phosphorus fertilisation causes iron deficiency, even if pH is low. Excessive manganese, copper, or zinc fertilisation may cause these metals to compete with iron for absorption by plants. This generally occurs with manganese and causes an iron deficiency. Root damage of any kind may induce iron deficiency. Excessive watering interferes with root's ability in absorption of iron and symptoms of iron deficiency may appear. Plant species responses for the conditions in soil-pH vary. Some plants are able to produce their own chelates and can absorb iron under most conditions, others that can't are under toxicity or deficiency conditions. According to Reed (1993) iron toxicity symptoms are usually bronze coloration and small necrotic spots on leaves. These symptoms appear when pH is too low or roots are under anaerobic conditions (excessive watering). Basic fertiliser can cause increase of soil pH (nitrate, or use of alkaline irrigation).

Manganese. The most required micronutrient after iron is manganese. Deficiency symptoms are very similar to iron deficiency. The only difference is that for iron the interveinal chlorosis progresses to a white appearance.

Boron is applied only when water analysis reveals less than 0.3 ppm boron. Toxicity occurs when the boron concentration is higher than 1.5 ppm (Reed, 1993).

Zinc is required in small quantities.

Copper is required in very small quantities and is difficult to control because too little causes a deficiency and just a little more causes toxicity.

Molybdenum is required by plants in the smallest quantities of all nutrients. When the pH is below 6, deficiency can appear as it is less soluble at low pH.

3.4.4 Micronutrient supply

The easiest and safest method to apply micronutrients is dissolving in water and applying through irrigation. They can also be provided by foliar application or sometimes, when necessary, from specific fungicides. Trace element application after the appearance of deficiency symptoms isn't suitable; "insurance" against a deficiency is needed and thus granulated trace elements are preferred. Under greenhouse conditions three micronutrients can be deficient or toxic i.e iron, boron, and manganese. Standard micronutrient application rate is given in Table 6.

Iron is not absorbed if pH is high, there is poor aeration, and there is a high soluble salt concentration. To alleviate the situation, the first step is acidifying the soil, but one or more foliar application of chelated iron may be more suitable. A solution containing 3 g of 12% chelated iron per 10 litres of water is used (Mastarlerz, 1977).

When boron deficiency symptoms appear, boron in the form of borax is recommended at a rate of 3 g per m^2 . For preventive purposes, 10-14 g/m^2 of borax should be applied (Mastarlerz, 1977).

Manganese causes problems only in soil that contains high manganese.

TABLE 6: Standard micronutrient application rate (Mastarlerz, 1977)

Elements	Nutrient analysis	Standard rate		Relative availability
		g / m^2	g / 100 litres	
Borax (sodium tetra borate) - $Na_2B_4O_710H_2O$	11 % B	0.75-1.5	7.5	Medium
Chelated iron - NaFe	12 % Fe	3	30	Rapid
Iron sulphate - $FeSO_47H_2O$	20 % Fe	3	30	Rapid
Manganese sulphate - $MnSO_4$	24-65 % Mn	0.75-1.5	376	Slow
Cooper sulphate - $CuSO_4$	25 % Cu	0.75-1.5	7.5	Slow
Zinc Sulphate - Zn SO_4	22-35 % Zn	0.75-1.5	7.5	Slow
Molybdenum (sodium molybdate) - $Na_2MoO_42H_2O$	22 % Mo	0.75-1.5	-	Slow
Rate depends on whether liquid or granulated.				

4. CLIMATE CONTROL

Internal greenhouse climate is determined by the covering or shielding of air movement by the reduction of wind velocity. This influences energy exchange, especially radiation, in respect to wind movement and reduces convective energy transfer by wind which allows the increase of internal temperature under clear skies. Greenhouse climate is also determined by energy conservation, CO_2 levels, and humidity. These factors have considerable impact on climate control.

An internal greenhouse climate is characterised as follows (Hanan, 1998):

Wind speed, usually < 0.1m/s and frequently < 0.04 m/s, whereas outside wind can be > 1m/s.

- Humidity with full crop cover in vegetative phase is > 90% RH. RH can reach 100% (saturation), chiefly at sunset. The vapour pressure will be less than 0.5 kPa; if it is < 0.3 kPa adverse effects on crop production can occur.
- CO_2 concentration generally decreases during the day, more so in the greenhouse, from 350 ppm to levels approaching 100 ppm, unless CO_2 injection is practised.
- Radiation inside is 60-70% of the outside, thus a greenhouse structure and cover must be chosen to maximise incoming radiant energy.
- Inside temperature ranges between 5 and 30˚C. Sensor location in the greenhouse is critical, varying with crop species and development stage and the kind of climate control.

4.1 Constituents of automated climate control

4.1.1 Sensors

Sensor devices are the basis of climate control because they provide necessary information for optimisation. There are three main applications: monitoring, qualification and control. Interchangeability, repeatability, productivity, output signal and usability by growers are the required characteristics of sensors. According to Gielding and Schurer (1994), there are 5 levels of sensing sophistication: conversion, environmental compensation, communication, diagnostics, and logic actuation. The following environmental parameters are of importance.

Temperature. Temperature is the most common measurement made in greenhouses. The temperature indicator shows only the temperature of the sensor. Precision in electric sensors is higher but the cost is also higher. Actually, digital computer systems merely provide an average value from hundreds of measurements very quickly. In greenhouse, a term of absolute accuracy of temperature reading of about ± 0.5 degrees is accepted (Hanan, 1998). In a greenhouse, a change in climate is relatively slow (Bot, 1980, 1989). According to Hanan et al. (1987), a temperature measurement every minute, and averaged over 5-10 minutes should be adequate to determine temperature in the greenhouse.

Sensors must be protected from unwanted disturbances like radiation or heat exchange. The location of sensors is very important. Best is to measure in several places in the greenhouse to obtain a reasonable average. Another important parameter is sensor response time.

Humidity. For measuring humidity a psychrometer, a thermohydrograph or capacitance humidity probe can be used. For computer input, electrical systems are preferred. There are three methods to control excessive humidity: ventilation, cover condensation and heating. Sensors must be protected.

Radiation. Three classes of instruments are used, radiometers, photometers, and quantum meters. Measurements of solar radiation have usually an error of ± 10 %.

Nutrition. There are different types of chemosensors which provide an electric signal proportional to the number of particles (atoms, molecules, ions) in nutrient solution. Ion selective electrodes (ISE) can be used, using membranes permeable to certain ions. Another instrument of interest is the ion sensitive field effect transistor (ISFET).

Carbon dioxide. For measuring CO_2 there are numerous methods, but the most utilised today is infrared spectroscopy, sensitive to the number of CO_2 molecules in unit volume or pressure.

Electrical conductivity. Electric conductivity (EC) can be monitored both in the fertigation solution or in the soil. Determination of EC in solution extracted from soils is a simple test, and provides information about fertility level and can warn about a salinity problem. It is measured between platinum electrodes.

pH. The common instrument used for controlling pH is a pH meter with electrodes. The electrodes have usually a short life span and must be calibrated regularly.

