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AGRICULTURAL GEOTHERMAL UTILIZATION IN KÉBILI REGION, TUNISIA

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ABSTRACT

Direct utilization of geothermal energy in the Kébili region is mainly in agriculture. It is used for irrigation of oases and heating and irrigation of greenhouses. Geothermal resources are rare and non-renewable due to the absence of recharge in aquifers which are over-exploited. The main reason is that the irrigation practised is by submersion and all the area is irrigated resulting in significant water wastage. Date palms, trees, grass and vegetables compose the oasis system. Generally, when the geothermal water temperature is less than 40°C, it is used directly for irrigation but when it exceeds 45°C, it is cooled by means of atmospheric towers. Although the date palms and trees can tolerate relatively hot water, the vegetation is sensitive and, for some farmers it is of low interest. Geothermal energy is also used in greenhouse farming which is considered a promising and feasible sector, but the reality of operation is totally different. In addition to bad conceptualization of some projects, farmers are confronted by several constraints such as lack of organization and of techniques. Therefore, obtained yields are very low and under expectations. A big variability between sites and inside the same site is observed and farmers show a real heterogeneity. The economical evaluation of the greenhouse sector shows bad results for one third of the growers. These bad results concern 50% of them when the risk is considered (increasing of prices inputs).

1. INTRODUCTION

Geothermal utilization is commonly divided into two categories, i.e. electricity production and direct application. Conventional electric power production is limited to fluid temperatures above 150°C, but considerably lower temperatures can be used with the application of binary fluids (Fridleifsson, 1996). The primary forms of direct use include swimming, bathing, space heating, agriculture, fish farming and industrial processes.

In Tunisia, the use of geothermal resources is limited to swimming, bathing and agriculture. The resources are localized mainly in the southern part of the country (Gabes, Kébili, Tozeur) and utilized mostly for agricultural purposes (irrigation of oases, heating and irrigation of greenhouses). The government's policy in the beginning of the 1980's was oriented to development of the oasis' sector and the main aim was to supply oases with geothermal water for irrigation. Therefore, 29 boreholes are operating in the Kébili region with a total flowrate of nearly 1,100 l/s and a temperature varying from 24 to 73°C. Most of the wells are used for the irrigation of 13,450 ha of oases and the water is cooled in 14 towers when the temperature exceeds 40-45°C. In 1986, the government started the use of geothermal energy for greenhouse farming, an area of 1 ha was planted, to reach today's level of 28 ha.

This report presents the agricultural use of geothermal energy in the Kébili region. The purpose is to define the different utilizations and to analyse constraints disabling oases and greenhouse operations. The study starts with an outline of the geothermal potential and resources in Tunisia and in the concerned region. Following this, the utilization of groundwater in the oases' irrigation and in greenhouse heating are discussed. Finally, technical and economical evaluation of the greenhouse sector is carried out.

2. GEOTHERMAL RESOURCES IN TUNISIA

The Geothermal resources in Tunisia have been described by Ben Dhia and Bouri (1995). They divide the country into five geothermal areas. This division is based on the geological, structural and hydrogeological features of the different regions. The northwest region (Province I) is greatly affected by the over thrust of the alpine napes, dated as upper Miocene, and thick deposits of sandy layers "Numidian formations". This region is geologically related to the Tuscan Italian province, and so is expected to be a potentially high energetic zone. Provinces II and III constitute the "Atlas domain", and are separated from Province I by the "Diapers zone". Rocks represent both marine and continental sedimentary facies and are relatively well known either by surface or subsurface surveys. Province IV, representing the "Chotts province" is structurally known as "Tebaga Anticline". This most important structure in Tunisia constitutes a transition between the Atlas and the Sahara domains. Sedimentary, Jurassic and Cretaceous rocks represent the most particular occurring layers constituting the extreme northern part of the most important aquifer of the whole north African Sahara. The southern province (Province V) contains the biggest sedimentary basin in Tunisia, with the thickest and widest deep aquifer system. It is located in the northern part of the stable Sahara platform.

The northwest region (PI) is characterized by a complex geological setting where volcanic rocks are more common than in other regions. The density of thermal manifestations is higher here than in other parts of the country. Out of 70 hot springs in Tunisia, 28 are located in this region. The hot springs are preferably associated with tectonic activity (faults and fissures) and the natural flow rate is usually small (less than 10 l/s). In South Tunisia the flowrate from the hot springs is usually higher (Stefánsson, 1986). Outside the northwest region, the geothermal aquifers have been found in well defined geological formations (sedimentary rocks) which in some cases are mapped over large areas (basins). These reservoir rocks often have very high permeability and many of the wells drilled in the south have artesian flowrates of the order 100 l/s.

A very coarse classification of the geothermal resources would, therefore, be to distinguish only between two regions, the northwest part and the remaining part of the country. The northwest region has many characteristics different from the other geothermal regions. In the southern part of the country the gradient is in the range of 21°C/km to 46°C/km. These values are in the same range as the world average values for thermal gradient. In general it is, therefore, expected that the geothermal resources in Tunisia are the result of normal conductive heat flow in the crust. This means that, in general, high-temperature (larger than 200°C) geothermal resources are not expected to be found in Tunisia, the only exception or question mark is the northern part of the country. At present it cannot be excluded that resources close to 200°C might be found in this area, but further investigations are needed in order to obtain better knowledge of the circumstances (Stefánsson, 1986). According to Mamou (1992), geothermal resources are found in northern, central and southern part of Tunisia. In the following, these areas are discussed.

2.1 North Tunisia

The springs are characterized by low flowrates and high salinities (10 g/l). They are used mainly for curative treatment and bathing. There are two types of springs, one called Flysch Numidian and the other Atlasic Tectonic. The Flysch Numidian is a result of abnormal contact of Tertiary and Quaternary formations with old formations. Temperatures of waters in these springs exceed 40°C and some springs such as Hammam Bourguiba and Hammam Sollah are above 50°C. Based on a gradient of 33°C/km, the water in this aquifer is estimated to have a temperature of 40°C at 600 m depth and 65°C at 1360 m depth. Springs associated to Atlasic Tectonic are from deep levels which reach the surface through big faults. The most important springs are Hammam Zriba, Djebel Ouest, Hammam Lif and Kourbous. The temperature is always higher than 40°C. The maximum temperatures predicted in the aquifers are 50°C at 1,000 m depth and 65°C at 1,500 m depth. They are at a depth exceeding 500 m and are characterized by a very high salinity (more than 10 g/l).

2.2 Central Tunisia

Generally aquifers are from Tertiary formations with a temperature between 20 and 25°C. There are two aquifers, the low Zerbag and the low Cretaceous. The low Zerbag is characterized by temperatures of 37-40°C, a depth of 480-540 m and a salinity of 4.3 g/l. The low Cretaceous is characterized by temperatures of 39-51°C, a depth of 1,300-1,800 m. The salinity varies from 3.3 to 9 g/l. The exploitation of this aquifer is estimated at 150 l/s.

2.3 South Tunisia

Aquifers are crossing from Atlasic Tectonic to the desert plate (Sahara). Generally the temperature is between 20 and 75°C. There are three main aquifers, the Complexe Terminal (CT), the Djeffara and the Continental Intercalaire (CI). Other formations with temperature above 35°C exist inside Prenien, Triassic and Jurassic but have a very high salinity (10-75 g/l). These formations are used for oil drilling.

The Complexe Terminal covers the regions of Nefzaoua, Gafsa and Djerid. It has been exploited at relatively low depths for more than thirty years and contains water with a low enthalpy which is characterized by a temperature ranging from 20 to 45°C and depth between 100 and 1,200 m. The salinity varies from 1 to 6.5 g/l. Geothermal resources are estimated at 1,125 l/s of which 1,000 l/s are used (about 89%). The Djeffara covers the regions of Gabes and Médenine. It is exploited at low depths (100-500 m) with a varying temperature of 21-29°C. Geothermal resources, which are estimated at 1,100 l/s, are all used. At present, the two reservoirs mentioned above are almost fully used (92%). The Continental Intercalaire covers the regions of Nefzaoua, Djerid, Gabes and the extreme south as shown in Figure 1. It is deeper than the CT and extends to Algeria (part of the Sahara) and Libya. It is mainly exploited for agricultural purposes (irrigation of oases, irrigation

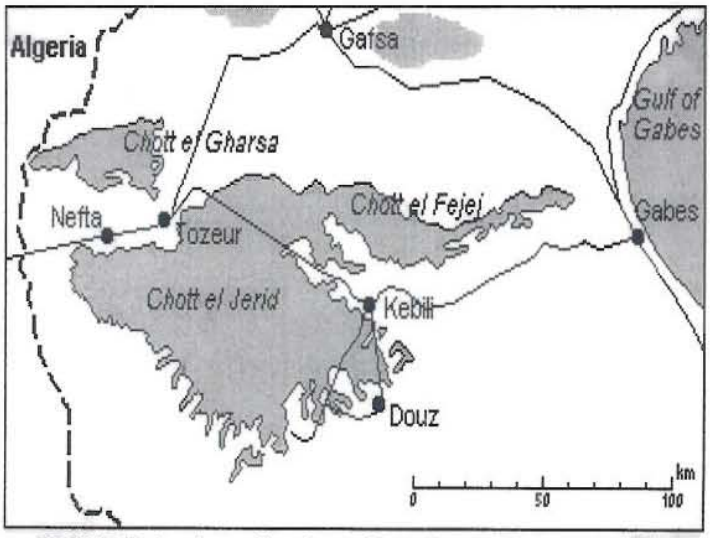

FIGURE 1: Localization of geothermal resources in the southernmost part of Tunisia

and heating of greenhouses). It is characterized by a temperature ranging from 35 to 75°C , a depth varying from 1,200 to 2,800 m, a high pressure and a salinity between 2.2 and 4.2 g/l. Geothermal resources in this aquifer are evaluated at 3,200 l/s and exploited at 90%. At present, the potential of geothermal resources in South Tunisia is estimated at 5,500 l/s and is exploited to 92%. To summarize, Table 1 shows their potential and exploitation.

TABLE 1: Geothermal resources and exploitation in South Tunisia (Mamou, 1992)

Aquifers	Total resources	Exploitation	
	(l/s)	(l/s)	(%)
Continental Intercalaire (CI)	3,200	2,900	91
Complexe Terminal (CT)	1,125	1,000	89
Djeffara	1,100	1,100	100
Total	5,425	5,000	92

3. IRRIGATION OF OASES

For thousands of years, geothermal water has been used for bathing in Tunisia. The swimming pool in Gafsa, built by the Romans, is still used these last years by the local children for swimming, fun and recreation. Many of the more than 70 geothermal manifestations in the country have the name of bath "hammam" which reflects the main use of geothermal resources through centuries. Natural springs in Tunisia have relatively low temperature (less than 75°C) which explains that this water has been used for bathing and in some cases for irrigation (Stefánsson, 1986). In recent years, large quantities of hot water have been identified in the country by drilling. This discovery is mainly a spin off from groundwater drilling and in other cases related to exploration drilling for oil. Due to climatic conditions in the country, clean water is one of the most valuable substances, at least in the southern part (desert). The hot groundwater is mainly used for agricultural purposes and principally for the irrigation of oases.

3.1 Water resources in Kébili

The region of Kébili (Nefzaoua and Régim Maâtoug) (Figure 1) is situated in the southern part of the country and characterized by two aquifers, the biggest in Tunisia (CT and CI). These two aquifers are the most important resources for the development of agriculture in the region but they are known as non-renewable resources. The medium aquifer (CT), for example, was exploited as springs until the end of the 1960´s. Now they have been replaced by artesian wells; many of them are already equipped with pumps and others will need the equipment in the future.

