Assessment of Impacts, Adaptation, and Vulnerability to Climate Change in North Africa: Food Production and Water Resources

A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. AF 90

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A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. AF 90

Submitted by Ayman F. Abou-Hadid
Central Laboratory for Agricultural Climate (CLAC), Agriculture Research Centre (ARC), Ministry of Agriculture and Land Reclamation,
Egypt

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About AIACC

Assessments of Impacts and Adaptations to Climate Change (AIACC) enhances capabilities in the developing world for responding to climate change by building scientific and technical capacity, advancing scientific knowledge, and linking scientific and policy communities. These activities are supporting the work of the United Nations Framework Convention on Climate Change (UNFCCC) by adding to the knowledge and expertise that are needed for national communications of parties to the Convention.

Twenty-four regional assessments have been conducted under AIACC in Africa, Asia, Latin America and small island states of the Caribbean, Indian and Pacific Oceans. The regional assessments include investigations of climate change risks and adaptation options for agriculture, grazing lands, water resources, ecological systems, biodiversity, coastal settlements, food security, livelihoods, and human health.

The regional assessments were executed over the period 2002-2005 by multidisciplinary, multi-institutional regional teams of investigators. The teams, selected through merit review of submitted proposals, were supported by the AIACC project with funding, technical assistance, mentoring and training. The network of AIACC regional teams also assisted each other through collaborations to share methods, data, climate change scenarios and expertise. More than 340 scientists, experts and students from 150 institutions in 50 developing and 12 developed countries participated in the project.

The findings, methods and recommendations of the regional assessments are documented in the AIACC Final Reports series, as well as in numerous peer-reviewed and other publications. This report is one report in the series.

AIACC, a project of the Global Environment Facility (GEF), is implemented by the United Nations Environment Program (UNEP) and managed by the Global Change System for Analysis, Research and Training (START) and the Third World Academy of Sciences (TWAS). The project concept and proposal was developed in collaboration with the Intergovernmental Panel on Climate Change (IPCC), which chairs the project steering committee. The primary funding for the project is provided by a grant from the GEF. In addition, AIACC receives funding from the Canadian International Development Agency, the U.S. Agency for International Development, the U.S. Environmental Protection Agency, and the Rockefeller Foundation. The developing country institutions that executed the regional assessments provided substantial in-kind support.

For more information about the AIACC project, and to obtain electronic copies of AIACC Final Reports and other AIACC publications, please visit our website at www.aiaccproject.org.

Summary Project Information

Regional Assessment Project Title and AIACC Project No.

Assessment of Impacts, Adaptation, and Vulnerability to Climate Change in North Africa: Food Production and Water Resources (AF 90)

Abstract

The climate change impact, vulnerability, and adaptation of the production of some major food crops and irrigation water requirements in Egypt and Tunisia were analyzed. The evaluation was based on the proposed stakeholder adaptation options with a range of modeling methodologies. The stakeholders engaged in the project represent the small-holder farmers, commercial farmers, and strategic resource managers. Simulation models were used to quantify some of the strategic adaptation options proposed by the stakeholders. The preliminary results show that there is an overall reduction in crop yields under climate change even when adaptation is taken into account. As well as, the project investigation found that, climate is perceived by North African farmers as one of the major risks of agricultural production, but the magnitude of the risk is perceived as higher than the risk derived from empirical knowledge. Changes in crop variety, crop calendar, and irrigation amount and nitrogen fertilization were the main options produced through the analysis steps. A combination between the three options were produced and tested too. Promoting education programs on water-saving practices and changes in crop choices was the fifth adaptation option resulted from the project investigation. The study concludes that the involvement of the rural population and extension services in capacity building programs is an essential adaptation measure, with information flows among and between these two groups of stakeholders.

Administering Institution

Central Laboratory for Agriculture Climate (CLAC), Agriculture Researcher Center (ARC), Ministry of Agriculture and land reclamation, Egypt

Participating Stakeholder Institutions

Soil, Water and Environment Research Institute (SWERI), Egyptian Agricultural Extension Services, INRGREF (Institut National de Recherche en Génie Rural, Eaux et Forêts), Institut de recherche sur l'olivier de Sfax (IO Sfax), Direction générale de la production agricole (DGPA), Commissariat régional de développement Agricole de Kairouan (CRDA Kairouan), Commissariat régional de développement Agricole de Sfax (CRDA Sfax)

Countries of Primary Focus

Egypt, Tunisia

Case Study Areas

Sakha at Kafr El-Shikh Governorate, and Mersa Matrouh in Egypt, and Kairouan area, Safax and Hendi Zitoun in Center Region in Tunisia

Sectors

Agriculture, Water Resources

Systems

Food Security, Land Use

Groups studied

Subsistence Farmers, Commercial Farmers, and Resources Managers

Sources of stress and change

Drought, Floods, Storms, Population Growth, Land Degradation, Desertification

Project funding

USD 190 00

Investigators

Principal Investigator: A.F. Abou- Hadid, Central Laboratory for Agricultural Climate (CLAC), Agriculture Research Centre (ARC), Ministry of Agriculture and Land Reclamation, Egypt.

Other Investigators: Eid, H. M., Soil, Water and Environment Research Institute (SWERI), ARC, Ministry of Agriculture and Land Reclamation, Egypt; A. Iglesias, Universidad Politecnica de Madrid, Spain; M. Medany, CLAC, ARC, Egypt; R. Mougou, INRGREF (Institut National de Recherche en Génie Rural, Eaux et Forêts), Tunisia; Samia. M. El-Marsafawy, SWERI, ARC, Egypt; Samiha. A. Ouda, SWERI, ARC, Egypt; N. G. Ainer, SWERI, ARC, Egypt; S. A. Abdel-Hafez, SWERI, ARC, Egypt; Mansour Mohsen, INRGREF, Tunisia; Karray Boubaker, Institut de recherche sur l'olivier de Sfax (IO Sfax), Tunisia; Zitouna Rim,INRGREF, Tunisia; Nafti Amal, Direction générale de la production agricole (DGPA), Tunisia; Osmane Naîma Commissariat régional de développement Agricole de Kairouan (CRDA Kairouan), Tunisia; and M. Moneo, Universidad Politecnica de Madrid, Spain.

Executive Summary

Research problem and objectives

Agriculture in North Africa is both the main use of the land in terms of area and the principal water-consuming sector. Therefore the adverse effects of climate change are perceived to be associated with agricultural activities, leading to conflicts over the use of resources with other sectors. Agricultural production in the region is expected to change rapidly due to technological advancements, and social changes. Water demand for irrigation is expected to increase in all countries of North Africa and it is important to define adaptation strategies that take into account the possible deficit of water for irrigation in the future. In all countries, expected climatic change, population increase, urbanization and industrial development as well as irrigation intensification constantly increase water demand and can intensify the vulnerability of agriculture.

Adaptation to climate change in North Africa is a major issue from the perspectives of food production, rural population stabilization, and distribution of water resources. Northern Africa's adaptation capacity to climate change is challenged in particular, as it comes in conjunction with high development pressure, increasing populations, water management that is already regulating most of available water resources, and agricultural systems that are often not adapted to local conditions.

The aim of the study is to enhance scientific and technical capacity in countries in North Africa for: (1) Assessing current and future adaptive capacity and vulnerability of food production and water resources; (2) Enhancing adaptive capacity in current and future conditions; and (3) Synthesis of lessons learned in the region. Also, it aims to evaluate the adaptation measures proposed by a range of stakeholders in North Africa derived by surveys to farmers and farmers groups, and interviews to sub-national technical resource managers. Information is provided to the stakeholders to increase the technical understanding of the interactions between climate and agriculture. The stakeholders' measures are evaluated qualitatively by interviewing agricultural managers and quantitatively by using agricultural simulation models. Within this broad framework, the scientific objectives of the project are; (i)Stakeholder engagement, (ii) Impacts detection, (iii) Evaluation of adaptation methods, and (iv) Linkages between climate information and scenarios and vulnerability.

Approach

The study was based on information exchange between project team and stakeholders to set definitions of adaptation measures, and to increase the capacity of stakeholders to understand climate-agriculture relationships. The stakeholders' measures were evaluated qualitatively by interviewing agricultural managers and quantitatively by using agricultural simulation models.

The main protocol of the project was divided to five main steps of; (i) Data collection, processing and analyzing at the case study level to provide the stakeholders with evidence of the current climate sensitivity of the different sectors and groups (Impacts and sensitivity), (ii) Evaluation of stakeholder perception of the impacts and their proposed adaptive methods, (iii) Qualitative and / or quantitative evaluation of adaptation measures and their technical and social limitations, (iv) Analysis of current and future vulnerabilities of the system, and (v) Definition of the underlying causes of potential damage caused by climate change.

Two 'case studies' - Tunisia and Egypt - are selected to study the impact and the vulnerability of agriculture to climate change, and to evaluate the adaptation strategies in a range of climate, agricultural, and socio-economic systems found in North Africa. The study analyzed cereal and horticultural production. Rainfed and irrigated systems are evaluated to understand the interactions between climate, especially drought, its impacts, and the vulnerability of the system. Rainfed systems are characteristic to current climate variability and drought episodes. Irrigated systems are analyzed to evaluate the demand of water under changed climate conditions and to determine the value of additional irrigation as an adaptation alternative to climate change in North Africa.

The study in Egypt focuses in the Nile Delta, represented by Sakha at Kafr El-Shikh Governorate, and Mersa Matrouh in the Northwest coast of Egypt. In Tunisia the study focuses in Kairouan area, Safax and Hendi Zitoun in Center Region. The area is characterized by medium/low- agriculture-production, and high competition for land and water resources

Climate and water availability is studied in North African countries of Tunisia, Morocco and Egypt, as a variability analysis of rainfall, and the relation between rainfall variability and evapotranspiration. Agricultural production variability as a function in rainfall and irrigation is studied for cereal crops, tomato and olive.