Water. Soil moisture can be measured with a tensiometer or by weighing a certain volume of the soil and comparing it to the dry weight.

Other instruments. An external set of meteorological instruments is needed (air temperature, global radiation, precipitation, humidity, CO_2, wind speed and wind direction).

4.1.2 Hardware

To avoid confusion, a sophisticated computational system is required for reading and recording the data input from the sensors. A computer is used to improve environmental conditions. According to Knight (1985), a properly programmed computer co-ordinates all operating systems, gives alarms, conserves energy, and reports on current and post conditions.

Information is the essential ingredient of control. Simple control devices require information in the form of signal feedback from process sensors in order to achieve their limited objectives. The computer is the logical tool to use because it is able to acquire, assimilate, analyse, and disseminate large amounts of information with high speed and accuracy. A computer control system is a computer which has the capacity to accept signals directly from process instruments and convert them into a form suitable for computer processing. It is an on-line system which receives information from sensors without human intervention. On-line refers to the method of data input to the computer. Output is done directly in a closed loop. The computer acts as a controller and give signals to the actuators depending on the desired setpoints.

4.1.3 Software

Usually the computer hardware available is reliable. The course of execution is determined by the software and what the PC does with respect to climate. Many properties of software are desirable. The most important for the grower is the information given in case of failure. In greenhouse climate control, the computer usually alerts the grower to prevent a catastrophe. New programs and changes in existing software may be made quickly whenever necessary. According to Schmidt (1986), error-free software does not exist, however, so the grower is dependent upon the program is quality.

The major segments of the overall control program involve the control functions, interrupt servicing, input and output, operator communications, bulk storage and computer malfunctions (Emanuel, 1965). The control functions are the central elements of the control program.

4.1.4 Effectors

Each environmental factor, measured for a greenhouse system, has an actuator or several actuators:

- Radiation: shade screens, day-night temperature settings, supplemental irradiation;
- Temperature: boilers, unit heaters, ventilators, evaporate pads, air mixing systems, exhaust fans,

actuating and mixing valves;

- Humidity: mist systems, ventilators, heating systems;
- Carbon dioxide: CO_2 injection, which may include liquid CO_2 or combustion systems;
- Wind: ventilator system;
- Precipitation: ventilation system, also heating system in case of snow;
- Water: irrigation system, controls in hydroponics culture;
- Nutrition: nutrient injection systems;
- Water potential: humidity, irrigation system;
- Photosynthesis: CO_2 injection systems.

4.2 Survey of the potential of climate computer

Use of computer control can help growers to maximise their income continuously. According to Hammer and Langhans (1978), there are more than 24 environmental parameters that we can control. However, according to Hanan (1998), there are at least 33 different measurements to characterise conditions outside and inside a greenhouse, necessary for adequate climate control. Temperature control is a dominant factor, following by humidity and CO_2. The most important factors to control are radiation, temperature, humidity, carbon dioxide, wind, precipitation, water, nutrition, water potential, and photosynthesis (Hanan, 1998). Feasibility, accuracy, and precision vary widely. Some main factors can only be determined indirectly at present (Hanan, 1998).

4.2.1 Some basics of control

The controller manipulates outputs to the actuators to achieve the desired setpoints. The grower can enter setpoints manually. There are others factors to be considered:

Analog versus digital signals. Signals from sensors are continuously varying in amplitude and over time. There is always variation above and below the zero reference line and the true situation is highly irregular. The number of inputs and outputs in the greenhouse is so large that it becomes complicated. In reality, a signal from a sensor is only determined at some particular moment in time. Fortunately, change of environmental parameters under greenhouse is slow. In this case, the first step is to obtain the signal; after that, it must be outputted to operate the correspondent actuator by comparing the sensor inputs to setpoints. The result is the return to the desired value.

Feedback and feedforward. A signal is given from the greenhouse to an error detector; the error signal is the difference between the setpoint and the present output. This error is corrected by automatic manipulation of the actuator. This is the essence of feedback control, which can stabilise an unstable system.

Uncontrollable factors (radiation, outside temperature, wind speed, etc.) may disturb for the greenhouse. Feedforward control is a means of cancelling their effect upon system output when these factors are measurable. For example, an outside air temperature measurement can be used to correct the control signal, compensating an outside temperature reduction by increasing the output from the controller. Contrary to a feedback system which starts corrective action only after the output has been affected, feedforward has no effect on the unmeasurable disturbances.

Closed and open-loop systems. A closed-loop system has a direct effect upon control action. However, an open-loop system has no effect upon the control action; no feedback is given for comparison. An open-loop system can be used only when the relationship between input and output is known without internal or external disturbances.

Controller functions. Mathematical calculations are not necessary for successful climate control. A published example is Hanan et al. (1987), in describing control of four (6x15 m) research greenhouses without utilisation of functions control theory.

On-off control. This is the most common and cheapest system to use, employed when several unit heaters or convectors are used, and with fan and evaporative cooling. Temperature control, ventilator positioning, screen positioning, CO_2 injection, etc., require an on/off control. To avoid simultaneous heating and ventilation, except in the interest of reducing humidity, setpoints between heating and cooling are almost invariably partially separated. Temperature lift varies with the system and plant species requirement.

Proportional, integral, and derivative. These control systems, in combination or on their own are used when hot water is employed. P, I, and D controllers are also used when the utilisation of several exhaust fans, unit heaters, or ventilators are required (Jones, 1994). Each type of control has its formula:

$$u(t) = K_p e(t) \tag{3}$$

$$u(t) = K_i \int_0^t e(\tau)\, d\tau \tag{4}$$

$$u(t) = K_d \frac{de(t)}{dt} \tag{5}$$

where *u(t)* = Output of the controller or input to the process;
K_p, K_i, K_d = Controller proportional constants or proportional gain, integral controller gain and derivative controller gain, respectively;
t = Time;
τ = A dummy variable in control theory, but it is listed as a time constant of the greenhouse (Bakker et al. 1995);
e = Error input signal resulting from comparison of the set point and feedback.

If the Laplace transform (Bontsema, 1995) is used, as in analog control, the following represents an approximation of the majority of processes:

$$H(s) = \frac{K_p e^{-t_d}}{\tau s + 1} \tag{6}$$

where t_d = Dead time, or the time for a response to occur;
e = Natural logarithm;
s = The Laplace operator.

For analog systems, the general formula is

$$u(t) = K_c\,[e(t) + \tau_I \int_0^t e(t)\, d(t) + \tau_D \frac{de(t)}{dt}] \tag{7}$$

where t_I = Integral time (reset time);
t_D = Derivative time (ratetime);
K_c = Proportional gain.

In the P processes, the actuator is varied with the deviation from the setpoint. The error between setpoint and actual output is multiplied by the gain, which can lead to an offset. With the I control, the value of the controller output is changed at a rate proportional to the error signal. The combination of P and I results in the error signal eventually being reduced to zero. In the D processes, the actuator is varied directly with the rate of change of the error signal.