3.1.1 The medium aquifer (Complexe Terminal, CT)

The water resources in this aquifer are evaluated at 6,500 l/s. They are located in two big areas: Nefzaoua with 4,500 l/s and Régim Maâtoug with 2,000 l/s. Water is generally taken at low depth and with a very low enthalpy (23-32°C) but the salinity is relatively high (3-4 g/l). In Nefzaoua, the depth varies from 50 to 300 m. Resources, which are estimated at 4,500 l/s, are over-exploited. In addition to 213 municipal wells yielding about 3,550 l/s, there are almost 1,700 other wells illegally drilled in order to supply new oases (extension), operating at a low flowrate (1.8 l/s) and exploiting about 3,055 l/s. Most of them are pumped, especially in the summer time when there is big need for irrigation. Thus, the total exploitation in this area is about 6,605 l/s and, the reservoir in Nefzaoua is over-exploited (147%). This is one of the reasons for the increasing salinity and consequently increasing production cost. In Régim Maâtoug Region water is reached at 300 m depth. The exploitation is proceeding in the normal way and is estimated at 785 l/s by the means of 25 municipal wells with a rate of exploitation of about 39%. The rest of the water quantity in this area (1215 l/s) will be used in the future for irrigating new oases estimated at 1,008 ha (the second part of Régim Maâtoug Project). Additional 20 wells with a flowrate of 60 l/s can be drilled in the same area. To summarize, we can say that the entire aquifer in the two areas discussed above is over-exploited (114%).

3.1.2 The deep aquifer (Continental Intercalaire, CI)

Generally this aquifer is characterized by relatively hot water (30-75°C) and a depth reaching 2,800 m. Geothermal resources are estimated at 1,000 l/s and they were exploited for the first time to provide a complete water supply for old oases which have a high density (more than 250 date palms per ha) and low productivity, in order to create new ones. The main target was to develop the oases sector in the south of the country by means of the rehabilitation of old oases and the installation of new ones (new farmers). The government's policy in the beginning of 1980's was oriented to encourage farmers. In that way, the operation consisted of pulling up the non-productive date palms to replace some of them by another more productive variety with good quality, intended for export. This was expected to generate more income for the farmer (micro-economy) and consequently for the country (macro-economy) by a better contribution to the agricultural commercial balance.

The aim was mainly to supply oases with this water but after few years (1986) it was utilized for heating and irrigating greenhouses (one ha as a first experiment in the locality of Limagues). The exploitation now is estimated at 1,288 l/s by means of 32 wells (seven with pumps). The first well was drilled at Oum Elfareth locality in 1952. The important period of drilling boreholes was in 1985 (six wells) and in 1986 (six wells). Then drilling activity was stopped until 1991 (one well) to start again in 1992 (three wells) and 1993 (three wells). From 1952 to 1993, 29 wells were drilled in the region. The latest period of drilling was 1994 when three wells were drilled giving a high flowrate (70 l/s each) and destined for the creation of new oases (Douz-Lazala CI.18, Souk Lahad CI.17 and Kébili-Bazma CI.16) but they are still not exploited at this moment. Table 2 shows the history of drilling boreholes in the region of Kébili with some characteristics such as temperatures, flow rates, depths and salinities.

Most of the geothermal resources are utilized mainly for agricultural purposes, irrigation of oases, heating and irrigation of greenhouses. They are also utilized for hotels (swimming pools), animal husbandry and for bathing. The distribution is given in the following:

- **Swimming pools**. Two pools in two different hotels at Douz locality are supplied by hot water from the well CI.12 with a total flowrate of 16 l/s (8 l/s for each hotel). The return water from the hotels is used for irrigating oases surrounding them. The rest of the water is used for heating and irrigation of greenhouses. It is important to mention that the temperature of the well is 53°C but the water is of high salinity reaching 4.2 g/l. There is another pool at Kébili-Ras-Elain alimented from the well CI.10; the water flows through it later to supply the surrounding oases (see Figure 2).

- **Animal husbandry**. Two wells are used, one at Chareb giving 4 l/s and another in Mahbes with 5 l/s.

- **Bathing**. Three wells are used for bathing, two of them at Menchia and Stiftimi have low flowrates (6 l/s for each well). The return water is used for irrigating the surrounding oases. The third well CI.10 is at Kébili, Ras-Elain with a high flow rate (71 l/s) from which 6 l/s are taken for bathing (Figure 2). The rest is distributed between the greenhouse area and the oases of Ras-Elain and Souk Elbayez.

TABLE 2: History of drilling in the region of Kébili (1952-1994) (CRDA, 1996a)

Year	Well name (Localities)	Temperature (°C)	Flowrate (l/s)	Depth (m)	Salinity (g/l)
(1)	Menchia	45	6	1,496	5.5
1952	Oum Elfareth 2	33.7	35	904	3.3
1955	Oum Elfareth 3	39.6	10	502	-
1958	Mazraâ Néji	27	42	651	4.7
1961	Steftimi 2	-	6	52	-
	Steftimi 3	44.7	12	1,005	3.1
1963	Ksar Ghilane 2	34.3	60	675	4.5
1980	Ksar Ghilane 3 bis	-	70	680	4.5
1983	Bouebdallah CI.1	46	38	1,420	2.8
1984	Mahbes	33	5	2,242	-
1985	Saïdane	55.6	25	800	2.9
	Zaouia CI.5	70.9	73	2,229	2.6
	Zouiet Chorfa CI.4	70.1	65	2,200	2.4
	Mansoura CI.3	52.2	3	2,200	3
	Taourgha CI.2	45.5	17	1,405	2.3
	Limagues CI.8	72.5	42	1,752	2.3
1986	Menchia CI.6	71	61	2,310	2.4
	Douz CI.12	53	20	2,080	4.2
	Kébili CI.10	66	71	2,580	2.4
	Jemna CI.11	59	118	2,192	2.8
	Steftimi CI.7	72.5	52	1,987	2.5
	Behaier CI.9	68	50	1,621	2.6
1991	Radhouane	23.5	15	200	-
1992	Chareb	-	4	560	-
	Mansoura CI.13	62	30	2,682	2.3
	Debabcha CI.14	72	71	2,480	-
1993	Faouar CI.19	51	50	1,894	-
	Ain Ghizi 1	-	2	93	-
	Ain Ghizi 2	-	25	80	-
1994	Kébili-Bazma CI.16	64	70	2,800	-
	Souk Lahad CI.17	68	70	2,500	-
	Douz-Lazala CI.18	44.7	70	2,020	-
Total	**32**	-	**1,288**	**46,796**	-

(1) This well was drilled many years ago in the locality of Menchia and has been used for a long time for bathing.

In most cases the hot water is cooled by towers and in a few cases in ponds of cement, subsequently utilized for irrigating 13,450 ha of oases. An area of 28 ha (566 greenhouses) divided into 8 sites is also supplied by geothermal water. This sector will be described in more detail in Chapter 4.

These hydraulic installations constituted the main part of the government interventions since 1980's by means of a big maintenance project called "Rehabilitation of oases". Since this time, the fittings costs exceed 40 million Dinars (CRDA, 1996a) and they included drilling 32 boreholes from the deep aquifer (CI) and 238 wells from the medium aquifer (CT), the construction of 369 km of pipelines for oases irrigation in order to save water, the installation of 550 km for a drainage system, the building of 11 atmospheric towers and 75 pumping stations. During 1996, many other installations were realized such as three atmospheric towers constructed at Debabcha, Faouar and Bazma, giving a total number of 14 towers in the region, the installation of 78 km of pipelines for oases irrigation and the implantation of two ponds covered by a geo-membrane with a total capacity of 3,500 m^3 involved in the programme of water conservation, and a drainage system covering 22 km.

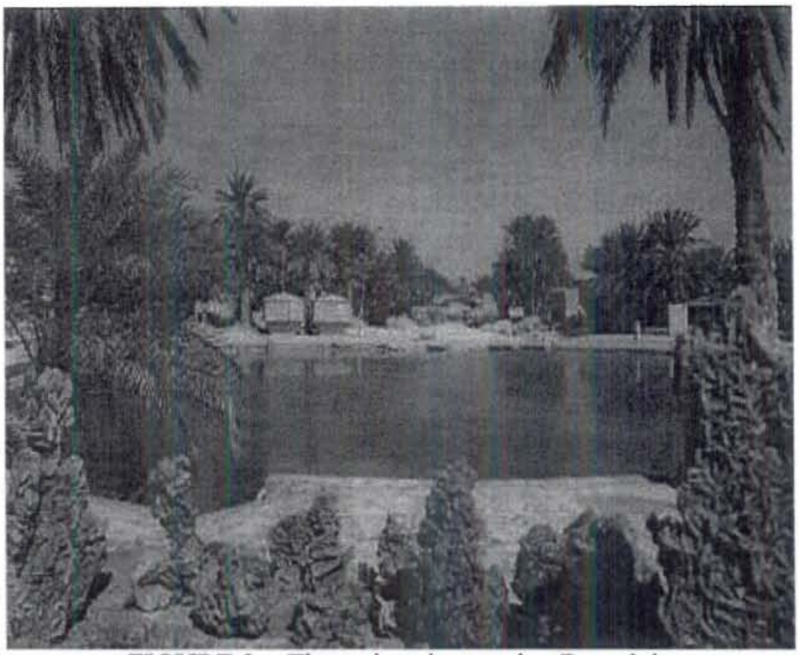

FIGURE 2: The swimming pool at Ras-elain

The Tunisian policy in the agricultural field and especially in its hydraulic aspects was oriented in the beginning of 1990's to give more importance, responsibilities and decision making to the organizations. In that way, 72 organizations related to the management of water resources, called AIC, are operating in the region and they contribute effectively to the distribution of these rare resources. The members of these organizations are elected by the farmers themselves. It is important to emphasize that the management of water resources by means of AIC in the region was successful and is considered the best example in the country, and that other big regions should follow the Kébili experience.

3.2 General data

The region of Kébili is located in the southwest of Tunisia. Administratively, it is divided into five zones, commonly called delegations: (a) the north of Kébili, (b) the south, (c)Souk Lahad, (d) Douz and (e) Elfaouar. The area is characterized by a desert climate (arid). The annual precipitation is irregular and less than 100 mm. The maximum temperature is about 42°C and the temperature range (the difference between maximum and minimum temperatures) is very high. The soil wind and the sirocco (very hot wind) blow, respectively, for 120 and 40 days per year. These unfavourable climactic conditions negatively affect many plantations inside the oasis system.

The total area is estimated at 2.2 million hectares in which 345,000 ha are exploitable. Only 8.6% of the total area is really exploited in the agricultural field (190,500 ha). The natural reserve covers 160,000 ha and the agricultural cultivation 30,500 ha. The oasis area is estimated at 13,450 ha and is classified into three floors (Figure 3): (a) the first floor which is called the upper floor is composed of date palms,

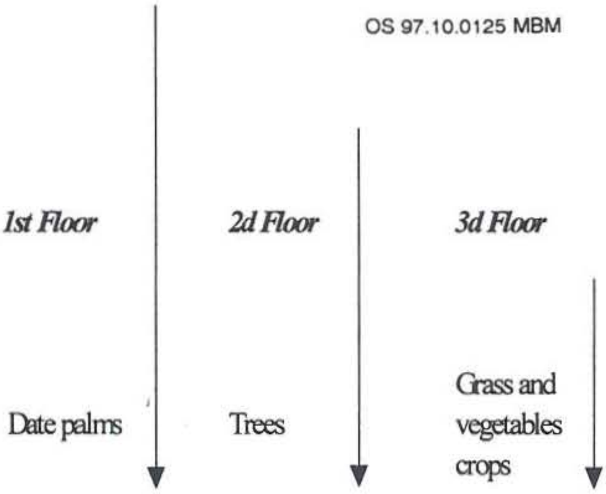

FIGURE 3: The oasis system

the second one or the middle floor is composed of trees under date palms (apple, fugue, grape, apricot, grenade) and the third one, the under floor or the open field composed of grass and vegetable cultivation in which winter and summer crops are raised. These three floors constitute the oasis system and are generally managed at the same time and irrigated by the same water (quantity and quality). The cultivation of these three floors together makes a microclimate, commonly called "oases' microclimate". This oasis system can be schematized as in Figure 3. The soil is known as very light soil, formed by gyps and calcite, hydro-morph with a relatively high salinity and poor of organic material.