Projected impacts on crop productivity in the project focal areas was assessed according to future conditions derived from MAGICC/SCENGEN software, with input data form HadCM3 GCM and A1 and B2 SRES scenarios experiments. DSSAT (Decision Support System for Agrotechnology Transfer) simulation model was the main tool for the analysis of climate change impacts on crops production. DSSAT is software combining crop soil and weather databases and programs to manage them, with crop models and application programs, to simulate multi-year outcomes of crop management strategies

Scientific findings

Egypt case study:

- There is an overall reduction in crop yields under climate change even when adaptation is taken into account.
- Under climate change conditions wheat variety, irrigation amount, sowing dates and water consumptive use (ET) have to be changed according to the growing area to overcome the reduction in yield.
- For the study sample, farmers with their own experiences and/or with the help of the agricultural extension personnel apply some tactics and adaptation options to face changes in temperature or rain fall. The most mentioned options were change crop sowing dates, use heat tolerant varieties, increase number of irrigation, increase irrigation amounts, apply irrigation early in the morning or late in the evening and avoid irrigation in the afternoon, use intercropping, fruit mulching in vegetables, manage pesticide and fertilizer applications, use underground and drainage water for irrigation and change varieties.

Tunisia case study:

- Among the research themes that provide results that directly constitute adaptation methods are:
  - Increasing of agricultural areas;
  - Management of water resources;
  - Improvement and the genetic selection of cultivars;
  - Improvement of techniques already used and use of new techniques (fertilization, irrigation, etc.) that are allow minimizing the negative effect of climate variability and climate.
- The involvement of the rural population concerned to attain the objective remains essential. That is why nowadays the participative approach is necessary for the use of new technology. The approach objective is to develop technologies adapted to the ecological and socio economic conditions. We can attend these objectives by research development programs realized taking into account the farmer's strategies.

In general, climate is perceived by North African farmers as one of the major risks of agricultural production, but the magnitude of the risk is perceived as higher than the risk derived from empirical knowledge. Farmers do not recognise the importance of farming techniques for adaptive management and therefore their investments may not be completely productive.

There is a range of adaptation measures but the have varying levels of effectiveness, feasibility of adoption at the farmers' level, and social and environmental consequences. Changes in crop variety, crop calendar, and irrigation amount and nitrogen fertilization were the main options produced through the analysis steps. A combination between the three options were produced and tested too. Promoting education programs on water-saving practices and changes in crop choices was the fifth adaptation option resulted from the project investigation.

Only a limited number of farmers follow the advice of the extension services that seems to be the key adaptation measure. The study concludes that the involvement of the rural population and extension services in capacity building programs is an essential adaptation measure, with information flows among and between these two groups of stakeholders.

Capacity building outcomes and remaining needs

The active participation in the AIACC Workshops and in other training activities contributed to the capacity building of the Project investigation team. Other relevant activities directed to increase awareness in the society were a course of "Climate change and Agriculture" was lectured at the University of Al Azhar, Faculty of Agriculture- department of ecology and bioagriculture. The same course was lectured at Cairo University, Faculty of Science. A number of lectures and short courses were offered for Egyptian and Arabian agricultural researchers. Besides, special short courses were offered for Egyptian undergraduate students, as a summer training courses. The Project supported the thesis of highly qualified students; three of them were presented them thesis, and about seven are in the analyses and writing phase. Very important experiences for most of the investigators of the Project were the work with stakeholder groups, working with climate models, and work with crop simulation modules.

National communications, science-policy linkages and stakeholder engagement

The results of the Project will be included in the 2nd National Communications of Egypt with the UNFCC. This task will start in 2006. Mahmod Medany is participating in the Fourth Assessment Report as lead author in the WG II, chapter 09; Africa. And the project investigators presented the project results in a number of national level lectures, conferences and meeting, as an interaction between the project team and the policymakers.

The project enhanced the stakeholder (farmers, extension service staff and agriculture advisors) engagement in defining adaptation measures, thus strength the relation between the scientific team and the agriculture society. Also, it helped the project team to select some of the stakeholders to be counterparts to be involved in any further studies.

Policy implications and future directions

The results of the Project and their dissemination between the stakeholders provide the basis for planning to a future national adaptation plans. The Egyptian project team is working now in shaping the AF 90 project-produced adaptation measures and its potentials in the form of a future agriculture adaptation plan or agenda to be linked with the long-term strategy of Ministry of agriculture.

1. Introduction

North African countries are located in the cool subtropics, which is one of the five eco-regions of world dry areas. North Africa is divided into five countries (Morocco, Algeria, Tunisia, Libya and Egypt) and extends over a huge area. Much of the geology across this region is remarkably similar. All North African countries are considered as low -income countries (Rodriguez and Thomas, 1997).

Agriculture in North Africa is the main utilize of the land and the principal water-consuming sector (over 70% of total water consumption; Iglesias, 2003; Iglesias et al., 2003).

Under semi-arid and arid regions the pressures of agricultural sector on the water and land recourses intensify, these pressures due to the increased irrigation water and fertilizers demands. In addition to, the agricultural activities affecting negatively on water resources quality that decreases due to the bad management of irrigation, fertilizers and pestsides. More over, Soil fertility decreases due to the same previous activities. In the other hand, North Africa region face a number of extreme events such as precipitation patterns changes, unexpected severe weather, extreme temperature events, and drought, which directly reflected on rainfed agriculture, and agriculture activities at all.

North African countries are considered as developing countries, which are highly vulnerable to climate change impacts, this due to its arid climate, and if climate change makes this regions' climate drier or warmer, pressure on agricultural sector would intensify. The adverse effects of climate change are perceived to be associated with agricultural activities, leading to conflicts over the use of resources with other sectors. The effects of sea level rise in North Africa, especially on the coast of the Delta region of Egypt, would reduce the area under cultivation and likely reduce agricultural production (IPCC, 2001). Moreover, it seems likely that climate change will expand the gap in grains self-sufficient, that already existed and facing North African countries under current conditions.

Agricultural production in the region is expected to change rapidly due to technological advancements, and social changes, such as the potential trade agreements with the European Union and projections of high population increase (Iglesias et al., 2004). In most countries, rainfed crop production accounts for over eighty percent of the total cropland (FAOSTAT, 2005). Rainfed production is characterized by very low and variable productivity. In contrast, irrigated production is characterized by relatively high productivity of commercial agriculture. Egypt is an exception in the region since it has a very large proportion of irrigated land (almost 95% of the cropland). Water demand for irrigation is expected to increase in all countries of North Africa. It is important priority to assess the impacts of climate change on agricultural sector and its water demands. Besides, studying the vulnerability of food production system in North African countries is a vital point too. And according to the impacts and the vulnerability of agriculture system an adaptation strategies have to be defined to take into account the possible deficit of water for irrigation in the future (Eid et al., 1997; Strzepek et al., 1995a; Iglesias et al., 2003).

An assessment of vulnerability and adaptive capacity is a means of prioritizing and directing action where it is needed most urgently by determining which regional areas and natural or human systems are most at risk.

Vulnerability can be defined as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC, 2001).

The adaptation science agenda should have two primary goals. One is to generate and provide scientific knowledge, working in partnership with decision-makers and other stakeholders that can be used to decide and implement vulnerability reducing adaptations. A second goal is to build capacity and partnerships for generating, evaluating, integrating, communicating and applying knowledge for adaptation (Anonymous, 2004)

Adaptation plans are mainly focusing on increasing the adaptive capacity of the different systems, by changes in processes, practices, or structures to reduce climate risks (IPCC, 2001). In developing countries, the priority of these plans is the high vulnerable systems to climate change. Therefore, the high vulnerability of agricultural sector put it in the top of priority list of adaptation plans.

Adaptation to climate change in North Africa is a major issue from the perspectives of food production, rural population stabilization, and distribution of water resources. Previous studies have addressed adaptation in a top-down approach, evaluating theoretical options with little relation to current agricultural management (Abdel Hafez et al., 2003; Eid, 1994; Eid et al., 1993, 1995, 1996, 2001). There is a need to incorporate the value of the management knowledge for formulating adaptation measures for agriculture in a bottom-up approach.

Northern Africa's adaptation capacity to climate change is challenged in particular, as it comes in conjunction with high development pressure, increasing populations, water management that is already regulating most of available water resources, and agricultural systems that are often not adapted to local conditions. Evidence for limits to adaptation of socio-economic and agricultural systems in the North African region can be documented in recent history. For example, water reserves were not able to cope with sustained droughts in the late 1990's in Morocco and Tunisia, causing many irrigation dependent agricultural systems to cease production (Iglesias and Moneo, 2005). In all countries, expected climatic change, population increase, urbanization and industrial development as well as irrigation intensification constantly increase water demand and can intensify the vulnerability of agriculture.

The aim of the study is to enhance scientific and technical capacity in countries in North Africa for: (1) Assessing current and future adaptive capacity and vulnerability of food production and water resources; (2) Enhancing adaptive capacity in current and future conditions; and (3) Synthesis of lessons learned in the region. Also, it aims to evaluate the adaptation measures proposed by a range of stakeholders in North Africa derived by surveys to farmers and farmers groups, and interviews to sub-national technical resource managers. Information is provided to the stakeholders to increase the technical understanding of the interactions between climate and agriculture. The stakeholders' measures are evaluated qualitatively by interviewing agricultural managers and quantitatively by using agricultural simulation models. Within this broad framework, the scientific objectives of the project are:

- Stakeholder engagement.
- Impacts detection.
- Evaluation of adaptation methods.
- Linkages between climate information and scenarios and vulnerability.

2. Structure of the Study

The study was structured as an information exchange between the stakeholders and the scientific team. It based on information exchange between project team and stakeholders to set definitions of adaptation measures, and to increase the capacity of stakeholders to understand climate-agriculture relationships. The stakeholders' measures were evaluated qualitatively by interviewing agricultural managers and quantitatively by using agricultural simulation models. Figure 1 represents the structure of the study.

The information was not treated as one-way flow form source (scientists) to consumption (stakeholders). The information was provided by the stakeholders, through interviews, surveys, and workshop participation, to the project team to be studied and analyzed. Feedback, Linkages and interactions are maintained throughout the analysis. Information is provided and interpreted according to the experience and technical expertise of each stakeholder group.