Analog systems are difficult to adjust (Tantau, 1980). Due to the large time constants of greenhouse, it is easier with a digital process. For digital systems, the equation for PI algorithm is:

$$U(k) = K_c + K_i t_s \sum_{j=0}^{k-1} e(k-j) \tag{8}$$

where K_c = Proportional gain, the first group in the right-hand side is being the proportional action;
K_I = $K_c \chi \tau_I$ = Integral gain, the right-most group;
$e(k)$ = $T_{sp}(k) - TI(k)$, setpoint minus measured integral temperature (˚C);
t_s = The sampling time integral;
K = An integer index.

Changing the setpoint should be done smoothly, especially in the mornings. If not, the heat source (boiler) cannot meet demands. Temperature change starts before sunrise, and reaches day setpoint after sunrise (1 to 3 hours). Maximum and minimum are necessary to keep saturation within limits. An anti-wind-up approach that keeps u(k) within limits of the pipe temperature was proposed by van Zeeland and Undink ten Cate (1981). Equation 8 becomes:

$$u(k) = U(k-1) + K_c[e(k) - e(k-1) + K_i^* e(k)] \tag{9}$$

with $K_i^* = K_c K_i$ and subject to $T_h(k\text{-}1) - c \le u(k\text{-}1) \le T_h(k\text{-}1) + c$

where T_h = Heating pipe temperature;
c = Constant (≅ 5°C).

The temperature at sunset should be allowed to return to night setpoint gradually.

Calculation of heat load of the greenhouse from the internal and external temperature difference, wind speed and radiation is made to increase accuracy and stability. It can be used to calculate a provisional setpoint for water temperature:

$$T'_h = T_{h\min} + \frac{T_{o\max} - T_o}{T_{o\max} - T_{o\min}} (T_{h\max} - T_{h\min}) + a\,WS - b\,R \tag{10}$$

where T_o = Maximum and minimum outside temperatures at which pipe temperatures are maximum and minimum, respectively; T_o being the outside temperature;
WS = Wind speed;
R = Global radiation inside;
a,b = Adjustable coefficients.

When using floor heating, the response time of a concrete floor is between 5 and 8 hours. The temperature control in this case is difficult, and the system must be highly sophisticated. The efficiency of a heated floor is stated as very low (Van Meurs, 1995).

Ventilation is also controlled by a proportional algorithm. According to Van Meurs (1995), the ventilator position is calculated every time the system is executed. Ventilator position depends upon wind speed and temperature difference between outside and inside and the proportional band. Humidity can be efficiently lowered when the control of relative humidity is managed by opening vents only. The proportional band of relative humidity is wider than that of temperature. When the difference between outside and inside temperature is small, the combination between heating and ventilation can be used. Ventilators are open when the temperature of the greenhouse rises above the ventilators setpoint, this results from the minimum pipe temperature, which is set first. When relative humidity (RH) increases, the vent setpoint decreases and vice versa. The program decides also which ventilator will be open first, in relation to wind direction. Rain or snow may also cause a limit on vent position, sufficient to allow drainage.

4.2.2 Control requirements

The main important attributes required of a control system are stability, accuracy, sensitivity, and reliability.

Stability. If the control system is able to pursue the input command, it is stable. It is unstable when output is not in control or there is a limit to this control.
Accuracy. This attribute deals with the ability of the system output to complete the wished output. There are many errors (measuring devices, necessary analog-digital, digital-analog conversions). The final error is the sum of all of these.
Sensitivity. Sensor output may be sensitive to environmental parameters subject to measurement, and insensitive to others parameters (unwanted disturbances).
Reliability. The system must be strong enough to work continuously without breakdown.

4.2.3 Optimisation

Climate control is optimised by adequate setpoint determination for climate and structure. Setpoints depend on the response time of the greenhouse and the crop. For adjusting climate control, different parts of the greenhouse must be considered: structure, air and soil (Bot and Van de Braak, 1995).

Setpoints. Setpoints are the desired parameters for maintaining a precise value for optimising climate control. They are: air temperature integral inside (T_l), pipe temperature (T_h), ventilation temperature (T_v), day temperature (T_d), night temperature (T_n), minimum radiation for thermal screen close (R_t), minimum radiation for supplementary irradiation (R_s), maximum radiation for shade screen (R_h), minimum vapour pressure deficit (VPD_h), maximum vapour pressure deficit (VPD_l), maximum CO_2 concentration (CO_{2n}), rate of CO_2 change with ventilation (CO_{2m}), minimum CO_2 concentration (CO_{2l}), water circulation (WC), soil water potential (suction) (SWP), electric conductivity limit (EC), nutrient solution pH (pH), ion setpoints (NO_3^-, NH_4^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, PO_4^{3-}, SO_4^{2-}), day-night change-over (rate of change CH) and radiation toggle setpoint (R_t).

Each setpoint has its source of disturbance. These disturbances are: outside air temperature (T_o), outside global radiation (R_o), outside wind direction (WD), outside wind speed (WS), outside vapour pressure deficit (VPD_o), inside air temperature (T_i), outside CO_2 concentration (CO_{2o}), vapour pressure gradient inside (VPG_i), fertigation water (EC), fertigation water quality (EC, pH), and day length (DL). Of course each set point has its own operatinng equipment, and there are interactions between the parameters. A computer system can be used to modify these setpoints.

Two main constraints are to be considered for the digital system: it requires limits that prevent unbounded output to actuating equipment and grossly exceed equipment capability, and limits are required in software programs. These constraints may be stated:

$$x_{t,\min}(t) \le x_i(t) \ge x_{i,\max}(t) \tag{11}$$

where x_i = Climate state variable, *i*, such as temperature, and must lie within the range expressed by $x_{i,min}$ and $x_{i,max}$

Limits may also be required on control inputs:

$$u_{i,\min}(t) \le u_i(t) \ge u_{i,\max}(t) \tag{12}$$

where u_i = a control input, I, such as valve position.

There are also requirements that allow determination of sensor failure and these may be in terms of limits on the output. Crop response can be described by the characteristic level: minimum, optimum, and maximum.

4.3 Advantages and possibilities with advanced climate control in greenhouses and tunnels in Tunisia

Production in greenhouses in Tunisia using geothermal water (temperature reaching 70°C) for heating and irrigation has developed rapidly, under difficult climatic conditions and unsuitable irrigation water quality. Geothermal resources are estimated at 4.7 m^3/s, which allows the installation of 400 hectares, but only 85 hectares are in use.

Geothermal water used for irrigation is cooled by ventilated atmospheric towers. Due to low temperature outside in winter, heating during this period is obligatory to maintain a minimum temperature inside the greenhouse of 12-14°C.

The greenhouse climate is chiefly characterised by inside temperature and humidity, which are the factors for plant comfort. The greenhouse environment is very complex. The common parameters depend on the location of the greenhouse project due to the climate. In Tunisia sunny days are common, and aeration is usually insufficient. With these climate conditions, greenhouse climate control is the biggest challenge farmers must face, in addition to combating poor water quality.

Ventilation is generally operated manually. Insufficient ventilation and its inadequate management lead to inappropriate extreme air temperatures and saturation deficits. These conditions are unsatisfactory for cultivation during an important part of the year.