Government policy has recently supported private initiative and professional organizations. In that way, the region contains one farmers' union (UTAP) with four local farmers' unions spread throughout four delegations (Kébili, Douz, Souk Lahad and Elfaouar), one date grouping (GID), four service cooperatives (CAS), one camel organization and 83 water organizations (AIC) in which 72 are operating.

3.3 Irrigation of the upper floor date palms

Date palms occupy first place in the agricultural activity of the region due to their social and economical interest. Social because of the big number of farmers living directly on this (about 30,000 farmers) and also families that are attached directly or indirectly. More than 80% of the population live on this sector. Government policy for a sedentary population has been reached. It is important to acknowledge the high level of employment generated by this sector. The economical interest is related to its profitability and the good income for its farmers (micro-economy) and consequently the favourable contribution to the commercial balance (macro-economy). Indeed, the dates' sector occupies the third place in the total agricultural export of the country after olive oil and fishing.

Due to the complexity of the oasis system, the number of trees gives more significance than the area which involves date palms, trees, grass and vegetable crops. The total number of date palms is estimated at 1,738,700 divided into two varieties (cultivars). The supreme quality deglat nour, destined for export with 1,350,400 trees and communes, commonly destined for the national market with 388,300 trees.

3.3.1 Production and yields per variety

The total production of dates in Tunisia is estimated at 75,000-80,000 tons per year. The region of Kébili contributes on average more than 55% of the total. The date's product was estimated at 44,500 and 40,355 tons, respectively, for 1995 and 1996; deglat nour variety contributes 70% of the total production. The production in 1996 shows yields of 32 kg per tree for deglat nour and 34 kg for communes. These yields are considered very low compared to the potential, especially the quantity of water used for irrigation (25,000 m^3/ha).

3.3.2 Commercialization and export

Annual growth of the GDP (Gross Domestic Production) in Tunisia was 4.2% (at constant prices) from 1987 to 1996 and is expected to reach 5.7% in 1997. The agricultural and fish sector has been a growth vector for many years and plays an important role. In 1995, the sector accounted for nearly 13% of GDP; Table 3 shows the evolution of agricultural and fish contribution in the GDP from 1991 to 1995.

TABLE 3: Agricultural contribution in the GDP in Tunisia

Years	1991	1992	1993	1994	1995
Agricultural and fish contribution (%)	17	16	15	13	13

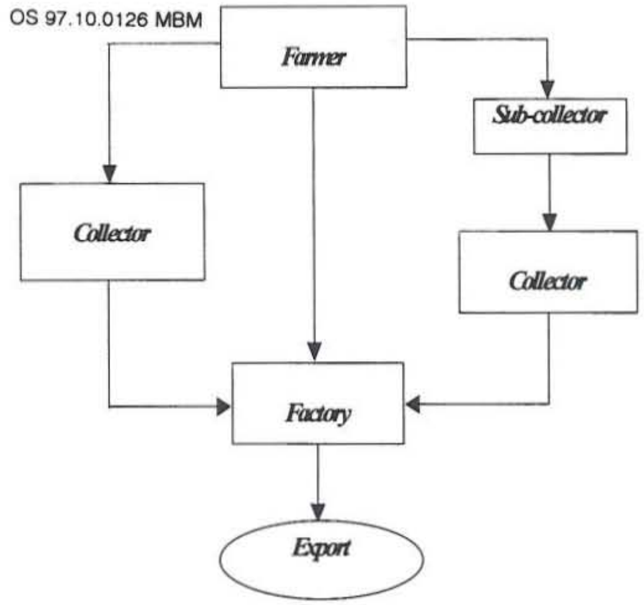

FIGURE 4: The commercialization circuit of dates

The date's sector occupies third place in the total agricultural exports of the country with 14% of the total value after olive oil (38%) and fish products (27%). About 20,000 tons of dates are exported per year mostly to European countries giving a currency of 50 million dinars. As said before, more than 55% of the total production comes from Kébili. However, the packaging and the refrigerator capacities for production storage are very modest. There are nine factories with a theoretical packaging capacity of 8,500 tons. The real capacity is estimated only at 1,000 tons and their refrigerator capacity is about 1,100 tons. It is important to note that there are nine refrigerators utilized only for production storage with a capacity of 900 tons. In 1996, only six of these nine packaging factories were operating due to the lack of proper funds. This resulted in low export quantities estimated to be 600 tons of dates. Almost 90% are Deglat Nour variety (540 tons). In fact, a very high quantity of date product is sold in the local market and in other regions of the country. The circuit of commercialization is very complex and three circuits, at least, can be distinguished as schematized in Figure 4. a) The farmer, in a few cases, can sell directly to the packaging factory. b) The farmer sells to a medium called a collector who sells the production afterwards to the factory. c) The farmer sells to an under-collector who works under a collector who sells to the factory. The complexity of the circuit increases the date cost.

3.3.3 Types of irrigation

As mentioned before, water resources utilized for irrigating oases are taken from two aquifers, the Complexe Terminal (CT) giving cold and warm water, which is over-exploited and the Continental Intercalaire (CI) with hot water, exploited at 1,078 l/s. Table 4 gives an overview of this.

TABLE 4: Water resources and their exploitation (CRDA, 1996b)

Aquifer	Zone	Resource (l/s)	Exploitation (l/s)	Rate (%)
Complexe Terminal (CT)	Nefzaoua	4,500	6,605	147
	Régim Maâtoug	2,000	785	39
Continental Intercalaire (CI)	Nefzaoua	1,000	1,078	108
Total		**7,500**	**8,468**	**113**

From 29 wells operating in the region, 2 wells are used only for animal husbandry and 27 wells for oases irrigation in which eight are also used for heating and irrigating greenhouses. The water temperature varies from 24°C (borehole in Rahouane) to 73°C (CI.7 and CI.8). The salinity can reach 4.5 g/l. Generally, water with low enthalpy (< 40-45°C) is used directly for irrigation. When the temperatures exceed 45°C, the water is cooled by means of atmospheric towers or ponds before being used for irrigation. Fourteen towers are utilized to lower the temperature to 30-35°C. However, these towers have the disadvantage of losing water via evaporation, estimated at 10% of the total flowrates.

The irrigation in the region is by the submersion method and all the area is irrigated (no localized irrigation). In this case, water is transported through a furrow to parcels causing high water wastage due to infiltration, evaporation and physical characteristics of the soil (light soil, sandy, silty soil). For saving purposes, the government encourages farmers to install and utilize PVC pipelines for irrigation by subsidizing 40-60% of the total investment.

3.4 Irrigation of the trees in the middle floor (apple, fugue, grape, grenade, apricot)

Trees symbolize the middle floor of the oasis system. It is composed of local species non-ameliorated and characterized by very low productivity. For the oasis farmer, trees under date palms don't represent much income and are mainly for self-consumption. Apples, fugues, grapes, grenades and apricot are the main species. The total number is estimated to be 295,000 trees, giving a production of 1,500 tons per year.

During 1996, a plantation programme was established by the CRDA and the regional development council in which 2,000 trees were planted (40 ha). According to the potential of the region and the large amount of water given to the oasis system, the productivity of the trees is very low (less than 7 kg per tree). The sector is managed without any special care and many operations of maintenance such as fertilization, treatments and cutting are absent. To promote this, it is necessary to adopt a good programme taking into account all of these constraints (maintenance, productivity) and to orient farmers, by means of popularization, towards selected species with high productivity. The promotion of the trees' sector should contribute effectively in the optimization of water use inside the oasis system.

3.5 Irrigation of the under floor, grass and vegetables

Grass and vegetable plantations are grown between date palms and trees and they benefit from the same input (fertilization, water, etc.) given to the system. Many years ago they were of no importance for the farmer but, at present, they are starting to be taken more seriously, especially grass cultivation.

The absence of vegetation outside the oases, due to the desert climate and the lack of precipitation in the area, gives a high interest in grass cultivation. That is why it occupies a good place in the oasis system. According to the considerable livestock in the region (60,000 sheep, 54,000 goats and 174 cows) the need for grass as fodder is high. The total area covered is estimated to be 5,000 ha classified into winter plantations (3,500 ha) and summer plantations (1,500 ha). About 300,000 tons of grass are produced each year, composed of lucerne, green barley and sorgho, but this is still below the real needs of the livestock.

Due to the hot weather and the relatively hot water utilized for irrigation in some oases, vegetable crops, especially summer crops, are under-developed and of little interest for the farmer. In most cases, they are used for self-consumption and the alimentation of the local market is too low. Because of their climatic sensitivity, summer crops such as tomatoes, peppers and melons are difficult to grow. Unfavourable climate conditions (sirocco, soil wind) are a real disability. Due to this and because of the lack of water in some oases vegetable crops are most under-developed. Only 2,500 ha are cultivated per year in which 60% are winter crops (1,500 ha). About 22,600 tons of vegetables are produced per year.

The winter crops are 12,800 tons of carrots, green onion, turnip, garlic and leafy vegetables. The summer crops are 9,800 tons of tomatoes, peppers, melons, watermelons, cucumbers, squash, courgette, bulb onions and leafy vegetables. By contrast, it is important to point out that the climate is favourable for out-of-season potato cultivation which is planted in late August but, unfortunately, it is practised in few areas (only 2 ha in 1995 and around 11 ha in 1996). This could be increased successfully in the region.

4. HEATING AND IRRIGATION OF GREENHOUSES

In addition to irrigation of the oasis system, the geothermal water is used for heating and irrigation of plastic greenhouses in South Tunisia. In this chapter, the greenhouse sector will be described by mentioning its historical aspects, the evolution of areas, production and commercialization, to deal at the end with a social, technical and economical evaluation by analysing the production system.

4.1 Description of the greenhouse sector

4.1.1 Historical aspects

Generally, without heating, vegetable crops such as tomatoes, peppers and melons are obtained mainly in the period of May and June. Considered very late, this product cannot get remunerative prices in the national market and even less in the European market (EEC). Compared to the north of the Mediterranean countries, the precocity of production in Tunisia is about 14 days. Therefore, the main target was set to obtain acceptable production between mid-February and mid-May when the prices of vegetables are highest in the European countries. To realize this objective, it was necessary to consider the utilization of hot water in greenhouse farming. The utilization of geothermal energy in agriculture had recently started in Tunisia as an experiment conduced by the National Agronomic Institute (INAT) in Mornag and Chenchou localities. The results of this experiment were very encouraging and led to the idea of a geothermal utilization project in agriculture (PUGA-project, TUN/85/004) financed by UNDP. In comparison with unheated greenhouses, the geothermally heated greenhouses generate better quality and higher yield.

In 1986 the government started to use geothermal energy in greenhouses in South Tunisia. After one year, many demonstration projects in several places had been established with the collaboration of the Energy Agency (AME) and the rural development programme (PDRI). The locality of Limagues, in the region of Kébili, was the first place where plastic greenhouses were implemented (1 ha). At the same time, the company "5th season" stocked the first part of a big project (5 ha). Furthermore, in 1991 a second project for greenhouse technique development was begun in cooperation between the government of Belgium and the Tunisian government. The exploitation of geothermal resources for heating and irrigating greenhouses on the edge of the desert seems to represent a promising alternative for the development of the sector.