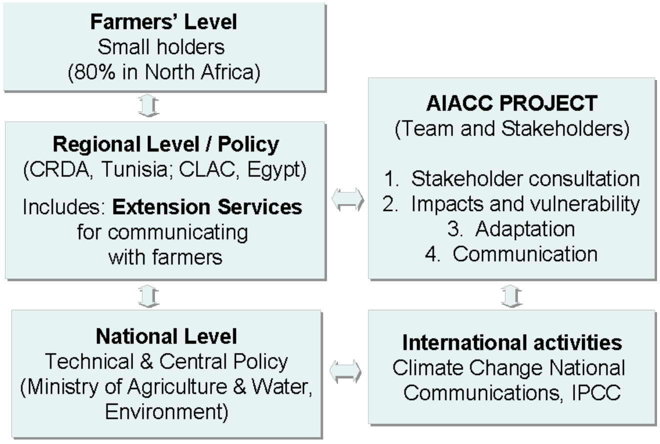

Fig. 1: Linkages of the AIACC project team with stakeholders in North Africa

The main protocol of the project was divided to five main steps (Figure 2):

Step 1: Data collection, processing and analyzing at the case study level to provide the stakeholders with evidence of the current climate sensitivity of the different sectors and groups (Impacts and sensitivity).

Step 2: Evaluation of stakeholder perception of the impacts and their proposed adaptive methods.

Step 3: Qualitative and / or quantitative evaluation of adaptation measures and their technical and social limitations.

Step 4: Analysis of current and future vulnerabilities of the system.

Step 5: Definition of the underlying causes of potential damage caused by climate change.

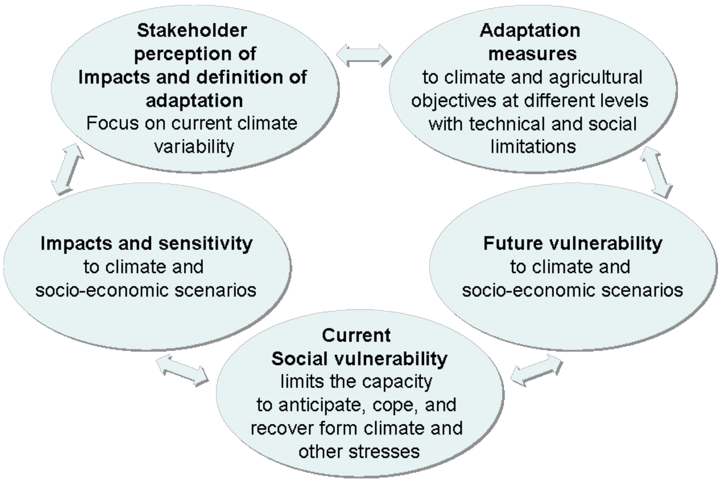

Fig. 2: Outline of the study protocol

3. Case Studies Selection

Two 'case studies' - Tunisia and Egypt - are selected to study the impact and the vulnerability of agriculture to climate change, and to evaluate the adaptation strategies in a range of climate, agricultural, and socio-economic systems found in North Africa (Figure 3). The study analyzed cereal and horticultural production since they define major agricultural systems in terms of land use in North Africa and they are common to most areas. Rainfed and irrigated systems are evaluated to understand the interactions between climate, especially drought, its impacts, and the vulnerability of the system. Rainfed systems are characteristic of subsistence farmers and very vulnerable to current climate variability and drought episodes. Irrigated systems are analyzed to evaluate the demand of water under changed climate conditions and to determine the value of additional irrigation as an adaptation alternative to climate change in North Africa.

Fig. 3: Geographical scope and case studies

Agriculture in Egypt is restricted to the fertile lands of the narrow Nile valley from Aswan to Cairo and the flat Nile Delta north of Cairo (5.5% of total country area). Egypt's entire agricultural water supply comes from irrigation, slowly from the Nile River. In 2000, agriculture (crops and livestock) accounted for 20% Egypt's GDP and about 50% of the Egyptian population relies on it for income generation and job opportunity creation (CAPMAS, 2000). From water situation point of view, Egypt considered as limited water resources country. Water available for irrigation varies due to changes in freshwater availability and to competition among water users. Crop prices and markets also fluctuate. The study in Egypt focuses in the Nile Delta, represented by Sakha at Kafr El-Shikh Governorate, and Mersa Matrouh in the Northwest coast of Egypt. The Nile Delta region is characterized by high-production irrigated small-holder agriculture, in a region with extreme urban water and land-use conflicts, with projections of high population increase. Mersa Matrouh region represents the unique rainfed agricultural region in Egypt characterised by low population and low productivity, and agricultural technical conditions and the socio-economic conditions are completely different than in the Delta region. This is similar to eastern rainfed Mediterranean agriculture in North Africa and includes olive production.

Tunisia belongs to the hydraulic poor countries. Rainfall is characterized by its scarcity and spatial and temporal variability (Mougou et al., 2002). The average of total annual rainfall varies from 1500 mm in the North to 100 mm in the South. Temperature and solar radiation are rather high, that leads to a higher evaporation from water resources. Variability and scarcity of water resources and high temperature affect negatively the production in rainfed agriculture, especially cereals that are mainly produced under rainfed conditions (over 97 percent of the total cereal area is rainfed). In Tunisia the study focuses in Kairouan area, Safax and Hendi Zitoun in Center Region. The area is characterized by medium/low- agriculture-production, and high competition for land and water resources.

4. Impacts and Sensitivity

4.1 Climate and Water Availability

Annual rainfall in North Africa is low and it is characterized by the large year to year variability (Figure 4). Currently, all countries are considered water stressed. At present, the annual per capita share of available water (underground and surface water) is far less than 1000 m^3 and is projected to decrease.

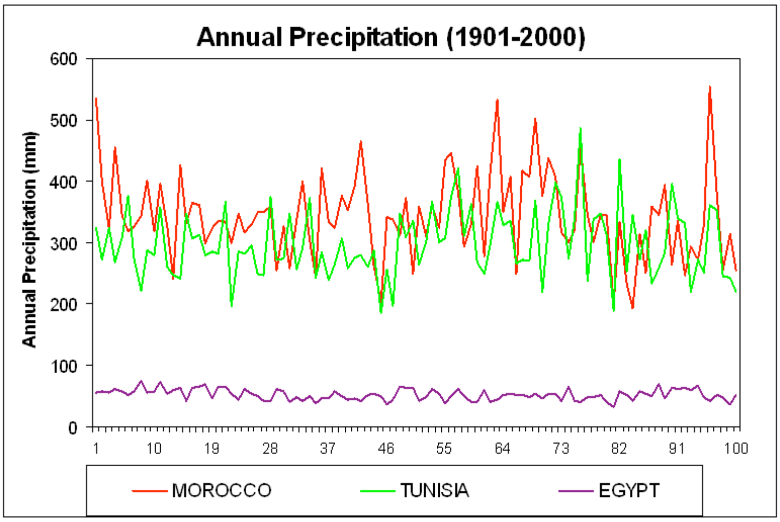

Fig. 4: Annual rainfall in Egypt, Morocco and Tunisia (1901-2000) aggregated at the country level. Data source: CRU, UEA

Precipitation in Egypt is only significant in the northern Mediterranean coast (about 180 mm/year) and it is extremely low in the rest of the country's desert territory. Rainfed agriculture is limited to a small area in the northern part of the country and accounts for less than 5 % of the total agricultural area. The Nile River provides surface water resource for agriculture in the traditional agricultural areas but the importance of groundwater is increasing as land reclamation continued.

In Tunisia, the case study area (Kairouan) is semi-arid region, and hot and dry conditions are frequent throughout the cereal growing period (Mougou and Henia, 1996). Several dry years (deficit of evapotranspiration over 50%) are frequent in this region representing a permanent risk for rainfed agriculture (over 88% of the total agricultural area). High temperature can occur during the grain filling period affecting crop growth and development. A major risk to the crop is the dry wind blowing from the Sahara known as "Sirocco". Sirocco occurs between May and September, but it has serious effects in the beginning of the spring season (Mougou and Henia, 1998). If Sirocco occurs during the grain filling stage of cereals, an irreversible lost of water from the crop occurred. In Kairouan average annual solar radiation is high (maximum annual solar radiation is 1965 hours/year during the period from 1960 to 1990) and average annual evaporation is also very high (average annual evaporation is 1390 mm/year). Therefore in this region, the possible increase in temperature and solar radiation, and as consequence the increase in evaporation, will result in an increment of the stress conditions for the crops.

4.2 Agricultural Production Variability

Empirical results of the interactions between climate and agricultural production are developed by scientists as the first step for validating the stakeholders' perception to climate. Current agricultural production fluctuates from year to year as result of climate and socio-economic changes. The climate component is larger in rainfed areas, especially in systems with limited diversification strategies, and affects mostly subsistence farmers. Figures 5, 6, and 7 show the relationship between wheat production and spring rainfall in Morocco, Tunisia, and Egypt, respectively. Spring rainfall is selected since it is the principal climatic component that explains the variability of cereal production. The correlation between wheat production and rainfall aggregated at the country level over a 40 year period is remarkably high in Tunisia and Morocco (over 40%) and almost non existent in Egypt, since most agricultural production is irrigated. At the site level, correlations are, of course, much higher in dryland systems.

In Egypt, wheat productivity is recorded as the highest in the world, reflecting agricultural systems that are highly managed in terms of fertilizer inputs, technology, and irrigation. Wheat productivity is an indicator commonly used for agricultural technology and development. In the case of Egypt, there are extremely limited options for improving crop management as adaptation measures to climate change. These methods are explored by using agricultural simulation models for cereal production (wheat) and horticultural crops (tomato) presented in this report.

At the site level, the correlations of rainfall to crop yield are more effective for communicating the information to local stakeholders. Rainfed yields are smaller than irrigated yields and irrigation decreases the risk to farmers by increasing and stabilizing production. That is why, when the irrigation is not possible, farmers are generally oriented toward breeding to ensure a minimum incomes and the survival of their system.