The main cooling practice in greenhouses in Tunisia is natural ventilation by vent openings (roof and side). It is not sufficient although the performance and control of ventilation are crucial factors for the crop.

In Tunisia, advanced climate control for greenhouses is needed, for obtaining adequate fertigation and adequate climate conditions to allow better plant development in greenhouses. At present, only one company, situated in Chenchou (Gabes region), uses computer climate control in glass greenhouses of 1 ha. Development of this sector in Tunisia is strongly related to climate control. The use of this technique is necessary for the expansion of this field, chiefly for the installation of new projects related to the national strategy for developing production in greenhouses using geothermal water.

5. USE OF CLIMATE COMPUTER TO CONTROL FERTGATION IN GREENHOUSES

There are mainly two types of fertigation control, with or without irrigation control.

5.1 Fertilisation without irrigation control

Injectors. The easiest system is where all the fertilisers are in the same stock solution and a pump is used to add the fertilisation solution to the water irrigation. In this case the injector is water-driven without electricity and without electronic control. The pump is a dosing one. This is a very reliable system and could be adequate as an initial step. Two injectors, connected in series, are also possible and provide better fertigation control.

Blenders. This system uses three stock solutions and a 100 litre tank for water irrigation. A small pump is used to conduct the solution to the plants. EC and sometimes pH are controlled (Figure 3).

5.2 Fertigation with irrigation control

Blenders based on 2-5 stock solutions. This system uses a computer for fertigation control. All the parameters related to fertigation are controlled. Irrigation frequency, duration etc. can be set for several different greenhouses. These systems are quite expensive.

Blenders based on 5 or more stock solutions. Generally, nutrition and water control have been considered separately. Gielding and Schurer (1994) indicated that up to 14 stock solutions may be used to dispense individual concentrates into the circulation solution. Each element with its counterion will be in a special tank (K^+, Ca^{2+}, Na^+, NO_3^- , Mg^{2+},SO_4^{2-}, PO_4^{3-}, and Cl); trace elements are together in the same tank. The system uses feedback to control nutrient levels. Excess water to plants is wasted when the use of feedback signals is limited in pH and electrical conductivity. A closed-loop nutrient control system is required for measurement and control: pH, EC, K^+, Mg^{2+}, Ca^{2+}, Na^+, NO_3^-, SO_4^{2-}, PO_4^{3-}, and Cl (van den Vlekkert et al., 1992).

Figure 4 shows the closed-loop nutrient control system. The procedure is an enclosed continuous recirculating setup in which specific nutrients are added as required to the solution, each element comes

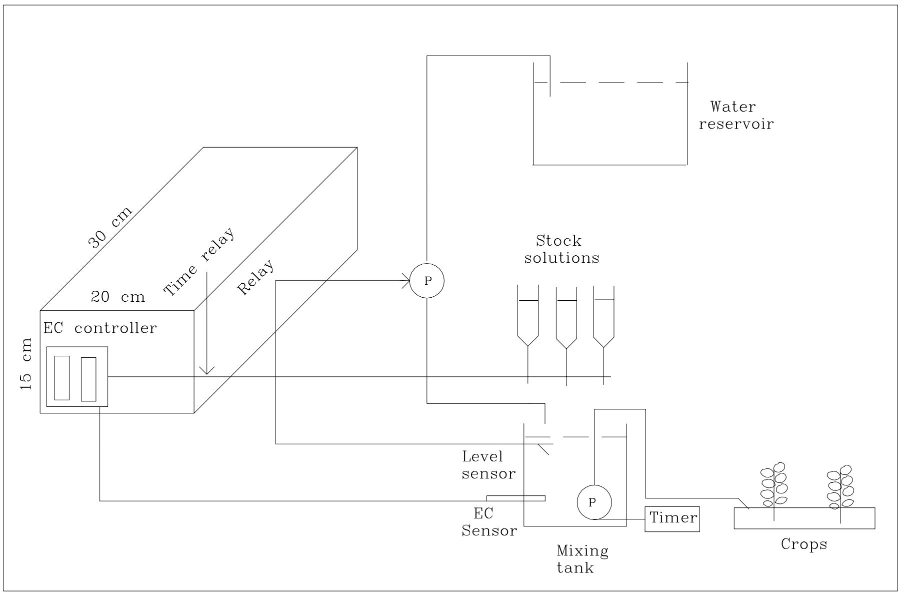

FIGURE 3: System used and designed by Dr. S. Adalsteinsson, Icelandic Horticultural College, Reykir, Iceland (pers. comm.)