4.1.2 Objectives of the PUGA-project

The objectives of this project are to develop utilization methods for geothermal energy. This is a part of a governmental programme to rehabilitate old oases and create new one in South Tunisia. The utilization method addressed in project TUN/85/004 is to use the geothermal water to heat greenhouses. When the hot water is cooled by the greenhouse utilization, it is subsequently used for irrigation. The main objectives are a control of the horticultural production (irrigation, heating, ventilation and fertilization), a global control of the production system oriented for export (choice of the best kind of vegetable crops, best period and quality) and finally a transfer of technology to technicians and growers.

4.1.3 Evolution of areas

Numerous commercially marketable crops have been raised in geothermally heated greenhouses in Hungary, Russia, New Zealand, Japan, Iceland, China and the United States. These include vegetables, such as cucumbers and tomatoes, flowers, house plants, tree seedlings, and cacti. The use of geothermal energy for heating can reduce operating costs and allow operation in colder climates where greenhouses would not normally be commercial (Lienau, 1997). Geothermal energy has been used most extensively in agriculture in greenhouse heating. Many European and other countries are experimenting, but also regularly using geothermal energy for commercial out-of-season production of vegetables, flowers and fruits. According to Popovski (1993) the main countries using geothermal energy in greenhouse growing are USA (183 ha), Hungary (130 ha), China-Taiwan (60 ha), Macedonia (51 ha), former USSR (25 ha), France (24 ha), Spain (20 ha) and Iceland (18 ha).

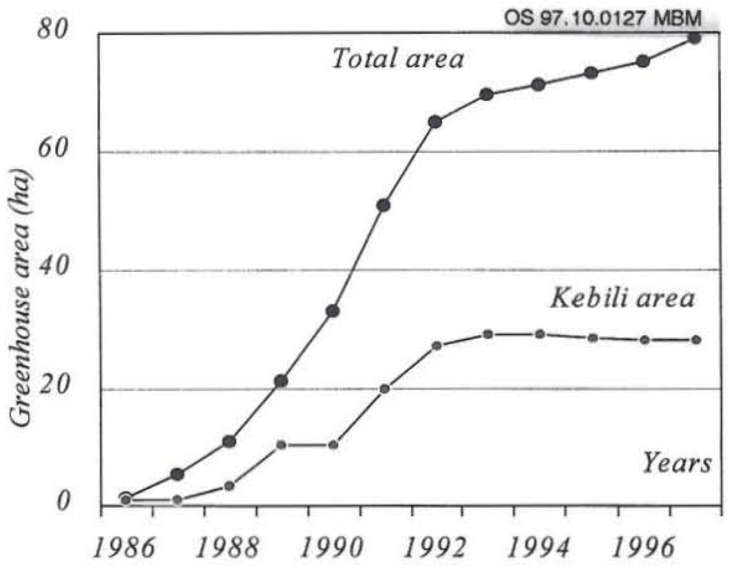

FIGURE 5: The evolution of total greenhouse area in Tunisia

In 1993, Tunisia occupied the third position with 71 ha, after the United States and Hungary. Starting with one ha as an experiment in 1986, the total area of geothermally heated greenhouses in Tunisia has increased considerably. Indeed, the area reached 33 ha in 1989-90 in which 31% were in the region of Kébili. In 1992 and 1993, the total area covered was, respectively, around 65 and 70 ha; 42% are located in the region. The total area continues to increase, attaining 75 ha in 1995-96 and near 80 ha in 1996-97, in which the region represents, respectively, 37% and 35%. Figure 5 shows the evolution of the greenhouse area in the country and in Kébili.

It is very clear that the significant increase was from 1987 to 1992. The greenhouse areas in Kébili region follow the same rhythm as the national evolution. Plastic greenhouses were attributed in the beginning to small farmers with two units of houses allocated for social aspects and financed by the PDRI programme. The first experience was in Limagues zone where 20 greenhouses covering one ha were planted in 1986. Further, an area of 10 ha spread over several places was added in the years 1989 and 1990. The original area of 1 ha was multiplied 20 times in a period of six years to reach 20 ha in 1990-91. Since then the sector has stagnated and the total area has stabilized in the range 27-29 ha.

The development of the greenhouse sector was very fast, at least, for some farmers starting with two houses, holding now 5-6 greenhouses. The average area exploited by each greenhouse grower is estimated at 0.7 ha (greenhouses and oases). Inside the greenhouse project which covers 0.48 ha, farmers exploit an open field in which they practice cultivation with the three floors (date palms, trees and grass and vegetable crops). In some cases, outside the greenhouse project, farmers have parcels in which they practice oasis cultivation estimated at 0.22 ha but they represent a small part of the farmers' income (5%) whereas, 95% come from the greenhouse project (Ben Mohamed, 1995). Greenhouses are spread over eight different sites, Limagues I and II (5.9 ha), Ras-elain I and II (7.7 ha), Hniche I and II (1.9 ha), Saïdane (3.15 ha), Oum-elfareth (2.45 ha), Steftimi (3.25 ha), Jemna (2.85 ha) and Menchia (0.8 ha).

4.1.4 Occupation of areas

Utilization of the greenhouse area in Kébili region is based on three cultivations, the first, from late August to late December, the second from late December to June and the third from late August to June.

The exploitation is more than one time per year and lasts nine months. The cultural system in 1993 was composed of melons and tomatoes representing, respectively, 32 and 31%, watermelons (18%), cucumbers (15%) and peppers only 4% (Ben Mohamed, 1995). In 1996 tomatoes and cucumbers were the main vegetables composing the system (72%) due to their commercial value. Figure 6 shows the composition in 1996. Inside a greenhouse, several species of crops can be raised simultaneously. Growers, in this way, try to diversify their production in order to bypass agricultural risk.

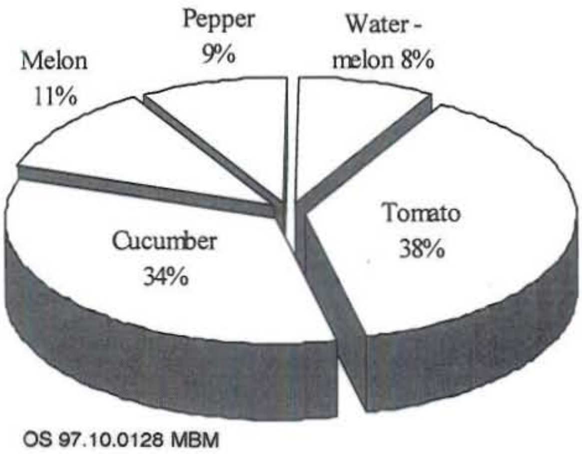

FIGURE 6: The cultural system composition in the Kébili region(1996)

4.1.5 Evolution of productions

Despite some problems handicapping the greenhouse sector in the beginning, such as lack of qualification and bad techniques of some farmers, production increased from year to year. This is not a result of good productivity but generated by the expansion of areas as mentioned above (Sghaier et al., 1991). The total production in Tunisia increased a lot in 1988-1992, or from 900 to 5,300 tons, but then it stabilized at about 5,600 tons. The production in Kébili region follows the same pattern, growing from 263 tons in 1987 to 1,122 tons in 1990. From 1992 to 1996 it varied as shown in Figure 7 with an average of 2,190 tons per year.

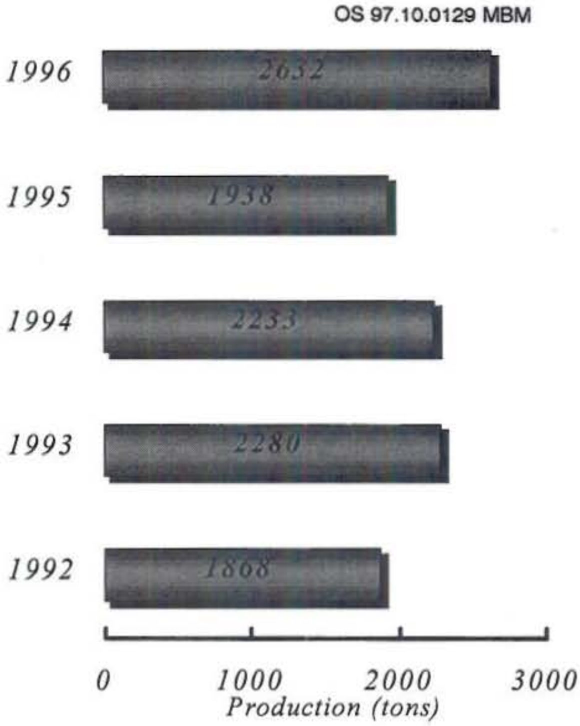

FIGURE 7: Evolution of production in Kébili region

Although the greenhouse sector is considered promising, it is confronted by many disabling constraints such as the lack of organization and techniques for a large number of farmers. These bad techniques have a direct effect on total production. In fact, yields observed are very low when compared to potential and, consequently, to projections by experts.

There is a big difference between what is expected and what is obtained. Based on the production in 1996, the difference between yields was more than 50% for pepper and reached easily 40% for tomatoes of second season and 42% for continuous tomatoes. It was estimated at 25% for cucumbers and watermelons. So, yields observed are very far from those predicted by specialists as shown in Table 5.

It is very important to point out the big differences in yields obtained between sites are caused essentially by differences in techniques. For melon crops raised in 1993-94, the difference between expected and observed yields attained 67% in Steftimi and Saïdane localities (Ben Mohamed, 1995). Table 6 explains clearly these differences.

TABLE 5: Difference between expected yields and observed yields
(Source: CRDA, 1996b and the author's calculations)

Season	Vegetable crops	Expected yield (kg/m^2)	Observed yield (kg/m^2)	Difference (%)
First season	Tomatoes	10	8	20
	Melons	3	2.5	17
	Cucumbers	3	3	-
Second season	Tomatoes	12	7	42
	Melons	6	5	17
	Watermelons	8	6	25
	Cucumbers	4	3	25
Third season (continuous)	Tomatoes	20	12	40
	Peppers	7	3	57

TABLE 6: Differences between expected and observed yields inside Behaier sites in 1994

Variability (%)	Steftimi	Limagues I	Limagues II	Saïdane	Oum-elfareth
Melons	67	60	53	67	50
Cucumbers	43	53	50	60	42

The variability between two sites and in the same site is also too high. This will be discussed in detail in the chapter on technical evaluation.

4.1.6 Commercialization and export possibilities

In order to promote the agricultural sector, Tunisian policy oriented towards diversification. Several actions were undertaken to develop the geothermally heated greenhouses in the south of the country. The target was to export 50-60% of the total production. This quantity has never exceeded 18%. In 1992 and 1993 it reached 22 and 27%, respectively, but is still under potential in the sector. The export production in Kébili is insignificant and never reaches 10% of the total production. However, about 8% were exported in 1992 but only 3 and 4% in 1993 and 1995. The production in 1996 was estimated at 2,632 tons in which 2.5 tons were exported (0.1%). Figure 8 shows the production and the export in the region.