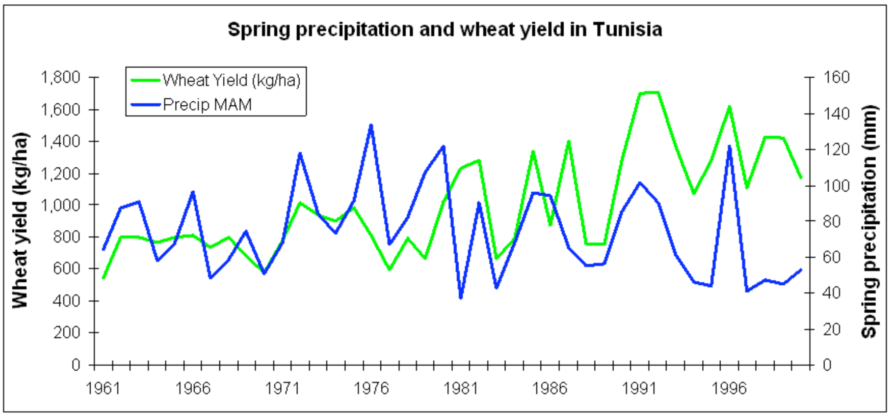

Fig. 5: Wheat yield and spring precipitation in Tunisia (1961-2000)

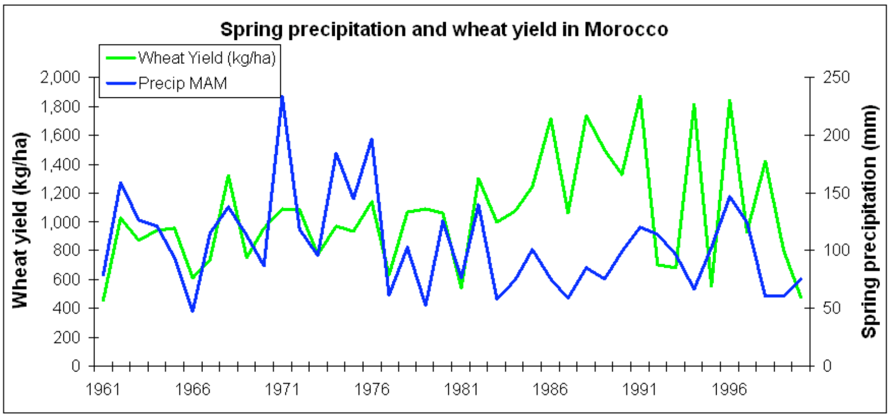

Fig. 6: Wheat yield and spring precipitation in Morocco (1961-2000)

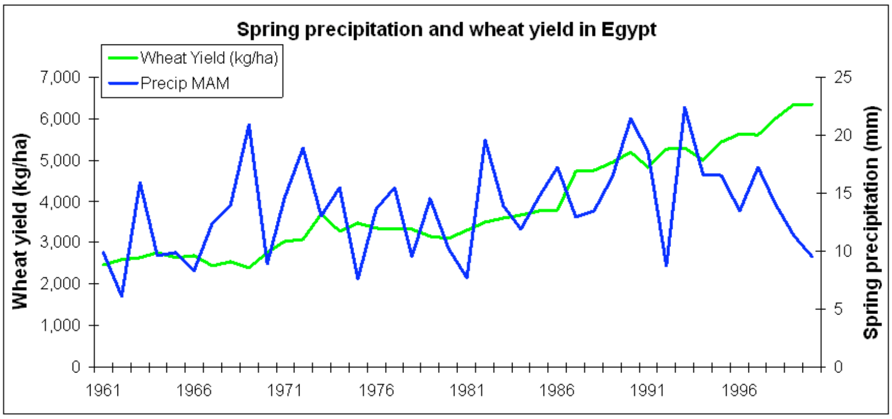

Fig. 7: Wheat yield and spring precipitation in Egypt (1961-2000)

The communication of the information of climate agricultural relationships to stakeholders is focuses on the understanding that such relationship is probabilistic. Figure 8 presents the probability levels of occurrence of different categories of crop yield associated to wet, normal or dry years in Tunisia. For this analysis years are classified as wet, normal or dry depending on deciles of spring precipitation. Years are considered dry when spring precipitation is below the second deciline of the series, wet when precipitation is above the 8th deciline and normal when the value of precipitation is among these two levels. The Figure highlights the proportion of high, medium, or low yields associated to years with different precipitation levels.

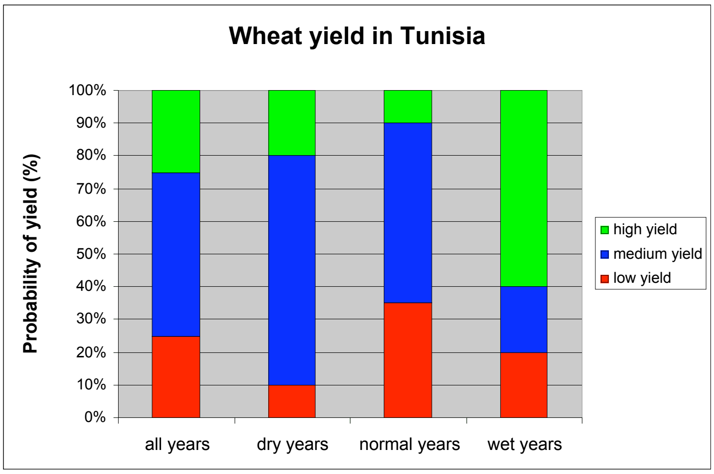

Fig. 8: Distribution of wheat yield in Tunisia according to annual precipitation (1961-2000)

4.3 Models and Scenarios

Projected impacts on crop productivity in the project focal areas was assessed according to future conditions derived from MAGICC/SCENGEN software of the University of East Anglia (UK), with input data form HadCM3 GCM and A1 and B2 SRES scenarios experiments (IPCC SRES, 2001; Eid et al., 2001). The tow scenarios result in an increase of temperature (1.5C for the B2 scenario and 3.6C for the A1 scenario) and precipitation decreases in most of the territory (about 10 to 20% decreases, depending on the season).

DSSAT (Decision Support System for Agrotechnology Transfer) simulation model was the main tool for the analysis of climate change impacts on crops production. DSSAT is software combining crop soil and weather databases and programs to manage them, with crop models and application programs, to simulate multi-year outcomes of crop management strategies. Historical databases of climatic data, soils and crop management variables for Egypt and Tunisia were used in the impacts assessment.

5. Egyptian Case Studies

Egypt is located in North Africa and considered as one of the developing countries, which burdened by the scarcity of natural resources associated with extreme population expansion. The Agricultural sector plays a significant role in the Egyptian national economy. It contributes to the overall food needs of the country and provides the domestic industry with agricultural row materials. Also, agriculture helps in financing economic and social development through the net capital outflow from agriculture to the other sectors of the economy. As well as, agricultural sector considered as the major water consumer (68% of annual water resources)

Egypt contributes very little to the global emission of GHG's, yet it is vulnerable to the negative impacts of climate change. Many studies emphasized that Egypt is highly vulnerable to climate change impacts, mainly due to the large and tightly packed population, and if climate change makes Egypt's climate drier or warmer; pressures on agriculture would intensify. Competition among the limited water resources states for water could escalate even without climate change, and the country could face an explosive situation (El-Raey, 1999).

Therefore, Impacts and vulnerability assessment studies in priority sectors have been undertaken as a part of process of developing the national action plan. Agriculture is one of the indicated areas as one of the most vulnerable sectors in order to severity and certainty of results.

In this study climate change impact, vulnerability, and adaptation of the production of the major food crops and irrigation water requirements in Egypt are analyzed by evaluating the proposed stakeholders' adaptation options with a range of modeling methodologies. The analysis includes both cereal and vegetable production. The stakeholders engaged in the project represent the small-holder farmers, commercial farmers, and strategic resource managers. An empirical statistical analysis is used to evaluate how agricultural cropping systems interact with intra and inter-annual climate variability. Simulation models are used to quantify some of the strategic adaptation options proposed by the stakeholders. The modeling studies consider on-farm adaptation techniques, such as the use of alternatives existing varieties, optimization of time of planting and other techniques, which can enhance sustainability under current conditions.

5.1 Stakeholders Analysis

The main goal of stakeholder engagement is increasing agriculture productivity and achieving the best possible use of water resources. The stakeholder engagement was conducted through four steps processes as follows:

- Identifying key stakeholders,
- Determining stakeholders' interests,
- Determining stakeholder power and influence, and
- Formulating a stakeholder participation strategy.

This Section of report is divided to three parts:

1. On-farm water management activities for the winter season of 1999/2000 and the summer season of 2000: Mahmoudi sub-project.
2. Demonstration mesqas and fields carried out in winter season.
3. Gharbia Governorate study.

5.1.1 On-farm water management activities for the winter season of 1999/2000 and the summer season of 2000: Mahmoudi sub-project

The Irrigation Improvement Project (IIP) concerns with the improvement of the existing irrigation system in Egypt over a total area of 248000 feddans in the northern part of the Nile Delta. The project area is divided into three sub-projects; Mahmoudia 131000 feddans; El Wasat 75000 feddans and Manaifa 42000 feddans. The project is implemented by the Irrigation Improvement Sector, Ministry of Water Resources and Irrigation of Egypt, and is organized by the Soil, Water and Environment Research Institute (SWERI), Ministry of Agriculture and Land Reclamation in coordination with the Agricultural Extension.

The overall objectives of the project:

1. Increase agriculture production and farm incomes by improving irrigation infrastructure, facilitating more equitable distribution of water and improving on-farm water management.
2. Minimize different irrigation water losses and increase water use efficiency for different crops.
3. Strengthen institutional planning and implementation capacity of MWRI in the irrigation sector.
4. Improve long-term sustainability of irrigation, through the assumption of responsibility for operation and maintenance at the tertiary level investment costs.

In Damanhour area, the field demonstrations were divided in the long-term and flying ones. The long-term demonstrations were selected to represent the different fields at the beginning, the middle and the end of each selected mesqua representing the beginning; the middle and the end of branch canals; the different long-term demonstrations will be organized until the end of the project time. The flying demonstrations are fields selected differently each growing season and it was changed one season after the other. The different demonstrations aim to achieve the best irrigation water use efficiency for the different crops raised in the area by applying the up-to-date agriculture, irrigation technology and recommendations of the Ministry of Agriculture and the Ministry of Water Resources and Irrigation. Mostly, they were land leveling; long irrigation runs and/or large borders; fertilizers application, when, how and at what quantity; pest control in when, how and at what quantity and irrigation organization.