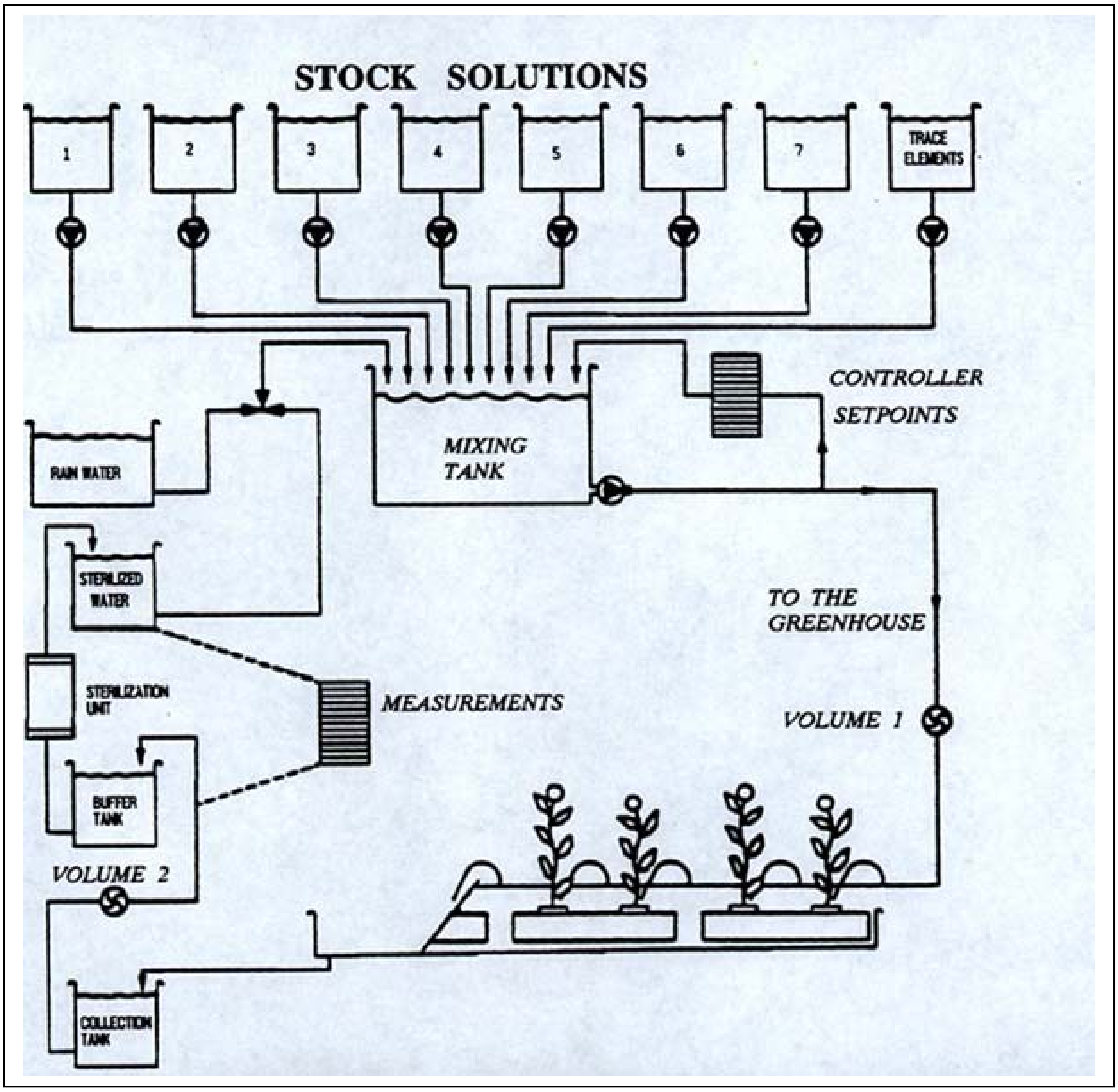

FIGURE 4: Closed-loop nutrient control system (Hanan, 1998)

from an individual tank, then all are mixed in the mixer tank and sent to the plants. The drain water is collected, and passed through a buffer tank, sterilised, and then returned to the mixing tank. Control of different element concentrations, pH, and EC, is related to setpoints. Output can be read on the computer and adjustments made if, for example, the concentrate of one element is more or less than indicated in setpoint (regulated relatively to the desired value conformable to plant needs). A signal can be given to the nutrition injection systems to regulate the situation by opening or closing the appropriate valve.

6. POTENTIAL DANGERS IN USING COOLED GEOTHERMAL WATER FOR IRRIGATION

6.1 General guidelines

The sum of cations and anions in the substrate solution is the total salts which may be expressed in terms of concentration or equivalency (Hanan, 1998). Salts affect osmotic potential. Beside this effect, specific ions may be high enough in concentration to cause toxicity and interference in nutrient uptake and balance. Salts can cause a change in colour and damage plants. According to Sonneveld and van

Beusekom (1974), cucumber is the most sensitive of commercial crops. Yield decreased 4, 7, and 14% for lettuce, tomato, and cucumber, respectively, when the EC of the irrigation water was increased by 1 ds/m. When the EC of soil increases, the yield decreases. An increase of 1 ds/m in the irrigation water causes an increase of 2 ds/m in the soil (Hanan, 1998). Cucumber showed a special sensitivity to an excess of calcium and magnesium. Some crop responses may be due more to nutrient imbalance than to high salts. Excessive and unbalanced salt levels have the practical influence of upsetting timing cycles made by the grower. Also quality reduction can be observed, as in smaller flowers or fruit and shorter stems. The effects of excessive salt concentration are mediated by osmotic inhibition, by specific effects of the constituent ions, or by the combination of both (Hanan, 1998). Dilution methods cannot be utilised in arid regions and calcareous soil (Richards, 1954). Washing excess salts from the soil layer or active root zone is not the solution because application of excess water, which itself contains high salts, will not reduce total soluble salts below that contained in the water supply. Saline soils are those in which the conductivity of the saturation extract is greater than 4 ds/m (Richards, 1954).

Water quality is highly important in greenhouses. The presence of salts in the irrigation water will influence the ability to manipulate nutrition. Water salinity ultimately limits capability and can markedly reduce profitability. Water analysis is important in greenhouse operation. The characteristics of irrigation water that are important to determining the quality are:

- Total soluble salt concentration;
- Concentration of individual ions;
- Concentration of boron and other elements that may be toxic;
- The bicarbonate concentration as related to concentrations of calcium and magnesium.

Sodium is particularly important in determining an alkali hazard. Sodium hazards of irrigation water are usually expressed as the sodium absorption ratio, *SAR*:

$$SAR = \frac{[Na^{+}]}{\sqrt{\dfrac{[Ca^{+2}] + [Mg^{+2}]}{2}}} \tag{13}$$

If $SAR > 10$ the water must be avoided, if soils are part of the substrate.

If the mixture contains appreciable amounts of gypsum, a SAR value of 10 can be exceeded. Continued use of high *SAR* water leads to a breakdown in the soil's physical structure. Absorbed sodium results in clay dispersion and the soil becomes hard and compact when dry, with slower water penetration when wet (Follet and Soltanpour, 1985). The US salinity laboratory (Richards, 1954) states that water with conductivity values below 0.75 ds/m is generally safe. However, sensitive species are likely to be affected at *EC*s above 0.25 ds/m. Use of irrigation supply above 2.3 ds/m is likely to result in crop failure (Hanan, 1998). *EC*s approaching 1 ds/m exclude the use of fertigation in crop culture (Hanan, 1998). For the manipulation of salty irrigation supplies, any program devised with the original water analysis in mind becomes improper, because the water quality changes slightly.

Evaluation of water quality needs the determination of the following parameters: concentrations of anions and cations, pH value, *EC* value, the absorption ratio (*SAR*) and the concentration of microelements. Table 7 summarises the various chemical properties of water tested and their evaluations (Reed, 1993).

Irrigation water can be an important source of salt. Hardness of water is not correlated closely with soluble salts or suitably for greenhouse crops. Hardness is important when calcium in leaves is objectionable. Geothermal water in Tunisia contains carbonate, calcium, and sodium; thus the volume and frequency of irrigation need more attention. Water quality can be evaluated with a conductivity test (Mastarlerz, 1977). When the salt content in water is high, more water is applied at each irrigation for removing the salt. It's useful to calculate the leaching requirement (*LR*). The following formula is used frequently with success (Ayers and Wescot, 1989):

TABLE 7: Quality of irrigation water as evaluated from chemical properties

Chemical property	Relative hazard				
	None (mg/l)	**Little (mg/l)**	**Moderate (mg/l)**	**High (mg/l)**	**Severe (mg/l)**
Bicarbonate	< 122	122-183	183-244	244-366	> 366
Chloride, foliar	< 108				
Chloride, root	< 144		144-216	216-360	> 360
Sodium, foliar	< 69				
Sodium, root	< 69		69-207		> 207
Lithium	< 2.5				
Zinc	< 2				
Iron	< 1				
Manganese	< 1				
Fluoride	< 1				
Boron	< 0.3	0.3-0.5	0.5-1.0	1.0-2.0	>3
Copper	< 0.2				
Electric conductivity (*EC*) ds/m	0.2	< 0.7	0.7-2	2-3	> 3
Absorption ratio (*SAR*)	< 3	3-6	6-8	8-9	> 9

$$LR = \frac{EC_W}{5(EC_e - EC_w)} \qquad (14)$$

where EC_W = Water *EC*;
EC_e = Desired *EC* in soil.