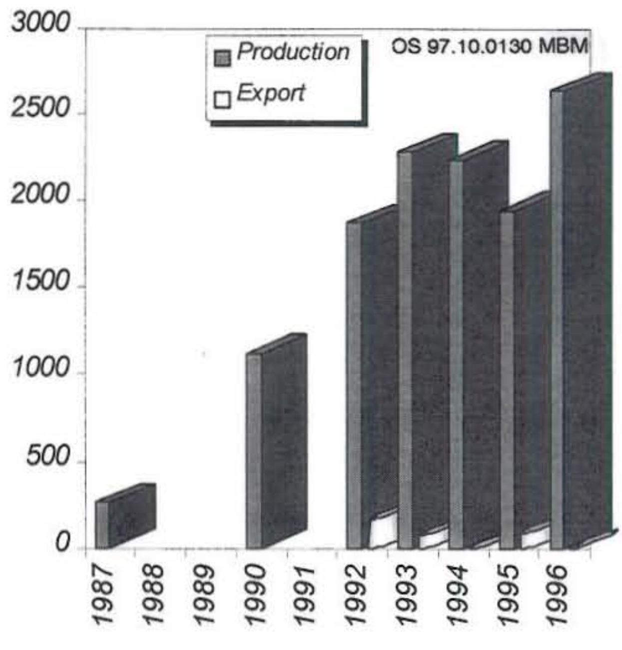

FIGURE 8: *Kébili* production and export (tons)

The disorganization of the greenhouse sector manifested essentially in the absence of service cooperative companies for selling the farmers' products, and the existence of remunerative prices in the local market is the cause of low quantities exported. Prices are variable and sometimes low in both regional and local markets. Farmers sell their products with no cooperation between sellers. and most sell directly from their farms at very modest prices to bypass uncertainties at the markets.

Export is strongly related to the quality of vegetable crops and the period of production. In Tunisia, when the time is suitable, quantity and quality are low. The adequate period for the European market is between November and April for tomatoes, and between April and May for melons and watermelons due to the low import taxes on the product. Tomatoes are not available for export in this period and they are sold in the national market (Ramadan). In the European countries, melons and watermelons are under-consumed in winter time and from April (favourable period for export), Spanish products cover the market. The entrance of Spain into the Economic European Community (EEC) upset the relationship between EEC and their partners from the south Mediterranean countries. The majority of these countries and principally Tunisia have oriented their production for a long time to communities demand and they are in direct competition and concurrence with Spanish products. It should be mentioned that most of the Tunisian trade is with the European market. In that way, 71% of Tunisia import comes from EEC and 76% of its export are destined to EEC (1991).

The Generalized System Preferences (GSP) was negotiated in 1968 in the United Nations Conference for Development and Trade (CNUCED) in which some imported merchandises from underdeveloped countries benefit from some low tariffs compared to merchandise coming from other countries. In 1971, the EEC introduced the GSP which was applied unilaterally without any exigence and discrimination. This system had, as a consequence, the suppression of tariffs on manufactured goods. In the agricultural field, the situation is different and EEC imports are not only controlled by tariffs, but also, and in most cases, by the reference system prices applied in the context of the Common Agricultural Policy (CAP). These reference prices constitute a real obstacle for countries outside the community. In fact, when the price at the entrance is under the reference price fixed inside the community, the EEC can decide to apply what is called an import tax which is equal to the difference between the reference price and the calculated price at the entrance.

4.2 Social evaluation

The development of greenhouse farming in Kébili started in 1986 by the attribution of two greenhouses (Limagues) financed gratuitously by the Rural Development Programme (PRD). Then, several other projects were established and financed by other funds such as FOSDA, FOSEP and PDRI. A typical greenhouse investment is composed of a loan (60-70%), a subsidy (15-35%) and a self-finance (5-15%). The objective of the project was to develop rural zones, commonly called unfavourable zones, in order to fix population and what should be paid by the farmer (self-finance) is often paid totally by the regional council, at least a good part of it. The social evaluation will be based mainly on the farmers' age, their social situation and the proximity of their residence to the farm.

The selection of the most motivated farmers contributes efficaciously to a successful sector. Greenhouses were attributed to relatively young farmers capable of practising high technology in greenhouse growing. The results of one investigation carried out in 1994 on a group of farmers based on 40% of the population, showed that 30% of them were under 30 years of age and 57% were less than 40 years old (Ben Mohamed, 1995). This confirms the authority's orientations of choosing young farmers for best control of techniques.

Most of the farmers originated from Nefzaoua and more than three quarters of them were married. This justifies the social aspect of greenhouse attribution especially based on the number of labour days that the greenhouse sector can generate, which is estimated as 7 permanent jobs and about 900 seasonal days of work per ha. If the education or the instruction levels are considered as good indicators for learning techniques, it can be noted that almost 75% of the farmers will face difficulties due to their illiteracy. They don't exceed the Koutteb level (first year of Koranic education). In addition, 64% of them have not had any agricultural formation.

It is very important to take into account the proximity of the residence to the farm because it can show the rate of horticulturists present in the fields. About 80% of them live less than 3 km away from the farm and almost 20% at a distance exceeding 5 km.

4.3 Technical evaluation

4.3.1 Soil preparation

Soils in greenhouse sites are poor of organic material. The prospecting studies showed that they are gypsy soils with low porosity. Therefore they need to be corrected and ameliorated by means of a deep plough in order to eliminate rocks. In some cases the soil is changed by another more fertile due to its poor chemical composition. About 30% of farmers from most of the sites have practised this operation in the beginning of their installation.

4.3.2 Fertilization

Fertilization of greenhouses can be of two different types: organic fertilization and mineral or chemical fertilization. The organic one consists of a manure amendment. In Kébili, the average of manure quantity used is about 3 tons per greenhouse (60 tons/ha) which corresponds to the quantity announced by experts. However, there is a big variability between sites and the amendments vary from 34 tons/ha at Limagues II locality to 100 tons/ha at Menchia. The chemical fertilization is based on the use of common fertilizers such as phosphates, nitrates and potassium. This kind of fertilization is given in two periods. The first one corresponds to the soil preparation, but the second one is during the growing season (maintenance period). Phosphate's amendment is very high, and it is exactly the double of the quantity advised (40 kg per greenhouse instead of 20 kg). A high variability between sites can be observed. The quantity differs from 18 kg in Ras-elain II to 58 kg in Oum-elfareth. Limagues I, Ras-elain II and Hniche sites respect this amendment.

Generally, the use of potassium in the first period is not advised due to the richness of both the soil and the water used for irrigation. In spite of this the farmers are supplying a quantity of 20 kg per greenhouse. The greenhouses are equipped with a localized irrigation system. That's why farmers, during the growing period, are giving nitrogen and potassium nitrates by means of the ferti-irrigation technique. It is fertilization combined with irrigation and contributes to a good distribution of fertilizers with low quantities. The use of this method is almost generalized in the region as more than 90% of the growers use it. The nitrogen quantity varies from 45 kg in Limagues I to 95 kg in Hniche. On the average it is about 60 kg per unit which is close to the recommended quantity (50 kg) but the variability should be mentioned. This kind of fertilization is over-utilized due to a relatively low price. On the contrary, potassium nitrates are utilized at low amendment due to their high prices and sometimes to their unavailability in the region. An average of 50 kg is used for one greenhouse which is very low compared to the needs of crops (120 kg). Quantities vary from 25 kg (Menchia) to 90 kg (Oum-elfareth). For each kind of fertilization, a high variability between sites is observed which is explained by different technical level and management of inputs between farmers. The maximization of the profit is strongly related to the best control of expenses.

4.3.3 Heating of greenhouses

Continuous low temperatures at 10-12°C during two successive days disturbs the physiological behaviour of plants. Paradoxically, temperatures higher than 30-38°C can provoke irreversible damage to crops. Normally, temperature variation should not exceed 5-7°C. In the south this is not common and the risk of temperature variation is frequent. In order to solve this problem, the use of geothermal water seems to be a good solution which can ameliorate the climate inside greenhouses principally during the night. The heating of greenhouses is through pipes lying on the ground between the plants. Several types of pipelines have been tried and polypropylene pipes are suitable (Mougou et al., 1987). Generally, an average of 8-10 loops are used per house and they are connected with the system by a valve, easily operated.

For heating greenhouses in Kébili region, eight wells are operating to supply eight big sites. One site is often subdivided into two or three small sites as Limagues (Limagues I, II & III), Ras-elain (Ras-elain I & II) and Hniche (Hniche I & II). An area of 28 ha is geothermally heated with a total flowrate of 154 l/s and a water temperature varying from 53 to 73°C. Boreholes supplying the area are listed in Table 7.

TABLE 7: Characteristics of wells supplying the greenhouse sites (CRDA, 1996b)

Site	Well	Temperature (°C)	Total flowrate (l/s)	Flowrate for heating (l/s)
Hniche I & II	CI.12	53	20	11
Ras-elain I & II	CI.10	66	71	44
Limagues I, II & III	CI.8	72.5	42	28.5
Steftimi	CI.7	72.5	52	15
Saïdane	Saïdane	55.6	25	17
Oum-elfareth	CI.9	68	50	15
Jemna	CI.11	59	118	18
Menchia	CI.6	71	61	5
Total	**8**	-	**439**	**153.5**

More than one third of the total flowrate is intended for the greenhouse heating (65% for oases irrigation and pools). The need for heating is estimated to be 5.5 l/s per ha, which corresponds approximately to the recommended flowrate (6 l/s/ha) but this amount depends strongly on the temperature of the water and the climate conditions. It is important to note that the concurrence between greenhouses and oases is low (only three months per year) particularly in the period of November, December and January. This period coincides with the date palms maturation in which farmers decrease the quantity of water for oases irrigation. Due to bad conceptionalization of some greenhouse projects, hot water sometimes cannot reach ponds. Therefore farmers throw it close to the fields provoking a big waste of water resources (case of Oum-elfareth, Steftimi, Hniche and Jemna). Normally, the return water should supply oases surrounding the area but this is often difficult to realize. Therefore, the location of a greenhouse project near the oases is preferred and a combination greenhouse-oasis must be considered in the future. The need for greenhouse heating is only six months, mostly during the night. Farmers start heating in November-December and stop it in April. The duration lasts 14 hours per day. This means that they open the system in the afternoon when they finish working to stop it the next morning when they reach the farm. The technique of heating is controlled by 75% of growers but one quarter of them prolongs the duration after April when the weather starts to be hot and a risk of crop damage is predicted (Ben Mohamed, 1995).

In colder countries like Iceland, the need for heating is obviously higher. Heating of greenhouses with geothermal water began there in 1920. Before that time, natural soil warming had been used for growing potatoes and other vegetables. Over the past years, the use of artificial lighting has increased, which has extended the growing period to 9 months. Over the years the total area has increased to 18 ha. Tomatoes and cucumber are the most popular crops. The total geothermal energy used in the greenhouse sector in Iceland is estimated to be 830 TJ per year (Ragnarsson, 1996). Artificial light is used to increase the period of light during the day in winter time but CO_2 distribution is used to increase photosynthesis and to get lower humidity (70-80%).

4.3.4 Geothermal production of CO_2

Carbon dioxide has many uses, e.g. in the food industry and in greenhouses. Geothermal production is found today both in Iceland and Turkey. The Haedarendi geothermal field in Iceland produces 550 tons, and the Kizildere geothermal field in Turkey, 30,000 tons per year. Well H-2 was drilled at Haedarendi farm to 532 m in 1983. It was soon discovered that it had a very high concentration of carbon dioxide. The single feed zone is close to the bottom of the well and has a temperature of 155°C. Initial well testing produced massive deposition of calcite in the surface pipe-work after initiation of boiling (flashing to atmospheric pressure). Pilot testing of operating the well at close to shut-in pressure and at a low flowrate (1,5 l/s) produced no scaling. The water was then admitted to a heat exchanger, under full wellhead pressure and cooled to 70°C. The well has a relatively high gas content, 1.25% by weight with a high concentration of CO_2 and low concentrations of H_2S (350 ppm).