Activities of the on-farm water management for winter season of 1999/2000 and summer season of 2000:

Different activities achieved during the winter season of 1999/2000 and summer season of 2000. It can be summarized as follows:

1. Demonstration work plan for winter season of 1999/2000.
2. Demonstration database for winter season of 1999/2000.
3. Demonstration data analysis of winter season of 1999/2000.
4. Demonstration database for summer season of 2000.
5. Demonstration data analysis of summer season of 2000.
6. On-farm training activities.
7. Suggested pilot mesqua demonstration.

Demonstration work plan for winter season of 1999/2000

A work plan for the winter cropping season "wheat and Egyptian clover" has been discussed with all the on-farm staff. Land leveling had been implemented to 50 feddans (Table 1) including different location selected for the on-farm demonstration. Topographic survey before and after leveling had been taken in consideration. A field manual for the demonstration application in Arabic and English languages has been prepared as a guide to all the agriculture extension field staff.

Year	Season	Crop	Land leveling area/feddan	Location
1999/2000	Winter	Wheat	10.00	Sahaly
			8.00	Bisintway
			20.00	El-Kammaheen
			7.00	Bisintway/Kabel Village.
			2.00	Bisintway/Kabel Ezba.
		Total	**47.00**	
		Berseem	2.00	Bisintway/Village.
			1.00	Bisintway/Kabel Ezba.
		Total	**3.00**	
		Grand Total	**50.00**	

Table 1: Selected areas for land leveling in winter season of 1999/2000

Some of the demonstration sites had been planted by clover after rice or cotton as follows:

1. Directly after rice, without any land preparation, which is the main traditional method of cultivating clover in the project area.
2. Land leveling and seed bed preparation when planting after rice.
3. Land leveling and seed bed preparation when planting after cotton.

The other demonstration sites had been planted by wheat after rice or cotton. Zero slope land leveling, seed bed preparation and mechanical sowing for wheat seeds took place in all the long-term sites.

Soil samples and field observation wells had been installed in each long-term site and the flying sites to follow up the soil chemical properties and the water table fluctuation in each site. Water table samples were collected periodically to be analyzed for the total soluble salts.

Demonstration data analysis of winter season of 1999/2000

Data analysis of the different data collected for each growing season took place to point out the output effects of the different on-farm activities recommended to the farmers. Results in Table (2) revealed that the highest average increase in wheat yield was 18.18% in El-Kammaheen canal, mesqa Baioumy, with average decrease in its irrigation time by 16.38%. Whereas, the lowest average decrease in wheat yield was 5.05% in Bisintway, Galia, with average decrease in its irrigation time by 32.66% (Table 2). Furthermore, the average of the total increase in wheat productivity was 10.8%, whereas the average of the total decrease in irrigation time was 24.57%, compared with the traditional farmers' practices (control).

Regarding to barseem, in Bisintway canal, mesqa El-Ahkar, “long term demonstration", the average increase in berseem cuts was 16.76%, whereas the average decrease for its irrigation time was 34.2%. Moreover, in Bisintway canal, mesqa, Galia, “long term demonstration” the average increase for berseem cuts was 2.12%, whereas the average decrease in its irrigation time was 24.78%.

In Bisintway canal, mesqa El Shalakany, “long term demonstration” the average increase in berseem cuts was 20.36%, whereas the average decrease for its irrigation time was 13.44%. Furthermore, the average of the total increase in barseem productivity was 12.8%, whereas the average of the total decrease in irrigation time was 21.54%, compared with the traditional farmers' practices (control).

Demonstration work plan for summer growing season of 2000

Land leveling program for the summer season of 2000 was implemented to 150 feddans (Table 3). The work plan of the summer growing season of 2000 included crops grown in the area i.e. cotton, rice and corn.

For Cotton, 50 feddans had been selected. All these fields were leveled for zero grade, medium irrigation runs had been prepared and mostly all were planted by cotton seed variety Giza 70, except Hammour area which was planted by Giza 89 variety. For Rice, 95 feddans were selected and leveled. The rice fields were cultivated by short growing season varieties i.e. Giza 102, Giza 78 and Giza 101. For Corn, 5 feddans were been selected to be cultivated by single cross 10. The Agricultural Extension supplied the farmers with that hybrid and seed bed was long furrows.

Soil samples and field observation wells were installed in each long-term and the flying sites to follow soil chemical properties and water table fluctuation in each site. Water table samples were collected periodically to be analyzed for the total soluble salts.

Year	**Crop**	**Canal**	**Mesqua**	**Demonstration**		**Control**		**Average Yield Change %**	**Average Irrigation Change %**
				No	**Area/fed**	**No**	**Area/fed**		
1999/2000	Wheat	El-Kammaheen	El-Hamamy	4	13.00	4	3.50	+ 13.85	- 17.49
			Baioumy	1	7.00	1	2.00	+ 18.18	- 16.38
		Sahaly	Khamees	4	4.66	4	4.66	+ 10.78	- 15.46
			El Mahada	6	5.32	6	5.32	+ 5.56	- 20.06
		Bisintway	El Ahkar	2	3.25	2	2.50	+ 11.94	- 37.28
			Galia	3	3.00	3	3.00	+ 5.05	- 32.66
			El Shalakany	2	3.00	2	3.00	+ 10.86	- 32.68
	Total (Wheat Crop)			**22**	**39.23**	**22**	**23.98**		
	Average of total increase for wheat							**+ 10.80**	**- 24.57**
	Berseem	Bisintway	El Ahkar	1	1.25	1	1.00	+ 16.76	- 34.21
			Galia	2	2.00	2	2.00	+ 2.12	- 24.78
			El Shalakany	3	3.50	3	3.00	+ 20.36	- 13.44
	Total (berseem crop)			**6**	**6.75**	**6**	**6.00**		
	Total field trials			**28**	**45.98**	**28**	**29.98**		
	Average of total increase for berseem							**+ 12.80**	**- 21.54**

Table 2: Data analysis of the winter season of 1999/2000 for crop production and irrigation

Year	Season	Crop	Land leveling Area/feddan	Location
2000	Summer	Cotton	15.0	El Kammaheen / Abou Kabaria
			15.0	Bisintway / Bisintway
			10.0	Sahaly / Sahaly
			4.5	Bisintway / Hammour
			3.0	Bisintway / Kabeel Village
			2.5	Bisintway / Kabeel Ezba
		Total	**50.0**	
		Rice	12.0	Bisintway / Abou El Khazr
			5.0	Bisintway / El Wakeel
			7.0	El Herfa / Abou Hawash
			5.0	Bisintway / Bisintway
			21.0	El Kammaheen / Abou Kabaria
			5.0	El Herfa / El Ashara
			10.0	Bisintway / Demisna
			10.0	Sahaly / Sahaly
			5.0	Bisintway / Kabeel Ezba
			5.0	Bisintway / Kabeel Village
			10.0	Bisintway / Hammour
		Total	**95.0**	
		Corn	5.0	El Kammaheen / Abou Kabaria
		Total	**5.0**	
Total leveled areas for summer season of 2000			**150.0 feddans**	

Table 3: Selected areas for land leveling, summer season 2000

Demonstration database file for summer season of 2000

Different field data of the selected sites (long-term, flying demonstration and control) were collected by the field staff day after day. Data analysis was done to point out the effects of different on-farm activities recommended to the farmers. Results in Table (4) show the depending on the selected site, the yield of the three crops: cotton, rice and corn under demonstration, either for the long-term or the flying sites were increased or decreases. The highest increase in cotton production was 9.48% for El-Shalakany mesqa, whereas the highest increase in rice yield was11.41% for Galia mesqa and it was 21.64% for corn. Meanwhile, the irrigation time for the different crops under demonstration decreased in all mesqas. The average of the total decrease in irrigation water was 24.35%, 15.55%, and 25.82% for cotton, rice, and corn, respectively. In other words, it could be conclude that since the yield of these crops increased and the irrigation water decreased, the water use efficiency for these crops increased.

Year	Crop	Canal	Mesqua	Demonstration		Control		Average Yield Change %	Average Irrigation Change %
				No.	Area/fed.	No.	Area/fed.		
2000	Cotton	Bisintway	El Mesery	3	3.00	3	2.50	+ 9.07	- 29.28
			El Shalakany	3	4.00	3	3.00	+ 9.48	- 6.75
			El Eslah	1	2.00	1	1.00	- 18.24	- 68.73
			Galia	1	1.00	1	1.00	- 6.22	- 6.12
	Total for Cotton Crop			**8**	**10.00**	**8**	**7.50**		
	Average of Total increase for Cotton							**- 5.55**	**- 24.35**
	Rice	Bisintway	El Mesery	3	4.00	3	4.25	+ 5.95	- 22.11
			Galia	3	3.00	3	3.00	+ 11.41	- 7.65
			El Shalakany	1	1.00	1	1.00	- 7.81	- 16.88
	Total for Rice Crop			**7**	**8.00**	**7**	**8.25**		
	Average of Total increase for Rice							**+ 3.18**	**- 15.55**
	Corn	Bisintway	M. Reiad	3	5.00	3	3.00	+ 21.64	- 25.82
	Total for Corn Crop			**3**	**5.00**	**3**	**3.00**		
	Average of Total increase for Corn							**+ 21.64**	**- 25.82**

Table 4: Yield and irrigation water amounts for crops of growing season of summer of 2000

On-farm training activities

An IIP on-farm and irrigation scheduling training program was provided by the on-farm irrigation management consultant in Damanhour to 15 trainees from both Damanhour and Kafr El Shaik areas at Damanhour training center on 8-10 July, 2000. The materials covered were, soil-plant-water relationships, soil water movements, crop evapotranspiration, irrigation efficiencies, leaching requirements, irrigation water requirements and irrigation scheduling. Lectures hand out of 76 pages was given to each trainee, and color transparencies were used to illustrate different items.

Different problems, as examples, for each item of the training materials were given to be solved by the trainees themselves to verify their perception towards the different materials covered. A part of the last day of the training scheduled for general discussions between the trainees (Training by doing and sharing).

On the 12th of the same month another training lecture for irrigation scheduling was held at Tanta training office. Fifteen trainees from Damanhour and Kafr El Shaik attended that training.