When the concentration of specific ions is excessive in water, the water must be diluted with water of better quality. To determine the degree of dilution, the following formula is used:

$$C_{BW} = (C_A)(P_B) + (C_B)(P_B) \qquad (15)$$

where C_{BW} = Concentration in blended water;
C_A = Concentration in water A;
C_B = Concentration in water B;
P_A = Proportion of water A used;
P_B = Proportion of water B used;
The concentration units are the same, me/l or ppm.

Another solution for combatting salinity is to maintain moisture at high level at all times.

Combatting poor water quality with water purification systems. The main problem is total dissolved solids (TDS), which are the total of the non-volatile solutes dissolved in water. TDS are composed of soluble salts. When they are high they cause decreased plant growth and salt burn on the leaves. For improving irrigation water quality many systems can be used. The target is the purification of water.

- Water purification systems for removing total dissolved solids are mainly: Reverse osmosis, deionization, distillation and electrodialysis;
- Pre-treatment systems: Complete water analysis is required to determine the necessary pre-treatment. Pre-treatment systems include the following: Suspended solids removal, scaling

prevention, pH and alkalinity control, declorination and water softening (cation exchange);

- Correcting specific ion problems:
  Total dissolved solids are removed by the systems, but in some situations (if TDS are not high enough to justify total salt removal) the problem is due to individual salts. Then correcting these ion problems can be sufficient.
  - Calcium and magnesium: Plants have tolerance to calcium and magnesium, but the problem is with irrigation overhead. When water is hard, it contributes to salt deposits on leaves. This problem can be solved with water softener charged with potassium to replace calcium and magnesium. Potassium is a fertiliser, of course, but when water is very hard, over-fertilisation with potassium can occur.
  - Carbonates: They rarely cause plants direct damage due to salt, however, they represent the major contributions to water alkalinity. Many secondary effects are caused by high carbonates, i.e. precipitation of nutrients, chiefly micro-nutrients, and an increase of pH.

6.2 Analytical results

For analytical results only 8 wells are considered. Others are cited in Chapter 2. Due to a shortage of data, they will be not discussed here. The concentrations are in mg/l and for conversion to me/l, the following formula can be used:

$$me/l = \frac{mg/l}{Equivalent\ \ veight} \tag{16}$$

The 8 wells are Steftimi, Kebili, Om-Elfareth, Limaguess, Jemna, Bouebdellah, Om-Somaa, and Debebcha. Analyses are presented in Table 8, the last well is Icelandic.

TABLE 8: Water analysis of several wells in Tunisia (8) and Iceland (1)

Wells	**Ca (mg/l)**	**Mg (mg/l)**	**Na (mg/l)**	**K (mg/l)**	**SO_4 (mg/l)**	**Cl (mg/l)**	**NO_3 (mg/l)**	**HCO_3 (mg/l)**	**pH**	***EC* (ds/m)**	**TDS (g/l)**	***SAR***
Stefti	250	95	312	39	613	674	1.86	107	7.5	3.40	2.44	4.24
Kebili	270	85	345	33	670	650	3.72	115	7.5	3.30	2.41	4.67
Om-f	282	108	340	36	725	733	2.48	113	7.6	3.80	2.67	4.35
Lima	276	93	342	36	822	639	-	120	8.0	3.37	2.45	4.53
Jemn	240	80	517	33	736	887	3.72	101	7.5	4.20	2.87	7.35
Boue	209	97	375	13	677	667	6.2	122	7.9	3.30	2.27	5.35
Om-s	188	105	389	55	562	567	16.74	293	8.0	3.40	1.84	5.61
Debe	228	145	265	28	816	568	-	123	8.0	3.13	2.76	3.36
Iceland	3.40	< 1	56	< 1	-	52	< 0.3	72	6.4	0.43		

The concentration of microelements and other elements are known in the Icelandic well. They are as follows: < 0.2 mg/l for P, 36 mg/l for S, 0.04 mg/l for Fe, 0.26 mg/l for B, < 0.01 mg/l for Cu, < 0.01 mg/l for Mn, 0.02 mg/l for Zn, 0.06 mg/l for Mo, 0.11 mg/l for Al and 52 mg/l for Si. This well is not considered in the discussion. Only Tunisian wells are considered, but because of a lack of data, the microelements are not discussed.

- Ca is below 240 mg/l only in the three last wells, but only slightly;
- Mg is always well above 48 mg/l;
- Na is always very high, or from 265 to 517 mg/l;
- SO_4 is very high between 562 and 822 mg/l;

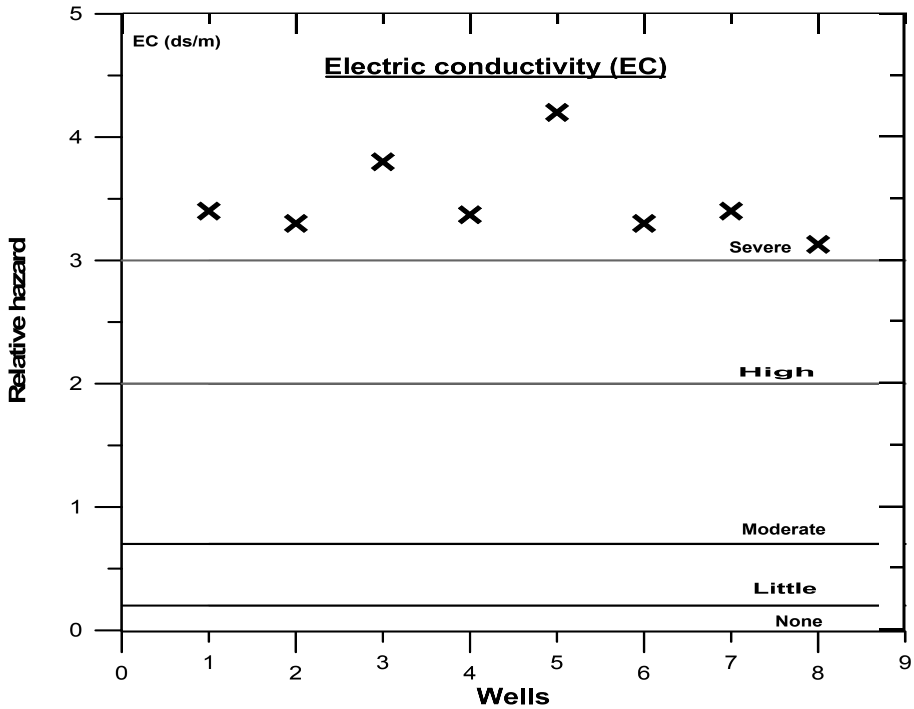

FIGURE 5: Relative hazard due to electric conductivity (EC) in the 8 chosen wells; the axis is numbered from 1 to 8, where 1 is Steftimi, 2 is Kebili, 3 is Om-elfarth, 4 is Limaguess, 5 is Jemna, 6 is Bouebdellah, 7 is Om-somaa and 8 is Debebcha.