The process for the production in Haedarendi is basically composed of four stages: cleaning, compression, dehumidification and storage (Bogarín, 1996). After separation, the gas volume flowrate was about 13 l of gas for every litre of water produced. This released the idea that the well could be a source of CO_2 in commercial quantities. During initial flow testing the well had a maximum discharge of 15 l/s. The temperature during production, the pressure profile and the temperature logs of the well H-2 are shown in Figures 9, 10 and 11. The plant was installed in 1986 to compress the CO_2 production with a capacity of 550 tons per year. This plant presently utilizes about 2 l/s of the well flow, and now

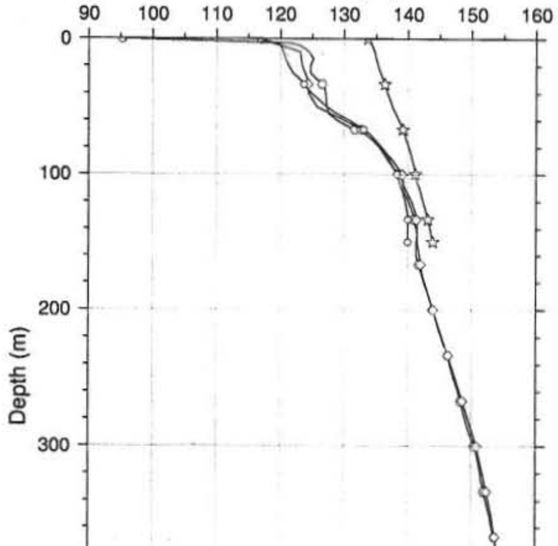

FIGURE 9: The temperature of well H-2, Haedarendi, during CO_2 production

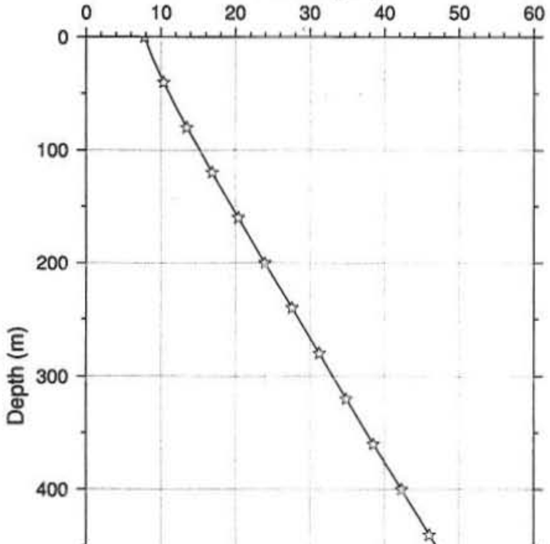

FIGURE 10: The pressure of well H-2, Haedarendi, during CO_2 production

the capacity is being tripled to meet the Icelandic demand of CO_2 for a multiplicity of uses, especially in greenhouses.

The extraction of CO_2 in Iceland started in 1986 at Reykjanes (Sjóefnavinnsla) from steam-holes. Before that time, few greenhouse growers used propane gas for CO_2 enrichment. Then, the Haedarendi plant started operation and about 75,000 m^2 of glasshouses are supplied by the CO_2, but some farmers are still using the propane gas because of the high price of CO_2. To control the quantity and for a best distribution, growers use CO_2 metres. Around 25,000 m^2 of roses consume 200 tons of liquid CO_2 per year. The use is combined with the artificial lighting for 18-20 hours per day in a period of almost 9 months (August-May). Generally the CO_2 is applied for vegetable crops such as cucumber, pepper and tomatoes and also for cut-flowers like carnations, lilies and alstroemeria but not for pot-plants because of their low prices. Furthermore, better humidity control can be derived to prevent condensation (mildew), botrytis and other problems related to disease control. The temperature in the greenhouses which is controlled by a sensor varies from 20 to 25°C but the average is 21°C.

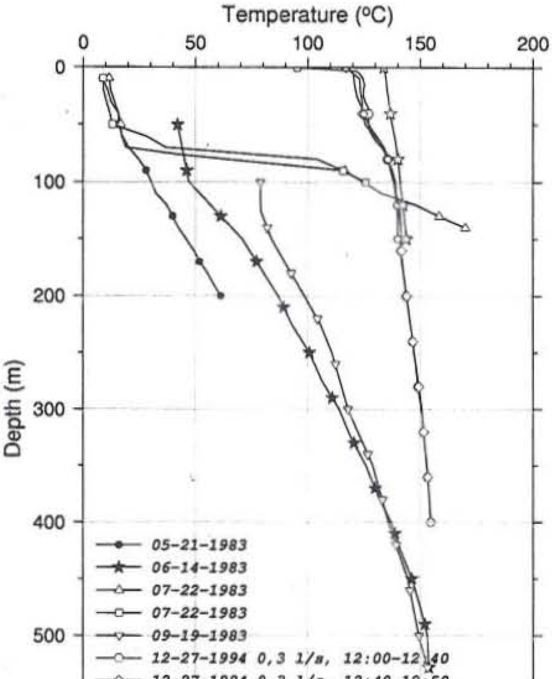

FIGURE 11: The temperature logs of well H-2, Haedarendi

4.3.5 Construction and ventilation of greenhouses

Many factors affect greenhouse growing, and as the light radiation is higher in southern Tunisia than in the north, the southern part allows more intensive growth rates. However, one of the most important factors in greenhouse growing is that both heating and cooling regulations are needed in the greenhouses. During the night, heating is required but during the day the houses have to be cooled so that the temperature will not exceed 30°C. At that temperature the plants stop producing fruits. The most suitable method to cool the greenhouses during the day is to open up part of the top of the greenhouse. By allowing for up to 16% of the area of the house to be opened during daytime, it is possible to maintain the inside temperature 1-2°C above the outside temperature (Stefánsson, 1986). To open up both ends of the greenhouse and regulating the inside temperature with a blowing wind will have a negative effect on the plants due to turbulence phenomena, especially when there is a high wind speed.

Compared to European countries, the construction of greenhouses in Tunisia is simple, inexpensive and well adapted to the environment. Half circle formed aluminium frames are used and covered by plastic polyethylene film. The covered area is about 500 m^2 and the construction costs for these greenhouses are 7-8 DT per m^2 for the frame, 1.2-1.5 DT/m^2 for the cover and 2-2.5 DT/m^2 for the material of heating and irrigation. Maintenance requirements for the plastic film are high in that it generally requires replacement on 3 year intervals, depending on the quality of the material. In Kébili the cover lasts only two years due to the unfavourable climate conditions (120 days per year). Other expenses should be added to the greenhouse such as the container for the fertilization-irrigation (1.2 DT/m^2), the external system (0.3 DT/m^2) and the ponds for cooling water (0.5 DT/m^2). These supplementary expenses are estimated at 2 DT/m^2 which elevate the cost of the greenhouse construction to 12.2-16 DT/m^2 (12-16 USD/m^2) the equivalent of 6100-7000 DT per greenhouse (6000-7000 USD).

Glass greenhouses are the most expensive to construct due to both the cost of the glazing material and the requirement for a stronger framework to support the glass. In Iceland, for example, glass greenhouses with an area of 400 m^2 are mostly utilized, especially in the southwest (Hveragerdi) and the northern part of the country. The cost of a glass house varies from 10,000 to 12,000 ISK/m^2 (140-170 USD/m^2).

4.3.6 Irrigation of greenhouses

After the thermal water has been used for heating it is collected in ponds for subsequent use for irrigation. These ponds need to be large enough to store all the cooled water until it is used for irrigation. A flowrate of 50 l/s is utilized for irrigating the total area (28 ha). For irrigation, horticulturists utilize a localized system. Water circulates inside a perforated pipeline lying on the ground. The chemical composition of the geothermal water used in irrigation must be monitored carefully to avoid adverse effects on the plants. In Kébili region, it has a high salinity varying from 2.3 to 4.2 g/l (0.1 g/l in Iceland) which can create obstructions in the pipelines. Table 8 shows the characteristics of the water.

TABLE 8: Characteristics of water supplying the sites (CRDA, 1996b)

Site	Well	Total flowrate (l/s)	Flowrate for irrigation (l/s)	Salinity (g/l)
Hniche I & II	CI.12	20	2.5	4.2
Ras-elain I & II	CI.10	71	13	2.4
Limagues I, II & III	CI.8	42	14	2.3
Steftimi	CI.7	52	3	2.5
Saïdane	Saïdane	25	2.5	2.9
Oum-elfareth	CI.9	50	5	2.6
Jemna	CI.11	118	9	2.8
Menchia	CI.6	61	1	2.4
Total	**8**	**439**	**50**	-

The frequency of irrigation differs from one site to another. The majority of farmers practise one irrigation per day (60% of them), 22% each 2-3 days and 18% irrigate two times per day (Ben Mohamed, 1995). A daily irrigation with low doses is recommended because, in one hand, the radiation and the temperature are too high in the region and, on the other hand, soils are very light and not deep. On the contrary, irrigating two times per day is not suitable notably where sites are not drained (Hniche). In this site, about 90% of farmers irrigate two times per day which increases the salinity of the soil. A soil-less technique was practised in order to resolve this problem of soil salinity but due to its high cost it was abandoned. The duration of irrigation is generally less than one hour (90% of farmers). This duration is totally respected inside six sites (Limagues I, Saïdane, Oum-elfareth, Ras-elain II and Menchia). The others (10%) can reach 2-3 hours per irrigation which is absolutely an aberration.

From the beginning of the greenhouse projects until 1994 problems connected to the damage of well heads and sometimes cooling towers' reparations have frequently happened causing a blockage of water. These problems coincide with the important period of greenhouse growing (installation period) causing heavy losses in the production. Nowadays, these problems are controlled by means of good well maintenance.

4.3.7 Problems and constraints

Besides problems related to the projects' conception such as the location of sites in low level and hydromorph soils and their exposure to wind, farmers are confronted with other difficulties related to cultural techniques. In spite of the remarkable experience acquired in greenhouse growing in the region (from 7 to 11 years), some farmers haven't a high technical level. The climate inside the greenhouse is characterized by high temperature and high humidity. These conditions became more delicate when farmers couldn't control techniques such as ventilation, irrigation and fertilization. This contributes to the proliferation of crop diseases such as nematodes.

Although a preventive treatment is practised by a big number of farmers, production is still exposed to some diseases which can reduce it. Up to now, farmers were not familiar with the use of pesticides. Sometimes, they use pesticides belonging to the same family without any regard to the dose. The majority of growers treat preventively against diseases by their own initiative but some of them await the passage of the technician for special advice.

4.3.8 Yields for different crops

In this part, differences between expected and realized yields will be analysed and the variability between sites and inside the same site will be explained. The purpose is to know how farms are operating. In that way, more attention will be given to the production techniques and the results that engender. As discussed before, different production schemes are utilized (plants raised during the first period, the second and continuously).

In 1996, tomato was the most important vegetable crop. It was grown on about 38% of the total area. Tomatoes raised in the first period (from late August to late December) actualized 16%. In 1993, for example, the yield was estimated at 7.2 kg/m^2 (3.6 tons per greenhouse) which is close to the expected yield (10 kg/m^2). Yields fluctuated from 6 kg/m^2 in Limagues II to 9.2 kg/m^2 in Limagues I. Tomatoes grown continuously (from late August to June) occupied about 11% of the total area. In 1993, the yield was estimated at 8.6 kg/m^2 which is very low compared to the predicted yield (20 kg/m^2). The high variability between sites should be observed. The highest yields were obtained in Saïdane (10.7 kg/m^2) and in Limagues I (10.3 kg/m^2) but the lowest yields were in Saïdane (6 kg/m^2) and Ras-elain I (6.6 kg/m^2). Concerning tomatoes raised in the second season (from late December to June), the occupation area was about 10% and the yields observed (6.7 kg/m^2) were approximately half of those expected (12 kg/m^2). The sites manifest a big disparity and yields variate from 4 kg/m^2 in Hniche to 12 kg/m^2 in Limagues II.