The same training courses were repeated again to another group of trainees through the period from the 15th to the 17th of July and on the 19th of July at Tanta and Damanhour, respectively. Nearly the same number of the trainees attends these training courses.

The on-farm water management component (SWERI) held two training programs. The first course was for land improvement of the project areas of Damanhour on the 15th of April, 2000 to the 20th.

Thirty-one trainees attend the course for six days, 16 of them were from the Agricultural Extension Department and 15 of them were from IPP; IAS. The second course was for integrated management and irrigation field efficiency. Thirty trainees attend the course for six days from the 9th of September 2000 to the 14th of September, 20 of them from the Agricultural Extension Department and 10 from IIP; IAS.

Another training program was provided by SWERI was held on the 11th of November 2000 to the 16th. The lectures were dealing with the irrigation organization and/or irrigation scheduling on the improved mesqas. The main aim of that program was to give a hand to the IAS and the farmers at the mesqa level and teach them how they should efficiently irrigate and manage their crops at the farm level to increase water use efficiency for growing crops and to prevent the soil deterioration.

Meetings held through the period of October 1999 to October 2000

Different field visits and office meetings were held to discuss the different field demonstrations concerning problems facing the field staff and the summer work plan. These meetings were held at Damanhour IIP office, Abou Homos Agricultural Extension Office, and at the Agricultural Co-operation Office at Damanhour.

Other different meetings and/or field visits were paid to the demonstration sites and field staff office to flow up on the different activities and to discuss collected data insure its reliability and consistency.

Different meetings also were held with the communication consultants, to prepare an integrated work on-farm different activities for the selected sites. The main idea is to prepare wide spread media about what it is and what it should be throughout the different field demonstrations.

Other different activities

Integrated work concerning communication and on-farm different activities was created to produce different leaflets to be distributed to the local leaders to illustrate to them the main objectives of the project. Four leaflets were suggested and prepared. The first was about the irrigation improvement project, the second was about the benefits of the irrigation improvement project, the third was about the raised mesqas and the fourth was about the pipe line mesqas. These leaflets helped the local leaders of the different mesqas to understand the different purposes of the project and its benefits.

A field day work was held with the communication for the TV shots for Ertwaa program to discuss problems facing the farmers and its solutions to overcome the different rumors they are facing towards the project. Furthermore, another successful field day visit was paid to Kafr El Shaik, Agriculture Research Station, cotton-farms to explain to the farmers the benefits of zero and little slope leveled long furrows cultivated with cotton. Fifteen farmers from Bisintway and Abou Homos areas, Damanhour Agriculture Extension director, Bisintway Agriculture Extension director, Abou Homos Agriculture Extension director were attended that day. One of the attendances was a farmer who has 15 feddans and he is the chief of the local council of Bisintway village. Through the visit, an introduction to the farmers by the Head of the cotton research department concerning the different recent recommendations to obtain high cotton yield, the benefits and the economics of the long furrow; its fertilization, irrigation tillage, and weed control. A part of the visit was to show them how to prepare seeds without fuzz of different cotton varieties; its treatments, objectives, planting rates to increase the production. The visit was very successful and had a great positive sound to all the farmers, they asked many questions, good and convinced answers were given to all of them. The farmers were very satisfied by the visit. Most of the farmer's comments were "it is the most reliable and very beneficial visit we have until now".

Suggested mesqa demonstration

A successful meeting was held at Abou Homos Agricultural Extension Office. At this meeting, a pilot area as a demonstration trial was suggested (the whole area served by one mesqa could be under the different agriculture and irrigation up to data recommendations), the IAS, the Communication and the Agricultural Extension field staffs should work together for such demonstrations. The main aim of that work was to teach the farmers by the objectives of the project and how they should organize their irrigated crops.

Different practices were taken into consideration for this pilot area, such as when to irrigate, how many farmers should irrigate in one time from the same mesqa, who should irrigate first, in addition to different agriculture practices such as leveling, new high yielding varieties, mechanical sowing, long furrows, when to apply fertilizers, how much and what kind, etc. In other words, the integrated work between the IAS and the Agricultural Extension Services field staff should took place together to achieve the best water use efficiencies.

The main objectives for mesqa demonstration:

1. To create a link between the Agricultural Extension and the IAS Staff.
2. Training the IAS office staff and the field staff how irrigation at the mesqa level should be organized between the different farmers.
3. To teach the farmers how to clean the raised mesqa and how to maintain it in good shape from time to time.
4. To keep an eye on the mesqa records from time to time.
5. To proof if there is any equity of irrigation water distribution between the farmers along the same mesqa.
6. To examine if the farmers at the tail mesqa still irrigating from the drain.
7. To examine whether water use efficiency was increased for the different crops served by mesqa.
8. To proof if there is any fuel hence energy saving.
9. To have a try if irrigation scheduling (when and how much) can be implemented along the mesqa.

Mesqa demonstration work plan:

1. Select one raised mesqa and/or one pipe mesqa.
2. Draw a sketch of each farmer's parcel identifying the actual area.
3. Identify the different crops sown by each farmer.
4. Land leveling program for the whole area should took place in a short time either individually for each farmer or for the whole area on one time.
5. The whole package of the up-to-date agricultural recommendations (seed bed preparation, varieties, fertilizers, irrigation, pest and disease control and mechanical planting) should be transferred to each farmer.
6. Irrigation organization should be operated according to the available pump discharge, in other words to maximize the irrigation efficiency at the field level the discharge through the irrigation time should be enough to be distributed along the pass of the irrigation efficiently. If any method of measuring the irrigation water will be available, irrigation scheduling (when and how much) could be taken in consideration. The available irrigation water in the root zone in some sites before and after irrigation could be taken as an indicator for overall field irrigation efficiency.
7. At the end of the growing season, the yield of each parcel and the water used for irrigation can indicate the water use efficiency for the different crops.

Different steps followed for mesqa demonstration:

1. Two mesqas have been selected, El Tawela, raised mesqa at Bisintway and Mahmoud El Tabakh, pipe line mesqa at Bisintway.
2. Field staff (IAS & Agricultural Extension) got draft sketch maps and the actual area owned by each farmer, the grown crops, the time when the land were empty for land leveling.
3. An approval by SWERI was sent to the department of land improvement for land leveling of sixty feddans on the 5th of October, 2000.
4. Different meetings with the IAS, Agricultural Extension staffs and the farmers were held to follow up the advantage of the field conditions. Regular meetings were held on each Saturday to discus all the work achieved, any problem and/or requests.
5. A request for using the laboratory of the IIP at Damanhour for field tests and estimates (soil moisture content and chemical analysis) was requested.
6. It was proposed to carry on, how the irrigation process is going through the mesqa and in the field to have an idea about the field irrigation efficiency, since most of the farmer's sites are very long strips compared by the width of these sites. Therefore, soil moisture samples should be taken before and after each irrigation in some selected sites to evaluate these processes.

7. A field training program (mostly training by doing) was requested to help the field staff (Agriculture Extension and IAS) in operating the mesqas.

5.1.2 Demonstration mesqas and fields carried out in winter season

Much attention had been paid to evaluate the educational effect of demonstration mesqas and fields carried out in winter season of 2002/03 for wheat and beans. These demonstrations were done to know the extent of farmers' knowledge of the technology used for each crop, farmers' attitude towards practices of water management, farmers' adoption of water management, farmers' reasons for using too much water in irrigation, and their suggestions for controlling the use of irrigation water.

This activity is intended to recognize the educational effect of the extension mesqas and fields of winter season of 2002/03 in order to:

1- Recognize some social and economical characteristics of growers on bisintway and sahaly canals at Bouhera Governorate.

2- Studying the effect of the demonstration fields on the farmers.

3- Estimating farmers' adoption on-farm water irrigation practices.

4- Recognize farmers' attitude towards managing irrigation water practices.

5- Recognize reasons for using too much water in irrigation by growers and their suggestions for good water management.

Characteristics of the growers

Age: average age of farmers in the demonstration field was 51.2 years. It was 51 years for farmers in the control fields and 52 years for the adoption sample growers.

Educational level: the %age of illiteracy among farmers in the demonstration field was 45%. It was 43% for farmers in the control fields and 44.5% for the adoption sample growers.

Average farm size: average farm size of demonstration field was 2.4 feddan. It was 1.5 feddan for farmers in the control fields and 1.8 feddan for the adoption sample growers.

Average crop yield per feddan: average wheat yield per feddan obtained from farmers in the demonstration field was 18 ardab, for beans were 14.5 ardab and 50 ton for berseem. Average wheat yield per feddan obtained from farmers in the control fields was16 ardab, for beans was 13 ardab and 40 ton for berseem. Average wheat yield per feddan obtained for the adoption sample growers' was16.25 ardab for beans was 13 ardab and 45 ton for berseem.

Irrigation machine: 95% of the whole sample using developed pumps.

Irrigation time: average irrigation time per feddan of demonstration field was 1.4 hour. It was 2.7 hour for farmers in the control fields and 2.5 hour for the adoption sample growers.

Educational effects of demonstration fields: demonstration fields helped in increasing growers' awareness of agricultural technology.

Growers' knowledge of wheat and beans practices: average knowledge of demonstration fields' growers about wheat and beans was 13.5 degree. It was 11.5 degree for farmers in the control fields and 11.5 degree for the adoption sample growers. Results also showed low knowledge of these farmers recommended dose of N-fertilizer and P-fertilizer (Table 5).

Growers' knowledge about water management practices: results in Table (6) showed low knowledge of demonstration and control fields growers of the importance of dry planting of berseem.