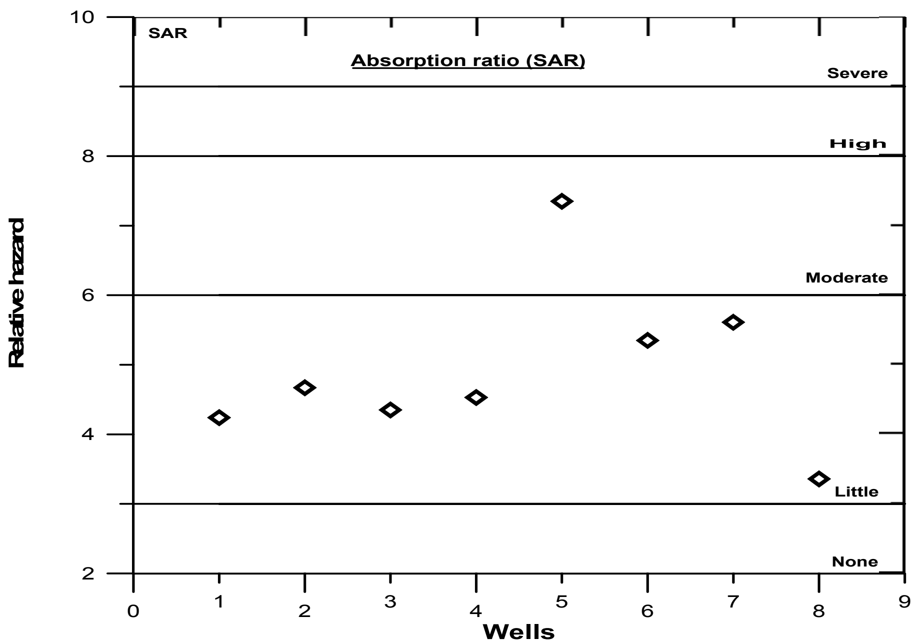

FIGURE 6: Relative hazard due to absorption ratio (SAR) in the 8 chosen wells, the same number code as in Figure 5

- HCO_3 is not important; it is generally less than 183 mg/l; only at Om-somaa is it 293 mg/l.;
- Cl is very high from 567 to 887 mg/l;
- K and NO_3 are feeble, generally less than 62 mg/l;
- Electric conductivity is always higher than 3 ds/m. (Figure 5);
- Absorption ratio (*SAR*) is generally located between 3 and 6; at Limaguess it is between 6 and 8 (Figure 6);
- pH ranges between 7.5 and 8.

7. DISCUSSION

Greenhouses in Tunisia, heated and irrigated with geothermal water, are expanding rapidly in area, but the yield is clearly below averages recorded in many countries. To increase this yield some problems have to be solved. Firstly, fertigation, especially micronutrients, needs more attention because they have the same importance as macronutrients, but are needed in small but correct quantities by the plants. It is therefore, important to equilibrate these microelements just as well as the macorelements. Secondly, water quality of the geothermal water used for irrigation when cooled must be given attention. It is very important to analyse this water at least once each year, because the fertilisation is related to the constituents of this water. In this report 8 wells are discussed.

Magnesium concentration is generally higher than 48 mg/l, thus magnesium precipitation risk is evident. Calcium concentration is generally higher than 240 mg/l. The risk of sulphate formation is real. Plants tolerate high levels of calcium and magnesium. Limits have not been determined for these two elements, but high concentration of both results in hard water and precipitation of calcium and magnesium carbonate can occur on leaves. High calcium and magnesium levels may also induce deficiency of other elements e.g. K^+ due to competition in uptake. Scaling may impair irrigation lines, valves and orifices. Sulphate is in very high concentrations for all the wells studied. It may cause a problem in fertilisation when low in concentration (less than 48 mg/l). In that case, the water might not supply all the required sulphur as sulphate, and supplemental sulphate must be applied through the fertigation program. That isn't the case for the discussed wells.

Chloride concentration is very high for the 8 wells. Always much higher than 144 mg/l, toxicity by root accumulation is very likely when the concentration is higher than 360 mg/l. Bicarbonate concentration is not very high, less than 183 mg/l so no problem should occur due to that. High bicarbonate gives rise to problems due to high pH. Only at Om-Somaa is a concentration of 293 mg/l considered high and may result in potential problems involving soil pH and precipitation of nutrients, mainly microelements. Sodium concentration is high, far more than 92 mg/l, and a risk of toxicity is evident. The concentration is higher than 207 mg/l in all the cases, and, thus, the hazard considered severe. K^+ and NO_3^- are in very small proportions.

Electric conductivity (*EC*) ranges between 3.13 and 4.20 ds/m, always more than 3 ds/m and the hazard considered severe (Figure 5).

Thus it can be concluded that water quality is inadequate in Tunisia and some kind of water purification must be envisaged.

Absorption ratio (*SAR*) ranges between 4.24 and 7.35, considered little except at Jemna where it is moderate (Figure 6).

Fertigation control is indispensable for optimal growing conditions. It is, therefore, important to examine the water frequently and to control the concentrations of the different fertilisers. Mainly two types of controllers can be used to control EC and pH i.e. blenders with or without irrigation control. Blenders without irrigation control (injectors and blenders), are relatively cheap and can give good results. Blenders with irrigation control (blenders with different numbers of stock solution), utilise computer control. These systems give secure results but they are too expensive.

Climate control is very important in greenhouses. Only the best structure of greenhouses is recommended and computer control is necessary. With the actual structure (plastic cover), climate conditions and manual ventilation, the mastering of greenhouse climate is very difficult and affects production. It's time to think about adequate structure (glass cover), appropriate growing media and computer climate control if the goal is expansion of this sector in Tunisia. The importance of this field for the national economy is substantial and increasing.

8. CONCLUSIONS

In this paper the emphasis is given to fertilisation, mainly micronutrients, geothermal water quality and the use of computers to control climate and fertilisation.

Different micronutrients are discussed. Deficiency symptoms, special consideration for each element and standard rate for each microelement is given. It is very important to equilibrate these elements as the macronutrients.

The geothermal water quality of 8 wells from the Kebili region used for irrigation is discussed. The different element concentrations (magnesium, calcium, sulphate, chloride and bicarbonate), are much higher than plants need. Essential elements like K^+ and NO_3^- are in low concentrations. *EC* is severely high. *SAR* is generally low; only at Jemna is it moderate, pH is high. These characteristics of the water don't allow cultivation without danger of toxic saline effects.

Utilisation of these geothermal water wells permits growth of different crops, but a reduction in yield is obvious. Better control of salinity should permit improvement and profitability of the sector and maintain good quality of the products. The actual possibilities are: regular measurements of *EC*, correct fertigation, flushing after each culture, maintaining the moisture at an adequate level at all times, collecting rain water for leaching and cultivation in the field. The possibilities for the future are a new norm of fertilisation with control of salinity (reduction of concentrations of some elements) and production of water with good quality from the geothermal water. Analysis of micronutrients is not done in this report because of a shortage of data, but it is very important and this work will be continued later.

Use of computers to control greenhouse climate and fertigation requires capital. In this paper a brief introduction of the potential of climate computer control, description of each constituent and use of the climate computer to cope with fertigation and climate is given. For fertigation control systems in greenhouses, injectors and blenders without irrigation control are recommended. They are relatively cheap and can be used immediately in Tunisia. The systems with irrigation control using computers are very sophisticated and give better results, but they are too expensive considering the current investment potential.