Cucumber has a high representation in the first season (23%) due to its short physiological cycle and its commercialization facilities. This plant is successfully produced in the region and the observed yield (2.6 kg/m^2) is near the expected one (3 kg/m^2) but with a big variability ranging from 1.3 kg/m^2 at Ras-elain II to 4.2 kg/m^2 at Limagues II. It should be mentioned that varieties utilized are local varieties destined only for the national market and they cannot satisfy the international market. The cucumber second season (about 12% of the area) gave a low yield with a variability of 1.6-4.5 kg/m^2. The melon is mostly raised in the second season representing about 10% of the total area. The observed yields (3 kg/m^2) are exactly the half of the expected ones (6 kg/m^2) and vary from 1.8 kg/m^2 at Hniche to 4 kg/m^2 at Menchia.

Pepper is normally raised inside unheated greenhouses due to its sensitivity to diseases particularly the nematodes but, unfortunately, it occupies a good place in the occupation area (9%). The yields obtained in the region (2.6 kg/m^2) are less than expected (7 kg/m^2) and vary from 1.9 to 3.6 kg/m^2. Watermelons occupied nearby 8% of the total area in 1996. The yield's average is about 2.9 kg/m^2 and the sites manifest a high disparity. The highest yields were obtained in Ras-elain I with 3.9 kg/m^2, the lowest were in Hniche and Limagues I with 1 and 1.9 kg/m^2.

Generally, the level of production manifests a high disparity between sites and inside the sites. The disparity explains the differences in site conception and mainly the difference in technical level and their utilization as expected by the heterogeneity of farmers in the region. The disparities in yields between sites are summarized in Table 9.

TABLE 9: Disparities in yields between sites (Ben Mohamed, 1995)

Season	Vegetable crop	Expected yield (kg/m^2)	Observed yield (kg/m^2)	Difference (%)	Variability (kg/m^2)
First season	Tomatoes	10	7.2	28	6-9.2
	Cucumbers	3	2.6	13	1.3-4.2
Second season	Tomatoes	12	6.7	44	4-12
	Melons	6	3	50	1.8-4
	Watermelons	8	2.9	64	1-3.9
Third season (continuous)	Tomatoes	20	8.6	57	6-10.7
	Peppers	7	2.6	63	1.9-3.6

Differences between expected and observed yields were more marked in 1993 than those in 1996 discussed before. They exceed 60% for peppers and watermelons. For the same crop, the yields for one site are four times higher than the yields for another site. This situation explains the real heterogeneity of farmers. The disparity exists also inside the same site. In fact, from one farmer to another, yields vary enormously. For example, concerning tomato raised continuously, both the lowest and the highest yields were observed in Saïdane Site (6 and 10 kg/m^2). Generally, the yields' average obtained are low in comparison to the objectives.

4.4 Economical evaluation

4.4.1 Structure of work in greenhouse farms

The objective in this part is to go deeply into the production units and to see how they are functioning, their activities, the decision making of farmers and their economical results. In that way, it is very important to discover the internal factors relative to these small units. The work is one of the most principal factors defining the process of the production system inside the farm. The kind of work in these units is on family basis and the permanent job is accomplished by the farmer and the family members. The contribution of the farmer in the family work varies from one site to another, from 44% at Saïdane to 92% in Jemna.

4.4.2 Gross income or outputs (*GI*)

To analyse the farmers' income, it is necessary to consider both prices and productions. In fact, one grower can obtain a good income not due to the high production realised, but because of high prices and vice versa. Therefore, prices and productions are considered together as a regulator of the farmers' income. Sometimes, low productivity is compensated by high prices.

Based on the year 1993, the farmer's income per greenhouse was estimated at 1,450 DT. The best incomes were observed in the sites of Limagues II and Ras-elain II representing, respectively, 1,915 and 1,740 DT per greenhouse. Thus, for one farmer exploiting two units, the income can reach 3,830 DT. For these two sites the yields of dominating crops are high and also commercialized with good prices. In a few cases, the obtained yields (for one or two crops) are low but the product is sold at high prices. That's why farmers obtained a respectable income. On the contrary, the lowest income was realized principally in Hniche and Ras-elain II sites. For the first one, the reason was that both prices and yields are very low. The main cause for a mediocre yield is the hydro-morph soil and its salinity which are accentuated by the salty water irrigation (4.2 g/l). For the second site (Ras-elain II), most of the dominating plants have low productivity.

Generally, the realized incomes are lower than the objectives. According to the estimations of experts, a farm of two greenhouses can generate an income of 6,160 DT (3,080 DT/unit) which exceeds the average income obtained in the region but certainly is far from the best income observed in Limagues II (1,915 DT/unit). Therefore, there is a big difference between potential and the realities of the sector. However, it is also important to indicate that gross income alone cannot dictate the economical results which depend tremendously on expenses (variable costs).

4.4.3 Variable costs or inputs (*VC*)

Variable costs are the costs related directly to the production. Their examination is very important because it justifies the rationality of inputs utilized in the production process and consequently the management of the farm. In fact, some growers try to maximize their income. The best way to reach the profitability nowadays is to minimize costs. The average inputs are estimated at 375 DT per greenhouse. The highest costs were observed in Oum-elfareth, Ras-elain I and Menchia with, respectively, 532, 474 and 405 DT per greenhouse. These are mainly due to a high use of fertilizers. The lowest inputs observed in Limagues I and Steftimi are 257 and 297 DT, respectively, which are explained by low inputs (fertilization, seeds). A deep study of input values shows that fertilization is by far most important (45%) followed by seeds (19%) and pesticides (11%). Transport cost and soil preparation represent, respectively, 9 and 7% of the total values of variable costs (Ben Mohamed, 1995).

The high use of fertilization in the region is due to the effort of the farmers to ameliorate the soil which is very poor in organic material. This is the case in Menchia, Ras-elain I and Ras-elain II. Concerning seeds cost, it is normal to see the big variability in values between sites because the cost depends strongly on the species of crops cultivated, their varieties, the quality and the quantity of seeds. The seeds' cost is about 27% of the total value for Saïdane and Menchia.

4.4.4 Net income or profit margins (*PM*)

As an indicator for the economical results, the Profit Margin (*PM*) will be considered. According to Marshall (1988), the profit margin of one production is the contribution of this production to cover the fixed expenses which are indirectly related to the production. The Profit Margins is defined as the difference between gross income (*GI*) and costs of purchase or variable costs (*VC*), or

$$PM = GI - VC \qquad (1)$$

The standard profit margin is defined as the profit margin of one farm (2-4 greenhouses) and it is estimated at 2,500 DT with a variability of 1,565 DT. However, the profit margin per greenhouse is evaluated at 1,070 DT. Limagues II, Ras-elain II and Limagues I show the best profit margins, respectively with 1,584, 1,373 and 1,217 DT. This is because these sites have the best incomes and also acceptable variable cost (*VC*). The lowest profit margins (*PM*) are observed in Hniche, Ras-elain I, Oum-elfareth and Menchia. Even there farmers sell sometimes at suitable prices, but have low outputs (*GI*) due mainly to low productivity. This low production can be explained by low technical standards and sometimes by bad project conception. Except for Hniche, these sites which are in difficulties also have the highest production costs in the region. Table 10 shows the distribution of the profit margins.

TABLE 10: Distribution of the profit margin in Tunisian dinars (DT) (Ben Mohamed, 1995)

Sites	Gross income - *GI* (DT)	Variable cost - *VC* (DT)	*VC/GI* (%)	Profit margin - *PM* (DT)
Limagues I	1,474	257	17	1,217
Limagues II	1,915	331	17	1,584
Saïdane	1,364	350	26	1,014
Oum-elfareth	1,403	532	38	871
Steftimi	1,408	297	21	1,111
Ras-elain I	1,287	474	37	813
Ras-elain II	1,740	367	21	1,373
Jemna	1,471	386	26	1,085
Hniche	993	331	33	662
Menchia	1,300	405	31	895
Average	**1,443**	**374**	**26**	**1,067**

As seen in the table, the gross income cannot effectively explain the economical results. For example, farmers in Oum-elfareth generate a good income but based on the *PM*, the site is considered in difficulty. The ratio (*VC/GI*) gives more significance about the rationality and the best allocation of inputs. According to this ratio, the contribution of inputs exceeds 30% of the outputs in Oum-elfareth, Ras-elain I, Hniche and Menchia. The results show clearly their difficulty in operation.

4.4.5 The commercialization circuit

The commercialization circuit in the region is characterized by a big complexity. Most of the production (60%) is sold on the farm. The market absorbs the remaining part (40%) which is sold in Kébili (regional market) and in other little markets (local markets). The national market (Djerba, Gabes, Sfax, Tunis) absorbs approximately half of the production. To supply the national market, 50% of farmers utilize their own transport means but 40% of them join together (partnership) in a group, generally two to three farmers, in order to minimize transport costs. The circuit is very complicated in which a big percentage of farmers have been confronted by difficulties in selling, such as low prices and the absence of export. The diversity of farmers' opinions concerning better commercialization attests to their perplexity. In front of a disordered sector, 60% of them hope to sell for a service cooperative company which take on the responsibility of commercialization, and about 20% prefer selling on the farm and for export, if it is possible. In order to resolve the problems of commercialization's circuit, the organization of the sector uphill and downhill the production is absolutely necessary.

The evaluation of one project's effect or impact can be measured by its static and dynamic influences in the economical activity but also by the socioeconomic change of farmers' conditions (before and after the project). In fact, the improvement of the situation will characterize the relation farmer-project by an incitation for further investment (expansion). The examination of the results' evaluation of the year 1993 shows that three quarters of growers have ameliorated their conditions and about 60% are not satisfied even though their condition was changed. The main reasons for dissatisfaction are numerous, bad conception (50%), diseases causing bad results (36%) and difficulties in commercialization (11%). Farmers declare that the size of two greenhouses is very small and doesn't satisfy their desires. The majority of them is very interested in investing in other greenhouses. This explains nowadays their expansion and some farmers own 5 or 6 plastic houses.

In order to estimate the attachment of growers to their greenhouses, they were asked about their interest in exchanging the greenhouse with an area of date palms. Half of them agreed to exchange only with a big area, larger than one ha. Some farmers, despite their dissatisfaction, refuse categorically any changes. The reason is not a high profitability of greenhouse farming compared to one ha of date palms, but because greenhouses allow a flux in the treasury. In contrast, for date palms, farmers have to wait for the production to the end of the year.

4.4.6 Farmers' classification

In order to analyse the operation of farms, a survey has been carried out by Ben Mohamed (1995). Its aim was to explain the functioning of farms by means of a classification (typology) based on 40% of the farm population. The objective was the construction of more homogeneous groups or classes. The characterization of each group is very important and the aim was to define and to apprehend the criteria of differentiation related to the groups. The results showed a classification of farmers in seven groups.

1. **Small farms in difficulties.** This group represents 34% of the total farms belonging mostly to Ras-elain I, Hniche, Jemna and Saïdane. Three dominant crops characterize the cultivation in this class, tomatoes, watermelons and melons raised in first period. This group is composed of small farms characterized by low cultural occupation rates and consequently low results due to low income.

2. **Mixed family farms.** This group represents only 10% of all the farmers belonging mainly to Limagues I, Limagues II and Saïdane. It is characterized by four dominant crops, watermelons, melons first period, tomatoes in continuous and melons second period. This group includes relatively big farms, characterized by high occupation rates and rational input utilization.

3. **Successful farms with best input allocation.** This class involves 15% of the total farmer population in which more than 60% are from Ras-elain II and Limagues II. Tomatoes in continuous, melons first and second period are the dominating crops. In spite of the low utilization of input, this class generates good products and is characterized by a good allocation of the production means.