Knowledge item	demonstration growers		control growers		adoption sample growers	
	Number	%	Number	%	Number	%
Ploughing of soil	58	96.7	54	90	53	88.3
Precision land leveling	60	100.0	-	-	22	36.7
Rate of irrigation	53	88.3	42	37.0	52	86.6
Time of the (El-Mohyah) irrigation	56	60.3	52	86.6	50	83.3
Time of sowing	53	88.3	42	70.0	52	86.6
Recommended dose of P-fertilizer	5	96.7	53	88.3	53	88.3
Recommended dose of N-fertilizer	45	75.0	38	63.3	40	66.7
Recommended dose of bio-fertilizer	25	41.7	22	36.7	20	33.3

N = 60 growers

Table 5: Distribution of growers according to their knowledge about bean and wheat

Knowledge item	demonstration growers		control growers		adoption sample growers	
	Number	%	Number	%	Number	%
Planting short life crop	60	100	60	100	58	96.7
Importance of cutting off irrigation time knowledge	60	100	50	88.3	48	80
Advantage of precision land leveling knowledge	58	96.7	53	88.3	48	80
Importance of long furrows\ borders	48	80	35	58.3	32	53.3
Importance of berseem dry planting knowledge	42	70	32	53.3	25	41.7

N = 100 for demonstration and control field growers; N= 84 for adoption sample growers

Table 6: Distribution of growers according to their knowledge of water management

Adoption of water management practices

A random sample was selected on Bersik and dimasna to identify growers' adoption of water management practices. The listed findings in Table (7) showed high adoption of planting short life crops. The reason that low number of farmers adopted precision land leveling is that the number of leaser units is not enough to meet the demand to perform it in a short time. Results also showed that low number of farmers adopted long furrows, dry planting of berseem because these practices are new to the farmers.

Knowledge item	demonstration growers	
	Number	%
Planting short life crops	60	100
Precision land leveling	45	75
Using long furrows\ borders	38	38
Berseem dry planting knowledge	25	41.7

N= 60

Table 7: Distribution of growers according to their adoption of water management practices

Results in Table (8) showed that the extension workers are the main resource of the demonstration and control fields' growers, and adoption sample growers.

Knowledge item	demonstration growers		control growers		adoption sample growers	
	Number	%	Number	%	Number	%
Village extension workers (VEW)	2.96	1	2.88	1	2.98	1
Local leader in the village	1.89	2	1.87	5	1.71	6
TV agricultural programs	1.81	4	2.04	3	1.96	2
Radio agricultural programs	1.72	5	1.78	6	1.82	5
Irrigation advisory engineer (IAE)	1.87	3	1.84	4	1.88	3
The farmers of extension field	-	-	2.05	2	1.85	4

Table 8: Distribution of growers according to their resources about water management

Growers attitude towards water management practices

Results showed that 91.7% of demonstration field growers, 83.4% of control field growers and 85% of adoption sample growers have positive attitude.

Growers reasons for excessive irrigation water and suggestions about managing it

Results are included in Table (9).

Reasons and suggestion	Frequency	
	Number	%
Reasons for using excessive irrigation water	170	44.4
Bad land leveling	100	55.6
On-off rotation	100	55.6
Low awareness of soil water content	80	44.4
Salt accumulation in the soil		
Suggestion about managing irrigation water		
Precision land leveling	170	94.4
Increase extension efforts regarding to the important of water management	150	83.8
Continuous follow of water in canals	150	83.8
Lining canals and mesqas	150	83.8
Executive field irrigation practices and marws	100	55.6

N=180

Table 9: Growers reasons for excessive irrigation water and suggestions about managing irrigation water

Finally, the different activities on-farm water management components achieve its goals toward teaching farmer new technologies. Furthermore, raising their awareness about good water management in their field to obtain the highest production and increase water use efficiency.

5.1.3 Gharbia governorate

The stakeholders in Egypt did field-based studies of the adaptation choices of small-holder farmers, commercial farmers and strategic resource managers. The methodology is based on survey analysis and communication with stakeholders by local training. The training includes the educational effect of the extension and field demonstration for growing winter crops (wheat and others) and summer crops (maize and others) at El-Beheira, Khafr El-Sheikh Governorates and also national workshops. A list of farmers from El-Beheira, Khafr El-Sheikh, and El-Gharbia Governorates was prepared representing stakeholders of the Delta region and will be included in the annual report.

With the goal of increasing agricultural production and achieving the best possible use of water resources, the study demonstrates the value of application of improved agricultural technologies in Behiera and Khafr El-Sheikh Governorates. The study depends on effective extension activities which provide the farmers with the knowledge needed and teach them how to apply this knowledg's. Extension efforts have been exerted to convince farmers that it is necessary to follow the agricultural practices which guide the use of water in irrigation. Among such activities were paying attention to the demonstration aggregates and fields to cultivate various crops where technologies are applied in order to increase production and guide to the use of water through the use of precession land leveling, long furrows, long borders, and planting dry berseem (as alternative to the traditional wet method), etc. In addition, to increase the educational effectiveness of the field demonstration, the analysis included meetings, and field visits made by researchers and extension workers.

Much attention has been devoted to evaluate the educational effect for such field demonstration during the winter season, including wheat, sugar beet, and clover (berseem) crops, and summer season crops, including cotton and rice to know the extent of the farmers knowledge of the technologies used for each crop, find out the growers attitudes towards practices of water management, farmers adoption of water management practices, farmers reasons for using too much water in irrigation, and their suggestions for controlling the use of irrigation water. It is here the process of learning by doing.

The analysis focused on the following headings in the field based studies:

- Characteristics of the growers.
- Educational effects of the field demonstration related to: (1) Growers knowledge about wheat, cotton and rice practices; and (2) Growers knowledge about water management practices.
- Adoption of water management practices.
- Grower's information resources about water management.
- Grower's attitudes towards practices of water management.
- Grower's reasons for using excessive water for irrigation and their suggestions as to how to manage it.

With regard to Gharbia Governorate, a short questionnaire was used to detect farmer's awareness recent climate variability as well as the adoption options to temperature and precipitation changes. A sample of 40 farmers was used to for that purpose. Results showed that, only 2 farmers did not notice any change in either temperature and/or precipitation. For the rest of the sample, farmers with their own experiences and/or with the help of the agricultural extension personnel apply one or more of the following tactics and adaptation options.

Temperature Adjustment

- Change crop sowing dates to be a side from the expected high temperatures.
- Use heat tolerant varieties.
- Increase number of irrigations (short irrigation duration).
- Increase irrigation amounts.
- Apply irrigation early in the morning or late in the evening and avoid irrigation in the afternoon.
- Use intercropping between different crop plant heights.
- Fruit mulching in vegetables.
- Manage pesticide and fertilizer applications.
- Plant trees as fences around the farm.

Rainfall Adjustment

- Use of underground water irrigation.
- Use drainage water for irrigation.
- Use varieties with high water use efficiency.
- Use early maturing varieties.
- Improve drainage.

Agriculture is the main sector in Egypt, which needs to be modernized to increase the welfare of our society. Extension plays an important role in conveying new technologies to farmers. Applying agricultural technologies depends on how effective is extension activities to provide farmers with the knowledge they need to increase productivity. Among such activities, were precession land leveling, long furrows, loge borders, and water management. Improving both the efficiency of technical water application and the efficiency of agronomic water use are very useful practices to increase crops productivity. Water has to be added timely and quantitatively with least losses. Irrigation application by night and/or early morning is a favorable practice in this connection.

We can come to some policies as follows:

Use of saline water and wastewater

1. Use of saline water: One of the key elements of the water management strategies in arid climates is concerned with the promotion of the use of saline water for irrigation/ crop production. In

this context, it is important to create an awareness of the degradation and pollution consequences that result from prevalent irrigation practices and the potential to minimize these problems through the interception, isolation and reuse of drainage water for irrigation employing appropriate strategies and practices.

2. Use of wastewater: Use of wastewater in agriculture could be an important consideration when its disposal is being planned in arid and semi arid regions. However it should be realize that the quality of wastewater available in most countries would account for only a small fraction of the total irrigation water requirements. Nevertheless, wastewater use will result in the conservation of higher quality water and its use for purposes other than irrigation. As the marginal cost of alternative supplies of good quality water will usually be higher in water-short areas, it makes good sense to incorporate agricultural reuse into water resources and land use planning.

Adaptation to climate change

Future adaptation strategies to climate change may involve the development of new, more heat tolerant cultivars, new crops (more cotton cultivation as alternative to some maize and more winter crops in stead of some wheat). Changing practices of cotton crop (optimum sowing date, cultivar, and water amount and plant population density) can be used to improve the benefit from the positive impact of climate change on cotton productivity with about 29%.

Modification of cropping pattern (i.e. partially growing cotton after wheat in the same year ad land), reducing or keeping on the current area under cultivation with some high water consumer crops (i.e. sugar cane and rice crops) and changing practices (optimum sowing dates, more water and nitrogen amounts use and cultivars for suitable agroclimatological regions) can be adopted.

Water management

The first imperative is to improve both the technical water application efficiency and the agronomic water use efficiency. This involves nothing less than revamping the entire system of water delivery and control. Ideally, water should be made available in demand (rather than on a fixed schedule), and be delivered in fixed quantities in closed conduits subject to effective monitoring and regulation while avoiding losses (i.e. water have to be added timely and quantitive with least losses). While this will be difficult to achieve in Old Lands (some of this being done), where traditional systems exist and traditional concepts die hard, it is certainly achievable from the outset in the new lands. More and continuous evaluation studies have to be done.

Optimal use of water by agriculture

1. Off-farm improvements: The off- farm measures include improvements in water delivery that are flexible, reliable and demand driven.

2. On-farm improvements: The on- farm measures to improve water use efficiency include applying water more uniformly and efficiently.

The government has done its best and strategy has been made to achieve the best possible use of water resources so as to develop and control this use. That strategy included strengthen the awareness of people, community and executive bodies awareness to control the use of irrigation water, to save 10-15% of irrigation water and increase the crop production by 15-20%, (El-Kady, 1995).

This strategy has led to a plan for developing irrigation systems at the farm level such as precision land leveling, long furrows, long borders, etc.