ACKNOWLEDGMENTS

I would like to extend my gratitude to all those who made possible my attendance at the Geothermal Training Programme. I would like to express my gratitude to Mr. Seddik Saad, the regional commissar of agricultural development of Kebili and Mr. Gallali Ghaleb, the chief of the department of vegetable production, who allowed me to participate in this training. I would like to express my gratitude to Dr. Ingvar B. Fridleifsson, director of the UNU Geothermal Programme, for the fellowship award and guidance, Mr. Lúdvík S. Georgsson, deputy director and Mrs. Gudrún Bjarnadóttir for their efficient help and kindness.

I would like to express my gratitude to my supervisor Dr. Sveinn Adalsteinsson, the director of the Icelandic Horticultural College, for his guidance and advice, also, to all the lecturers and staff of Orkustofnun.

REFERENCES

Ayers, R.S., and Wescot, D.W., 1989: *Water quality for agriculture.* Food and Agriculture Organisation of the United Nations, FAO - Irrigation and drainage, Paper 29, rev. 1.

Bakker, J.C., Bot, G.P.A., Challa, H., and van de Broek, N.J. (eds.), 1995: *Greenhouse climate control.* Wageningen Pers, Wageningen, Netherlands, 279 pp.

Bontsema, J., 1995: Greenhouse climate control. Control Principles. In: Bakker, J.C., Bot, G.P.A., Challa, H., and van de Broek, N.J. (eds.), *Greenhouse climate control*. Wageningen Pers, Wageningen, Netherlands, 279 pp.

Bot, G.P.A., 1980: Validation of a dynamical model of greenhouse climate. *Acta Hort., 106,* 149-158.

Bot, G.P.A., 1989: A validated physical model of greenhouse climate. *Acta Hort., 245*, 389-396.

Bot, G.P.A., and Van de Braak, N.J., 1995: Physics of greenhouse climate. Basic principles. In: Bakker, J.C., Bot, G.P.A., Challa, H., and van de Broek, N.J. (eds.), *Greenhouse climate control*. Wageningen Pers, Wageningen, Netherlands, 279 pp.

Brennan, E.G. and Shive, J.W., 1948: Effect of calcium and boron nutrition of the tomato on the relation between these elements in the tissues. *Soil Sci., 66,* 65-75.

Chapman, H.D., 1960: *The diagnosis and control of zinc deficiency and excess*. Bull. Res. Council Israel, 8D.

Emanuel. S.S., 1965: *Computer control of industrial process*. McGraw-Hill Inc., NY, 400 pp.

Follet, R.H. and Soltanpour, P.N., 1985: *Irrigation water quality criteria*. Service in Action, Co. State Univ., Ext. Service. No. 506, 2 pp.

Geraldson, C.M., Kalcan, G.R., and Lorenz O.A., 1973: Plant analysis as an aid in fertilising vegetable crops. In: Walsh, L.M. and Beaton, J.D. (eds.), *Soil testing and plant analysis*. Soil Sci. Soc. Amer., Madison, WI.

Gielding, T.H. and Schurer, K., 1994: Sensors for information acquisition and control. In: *Greenhouse systems: Automation, culture and environment.* Proceedings from the Greenhouse Systems International Conference, Northeast Regional Agricultural Engineering Service, NRAES-72, Ithaca, NB, NY, 306 pp.

Hammer, P.A., and Langhans, R.W., 1987: Modelling of plant growth in horticulture. *Hort. Science, 13,* 456-458.

Hanan, J.J., 1998: *Greenhouses. Advanced technology for protected horticulture*. C.R.C. Press, New York, 684 pp.

Hanan, J.J., Coker, F.A., and Goldsberry, K.L., 1987: A climate control system for greenhouse research. *Hort. Science, 22*, 704-708

Jones, P., 1994: Environmental control: Thermostats to computers. In: *Greenhouse systems: Automation, culture and environment.* Proceedings from the Greenhouse Systems International Conference, Northeast Regional Agricultural Engineering Service, NRAES-72, Ithaca, NB, NY, 306 pp.

Knight, J., 1985: *Computers for environmental control*. Canadian Greenhouse Conf., Univ. Guelph., Ontario.

Mastarlez, J.W., 1977: *The greenhouse environment*. John Wiley and Sons, Inc., NY, 596 pp.

Mengel, K., and Kirkby, E.A., 1987: *Principles of plant nutrition (*4th Ed.). International Potash Institute, Bern, Switzerland, 687 pp.

Reed, D.W., 1993: *Water, media and nutrition for greenhouse crops.* Ball Publishing, Batavia, IL, USA. 314 pp.

Richards, L.A. (ed), 1954: *Diagnosis and improvement of saline and alkali soils.* Agric. Handbook no. 60, USDA, Washington DC, 160 pp.

Schmidt, W., 1986: Test and maintenance of quality standards for agricultural software. In: *Microelectronics in agriculture. Facts and trends*. Deutshe Landwirtschafts gesellschaft, Frankfurt, 197-208.

Smilde, K.W., and Van Eysinga, J.P.N.L.R., 1968: *Nutritional diseases in greenhouse tomatoes*. Inst. Voor Bodemvrucht, Wagening, 47 pp.

Sonneveld, C., and van Beusekom, J., 1997: The effect of saline irrigation water on some vegetables under glass. *Acta Hort., 35,* 75-86.

Sonneveld, C., Vlekkert, H.H., Kouwenhoven, j.P.M., and Van Wingerden, A.A.M., 1992: Application of ISFETs in closed-loop systems for horticulture. *Acta Hort., 304,* 309-320.

Tantau, H.J., 1980: Climate control algorithms. *Acta Hort., 106*, 49-54.

Van Meurs, W.T.M., 1995: Current implementation of hardware and software. In: Bakker, J.C., Bot, G.P.A., Challa, H., and van de Broek, N.J. (eds.), *Greenhouse climate control*. Wageningen Pers, Wageningen, Netherlands, 279 pp.

Van Zeeland, J., and Undink ten Cate, A.J., 1981: A modified PI-algorithm for a glasshouse heating system. *Acta Hort., 115,* 351-358.

Verlodt, H., 1991: *Geothermal utilisation for heating vegetables under greenhouses. Direction generale de la production agricole, Tunisia*. Technical document, UNDP project / TUN 85/004, report (in French), volume 1, 96 pp.

Vlekkert van den, H.H., Kouwenhoven, J.P.M., and Van Wingerden, A.A.M., 1992: Application of ISFETs in closed-loop systems for horticulture. *Acta Hort., 304,* 309-320.

Winsor, G.W., 1973: Nutrition. In: Kingham, H.G. (ed.), *The U.K. Tomato Manual.* Grower Books, London, 223 pp.

Wittwer, S.H., and Honma, S., 1979: *Greenhouse tomatoes, lettuce and cucumbers*. MI State Univ. Press, East Lansin, MI, 225 pp.