4. **Farms in expansion.** This group represents 6% of the population, but includes only Oum-elfareth and Limagues II. It is characterized by three crops dominating the occupation area, melons first and second period and watermelons. This group constitutes the biggest farms (only greenhouses) with high intensification manifested by the occupation rate, the input utilization and the investment. It produces some respectable yields but commercialized with low prices.

5. **Family farms with high intensification.** 17% of the growers compose this group, belonging mainly to Oum-elfareth, Saïdane and Ras-elain I. Watermelons, melons first period and tomatoes in continuous dominate the cultural system. Importance of family work at the farm symbolizes the group. In spite of high intensification, it has low results, due to bad allocation of inputs and bad control of techniques.

6. **Small farms non-intensified.** This group includes 14% of the horticulturists belonging mainly to Steftimi and Jemna. Tomatoes in continuous, watermelons, melons and cucumbers raised in second period dominate it. The group is characterized by some small farms with a very low occupation rate and consequently the lowest production cost, but allowing a modest profit margin.

7. Big farms with salary work. This group represents only 4% of the total producers, mostly from Jemna and Ras-elain I. The dominating crops are, respectively, tomatoes and melons in continuous, melons second period and cucumbers first period. It represents big farms with low family work which is compensated by the salary work.

The most important results characterizing the groups are resumed in Table 11.

TABLE 11: The main results of characterizing farmers' classification groups (Ben Mohamed, 1995)

Group	Gross income - *GI* (DT/unity)	Variable costs - *VC* (DT/unity)	*VC/GI* (%)	Profit margins - *PM* (DT/unity)
1 (34%)	974	355	36	619
2 (10%)	1,814	337	19	1,477
3 (15%)	2,177	295	14	1,882
4 (6%)	1,860	473	25	1,387
5 (17%)	1,415	490	35	926
6 (14%)	1,378	266	19	1,111
7 (4%)	1,328	472	36	856

What differentiates the farms in the region? Based on the classification, the farms in the region are characterized mainly by the differences in yields which depend on the technical standard. The farm management and the best control of production means are very important criteria to take into account. In that way, some low incomes are compensated by good control of the production costs generating consequently some respectable profit margins.

Which conclusions can be deduced from the classification?

1. The classification confirms the results analysed in Chapter 4.4.4 dealing with the profit margin factor. Limagues II and Ras-elain II which have the best profit margins contribute enormously in the composition of group 3 symbolizing the best allocation of input and the best results.

2. It shows that the economical results are independent of the size of the farm and the occupation rate. In fact, a successful farm can be small, medium size or big. Group 3, for example, is characterized by small farms and low occupation rate and it generates good profits.

3. The economical results are more dependant on the yields than on the prices. However, the realized yields are under the theoretical ones projected by experts. Although, the prices are good in some cases, these yields are too low for acceptable results.

4. The variable cost is too high compared to the outputs. It reaches 35% of the gross income for groups 1, 5 and 7. For these classes, representing more than two thirds of the growers, the profit margin is very low, never reaching 1,000 DT per greenhouse.

The economical results obtained so far are based on the profit margin criteria which should be interpreted with prudence. They will be analysed in more detail later when the fixed costs are taken into account.

4.4.7 The basis of simulations

The simulations take into account the factors influencing the risk in the greenhouse sector such as the increase of input prices and the payment of water supply. The increase of prices is obviously the result of the elimination of the subsidy in agriculture because of the entrance of Tunisia in the GATT. The objective is to create more concurrence in the sector using liberalized prices. The methodology is to apprehend the production' system, to identify the factors causing the risk and to explain the variability between and inside the sites. The target is also to understand the success or the failure of farms. However, the variability affects the yields and the prices, that's why the combination "product-price" is taken into consideration. One farm-type is taken from each group on which the simulations are applied. This farm-type should best represent the farms composing the group by its closeness to the average.

4.4.8 Results of simulations

The only criteria utilized for analysing the economical results was the profit margin. On the other hand, the simulations are based on all the economical parameters (variable costs (*VC*) and fixed costs (*FC*)) and the criteria of "net results" will be used. The net result (*NR*) is defined in the following equations:

$$NR = GI - (VC + FC) \tag{2}$$

With regards to Equation 1

$$NR = PM - FC \tag{3}$$

or

$$NR = GI - TC \tag{4}$$

where *TC* stands for the total costs.

Two kinds of simulations have been realized (Ben Mohamed, 1995). They are based on the construction of several year-types such as good years, bad years, medium years and also exceptional years. Several scenarios are combined with these year-types to see their probability of appearance. The first simulation does not consider the variability related to the risk (increasing of prices, remuneration of water supply). The second simulation includes the risk.

The simulations without risk show that the best net results are observed in groups 2, 3, 7, 4 and 6 and the mediocre results are in groups 1 and 5 which represent about 50% of the growers. It is very interesting to see the negative net result in group 1 which includes one third of the farmers. Table 12 summarizes the net results characterizing the farm-type for each group.

TABLE 12: The net results characterizing the farm-type (Ben Mohamed, 1995)

Group	Gross income - *GI* (DT/unity)	Profit margins - *PM* (DT/unity)	Net results - *NR* (DT)
1	1,010	702	-54
2	1,941	1,598	2,332
3	2,175	1,954	2,166
4	1,567	1,166	1,733
5	2,335	1,828	985
6	1,517	1,237	1,385
7	1,603	1,249	2,064

It is important to mention the high variability between groups principally for melons, cucumbers and watermelon crops. For example for the melons raised in continuous, the gross income in one group is nine times higher than another. The same applies to farmers in the same group. Indeed, for melons in continuous, the highest gross income is 80 times the lowest income, 40 times for watermelons and 30 times for cucumbers. Generally, the study shows high variability especially for melons, watermelons and cucumbers. Including the risk aspect, groups 1 and 5 which represent 50% of the population generate always negative net results due to the domination of the risky crops in the cultural system (watermelons). Table 13 shows the results of the simulation including the risk from 1993 to 1998.

TABLE 13: The net results (in DT) of simulations including risk, from 1993 to 1998 (Ben Mohamed, 1995)

Group	1993	1994	1995	1996	1997	1998
1(<0)	-	-	-	-	-	-
2	1,381	1,557	1,696	1,917	2,587	2,493
3	950	1,447	1,738	1,809	1,805	1,978
4	1,414	1,840	1,408	2,111	2,341	2,662
5 (<0)	-	-	-	-	-	-
6	1,260	1,299	1,248	1,351	1,225	1,474
7	1,841	2,511	2,715	2,968	3,155	3,068

The scenarios analysed for groups 1 and 5 show negative results in the future. This explains the instability of their production systems related to the risk. In spite of the risky crops (high variability) in groups 2 and 4 occupying more than 65% of the total area, they generate always acceptable results due, essentially, to the diversification of cultivation (5-6 crops). In that way, the double occupation seems to be a good solution for bypassing the risk.

In conclusion, the simulation without risk demonstrates a certain dependance of the economical result on the size of farms. This simulation of the risk confirms this dependance. The simulations of the matrix "product-prices" show the success of the relatively big farms (more than three greenhouses). The present situation of the greenhouse sector in the region is discouraging. Farmers are really confronted by serious constraints due to the negative results realized by 34% of them. The situation becomes more delicate if the parameter risk is introduced in which 50% of the population generates negative results.

5. CONCLUSIONS AND DISCUSSIONS

The present agricultural utilization of geothermal energy in Tunisia is limited to irrigation of oases and greenhouse heating and irrigation. The irrigation of oases by relatively hot water (35-40°C) affects negatively the development of the under floor composed of vegetable crops and mainly grass cultivation. For agricultural use, 27 boreholes are operating in the region equipped with only 14 atmospheric towers for cooling. For future development and in order to maximize the use of water resources, the rest (13 wells) need to be similarly equipped. The irrigation in the southern part of the country is by submersion and all the oases area is irrigated, causing a big water wastage. The water resources are known as non-renewable and a water conservation programme should be continued.

Greenhouse heating is considered to be the first step in the development of geothermal utilization in agriculture. The experiments in South Tunisia indicate the feasibility of some greenhouse projects but, unfortunately, for many farmers, the technical level is rather low and the observed yields are very low compared to the sector potential. The utilization of the low-enthalpy geothermal resources will without doubt increase in the future by the application of the greenhouse strategy to reach 70 ha (installation of additional 40 ha). In order to promote the sector, it is important to concentrate efforts on a better conception of projects and good techniques by means of popularization. Several current projects were badly conceptualized (exposed to wind, low level) and the hot water cannot reach the ponds to be cooled and used again for irrigation (return water). The concurrence in water utilization between oases and greenhouses is low (only 3-4 months) and the installation of greenhouses near oases seems to be suitable for a return water possibility. Greenhouse farming is also confronted with difficulties in commercialization and the prices of some products are very low due to the absence of a farmers' organization such as a service cooperative company. To reach the export target, a better organization of the sector and a high quality of vegetables such as tomatoes and melons are required.

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NOMENCLATURE

AIC	Water organization
CAP	Common Agricultural Policy
CRDA	Regional Commissariat for Agricultural Development
EEC	Economic European Community
FOSDA	Special Funds for Agricultural Development
GATT	General Agreement on Tariffs and Trade
GSP	Generalized System Preferences
GDP	Gross Domestic Product
UNDP	United Nations Developing Programme
PDRI	Integrated Rural Development Programme
PDR	Rural Development Programme

REFERENCES

Ben Dhia, H., and Bouri, S., 1995: *Overview of geothermal activities in Tunisia.* Ecole Nationale d'Ingénieurs de Sfax, Tunisia, 5 pp.

Ben Mohamed, M., 1995: *Analyses and perspectives of development of the greenhouse production systems in Kébili region.* Centre International de Hautes Etudes Agronomiques Méditerranéennes, Institut Agronomique Méditerranéen de Montpellier, Montpellier, M.Sc. thesis (in French), 145 pp.

Bogarín C., R., 1996: Geothermal gases as a source of commercial CO_2 in Miravalles, Costa Rica and Haedarendi, Iceland. Report 3 in: *Geothermal Training in Iceland 1996*, UNU G.T.P., Iceland, 23-44.

CRDA, 1996a: *The agricultural sector in Kébili region*. CRDA, report (in Arabic), 10 pp.

CRDA, 1996b: *Annual reports 1996.* CRDA, Kébili, Tunisia, regional report (in French), 113 pp.

Fridleifsson, I.B., 1996: *Present status and potential role of geothermal energy in the world.* World Renewable Energy Congress IV, Denver, Colorado, USA, 6 pp.

Lienau, P.J., 1997: Geothermal greenhouse development update. *Geo-Heat Center, Quart. Bull., 18-1*, 5-7.

Mamou, A., 1992: *Notes on geothermal resources utilized in Tunisia.* Direction Génerale des Ressources en Eau, Tunisia, ministerial report (in French), 24 pp.

Marshall, E., 1988: *The concept of the exploitation system.* Ecole Nationale des Sciences Aronomiques Appliquées (ENSSAA), Dijon, report (in French), 7 pp.

Mougou, A., Verlodt, H., and Essid, H., 1987: Geothermal heating of greenhouses in the south of Tunisia. Proposals for a simple control. *Plasticulture, 75*, 41-50.

Popovsky, K., 1993: *Heating greenhouses with geothermal energy*. International Summer School, Skopje, Macedonia, 326 pp.

Ragnarsson, Á., 1996: Geothermal energy in Iceland. *Geo-Heat Center, Quart. Bull., 17-4,* 1-6.

Sghaier, M., Ben Mohamed, M., Haddad, M., and Fakhfakh, F., 1991: *Technical, social and economical evaluation of greenhouse experience in the south of Tunisia: Case of Kébili region*. O.D.S., Médenine, Tunisia, report (in French), 66 pp.

Stefánsson, V., 1986: *Report on an advisory mission 1986 in Tunisia.* United Nations, New York, report, 24 pp.