5.2 Evaluation of the Impacts and Adaptation of Wheat and Tomatoes Productivity to Climate Change

5.2.1 Regression analysis

Empirical models are defined as models directly describing observational data, while containing no information beyond the original data (Thornley and Johnson, 1990). One form of empirical model is prediction equations resulted from regression analysis. Regression analysis (Drapper and Smith, 1987) is a technique utilized to fit a line through a set of observations, and test how a single dependent variable is affected by the value of one or more independent variables. As a result, a prediction equation is developed and used to predict the performance of those dependent variables, when values of these independent variables vary. The aim of using regression analysis in this project is to predict wheat (grown under irrigation and rain fall) and tomatoeses productivity under climate change conditions

Data for mean temperature[1], wheat and tomatoes productivity were collected[2] for twenty five years (1975-1999) for Sakha, Kafer El-Sheikh governorate, Egypt (as a representative of Delta region). In addition to, another set of data was collected for wheat productivity planted under rain fed conditions at Sidy Baraney, Marsa Matrouh governorate at the Egyptian North West coast for three years (1993-1995) from 12 experiments. Sowing was assumed to be done on November, 20 for wheat planted under irrigation. Whereas, wheat planting date under rainfed conditions was 1 November. For tomatoes, it was assumed to be done on July, 1. Both wheat and tomatoes season length for each year was determined and mean temperature was summed throughout the growing season. For wheat grown under irrigation and tomatoes, mean temperature (Mtemp) was used to predict both crops productivity, where a straight line was fitted to the yield as a function of temperature. Whereas, for wheat grown under rain fed conditions, mean temperature and/or rain fall was used to predict wheat yield. This assumption was examined by testing for lack of fit. The developed equation was used to assess the impact of high temperature by predicting wheat yield grown under irrigation (kg/ha) and tomatoes yield (ton/ha) under current temperature, current temperature + 1.5° C (MAGICC/SCENGEN results), and current temperature +3.6° C (GCMs results). To assess the impact of climate change on wheat grown under rain fed conditions eight scenarios were used:

1) 1.5 ° C increase in temperature and 10% decrease in rain fall.
2) 1.5 ° C increase in temperature and 20% decrease in rain fall.
3) 1.5 ° C increase in temperature and 10% increase in rain fall.
4) 1.5 ° C increase in temperature and 20% increase in rain fall.
5) 3.6° C increase in temperature and 10% decrease in rain fall.
6) 3.6° C increase in temperature and 20% decrease in rain fall.
7) 3.6° C increase in temperature and 10% increase in rain fall.
8) 3.6° C increase in temperature and 20% increase in rain fall**.**

1. Wheat Yield prediction at Khafr El-Sheikh:

Wheat yield was predicted using the following equation:

Y` = 14205.25 - 610.85 * Mtemp Mean = 4673 ± 229.1 [1]

To overcome the adverse impact of high temperature on yield and reduce vulnerability, different adaptation techniques were examined e.g. delay sowing, and altering irrigation amounts. Three sowing dates (November, 30; December, 10; December, 20), and/or four irrigation amounts (300, 400, 500, 600 mm/season) were included in the prediction and new prediction equations were developed. The percent of yield quantity improvement as a result of these adaptation techniques was then determined. Wheat yield was predicted using equation [1] under current temperature, current temperature + 1.5° C, and current temperature +3.6° C. The vulnerability of wheat to high temperature increased by 20.96% when temperature increased from + 1.5° C to + 3.6° C as it shown in Table 10.

Temperature	Predicted yield (kg/ha)	Impact (%)
Current temperature	6129.81	0
Current temperature + 1.5° C	5215.50	-14.91
Current temperature + 3.6° C	3930.75	-35.87

Table 10: Predicted wheat yield under current temperature, and with temperature increase.

Reduction in yield as a result of heat stress could be attributed to low biomass accumulation as it affected by reduction in the growth duration (Ritchie and Nesmith, 1991).

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[1] Agricultural Extension Bulletin

[2] Agricultural Economics Bulletin

1.1. Using regression models to evaluate the effect of adaptation strategies

1.1.1. Effect of sowing date

Although delay sowing reduces season length and consequently reduces yield, it could be useful to overcome the impact of high temperature on wheat yield, and reduce vulnerability. Prediction equations that include different sowing dates could be stated as follows:

- Sowing at November, 30: Y` = 13856.32 - 588.32 * Mtemp [2]
- Sowing at December, 10: Y` = 14565.38 - 647.06 * Mtemp [3]
- Sowing at December, 20: Y` = 14620.89 - 658.04 * Mtemp [4]

As it shown in Table 2, wheat yield was predicted using equations [2], [3], and [4]. Results in Table 11 indicated that delay sowing to December, 20 reduced wheat yield. Figure 1 showed differences in yield under different sowing dates and under a raise in temperature. Similarly, Results in Table 12 showed that sowing wheat on December, 20 reduced vulnerability by 1.61, 1.64 % under a raise in temperature by 1.5° C and 3.6° C, respectively.

Sowing Date	Predicted yield under current temperature (kg/ha)
Nov, 20	6130
Nov, 30	6079
Dec, 10	6011
Dec, 20	5922

Table 11: Predicted wheat yield using different sowing dates under current temperature.

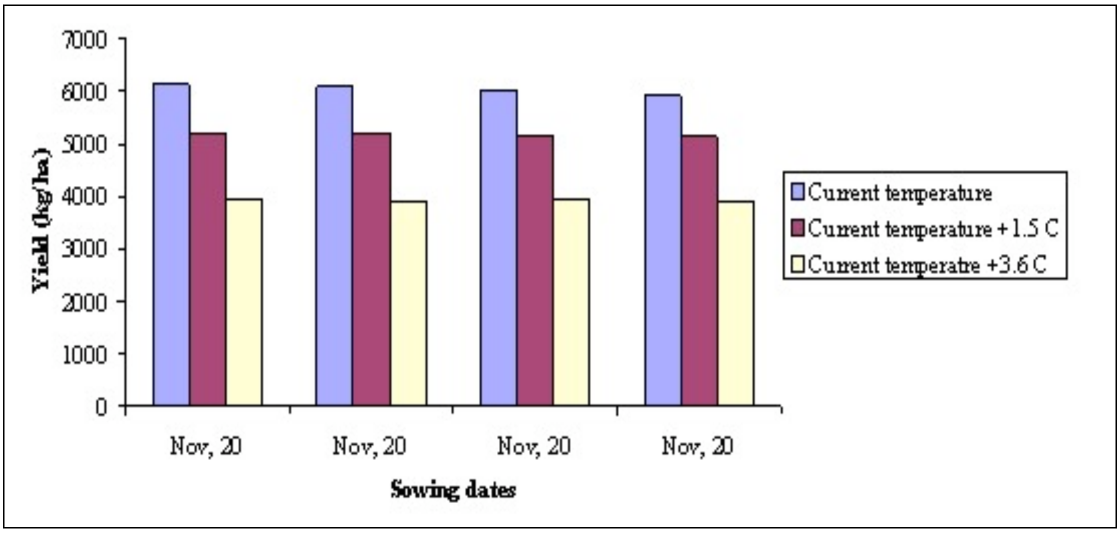


Fig. 9: predicted wheat yield using different sowing dates under current temperature, and with a rises in temperature

Sowing dates	+ 1.5° C			+ 3.6° C		
	Impact	Adaptation	Vulnerability	Impact	Adaptation	Vulnerability
November, 20	-14.95	0	-14.95	-35.87	0	-35.87
November, 30	-14.95	+0.43	-14.52	-35.87	+0.29	-35.58
December, 10	-14.95	+0.96	-13.99	-35.87	+1.42	-34.45
December, 20	-14.95	+1.61	-13.34	-35.87	+1.64	-34.23

Table 12: Effect of delay sowing on wheat yield vulnerability to high temperature.

1.1.2. Effect of irrigation amounts

As a result of heat stress, the atmospheric demand increases, that in turn, increases evapotranspiration (Gardner et al., 1985). Therefore, increasing irrigation amounts could reduce the impact of heat stress. Prediction equation that includes different irrigation amounts (Irri) could be stated as follows:

$Y` = 14043.10 - 611.55 * Mtemp + 0.86 * Irri$ [5]

Wheat yield was predicted using equation [5]. The differences in wheat yield as a result of a raise in temperature were found to be decreasing with the increase of irrigation amount per season (Table 13 and Fig 10).

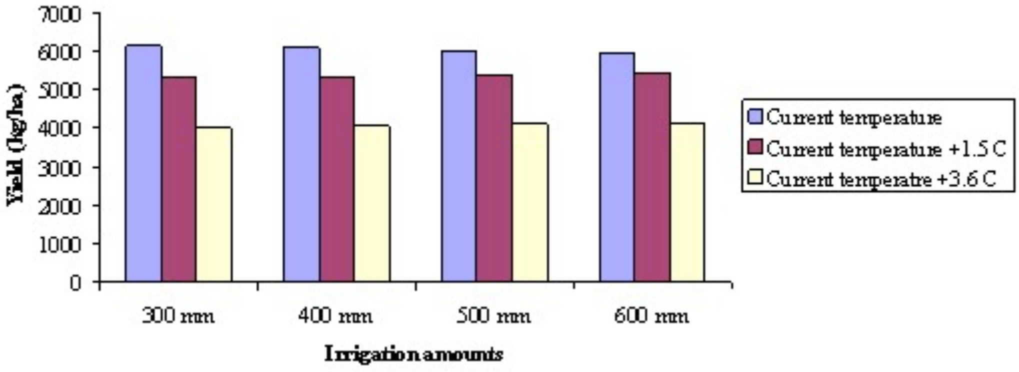


Fig. 10: Predicated wheat yield using different irrigation amounts under current temperature, and with temperature rises

Irrigation amounts	Predicted yield under current temperature (kg/ha)
300 mm/season	6216
400 mm/season	6302
500 mm/season	6388
600 mm/season	6474

Table 13: Predicted wheat yield using different irrigation amounts under current temperature.

Results in Table 14, showed that increasing irrigation amount could serve as a relief factor to overcome heat stress. Irrigation with 600 mm/season reduced wheat yield vulnerability by 5.60 and 5.57 %, when a raise in temperature by 1.5° C and 3.6° C occurred, respectively.

Irrigation amounts	Current temperature + 1.5° C			Current temperature + 3.6° C		
	Impact	Adaptation	Vulnerability	Impact	Adaptation	Vulnerability
300 mm/season	-14.95	+1.39	-13.56	-35.87	+1.36	-34.51
400 mm/season	-14.95	+2.80	-12.15	-35.87	+2.76	-33.11
500 mm/season	-14.95	+4.20	-10.75	-35.87	+4.17	-31.70
600 mm/season	-14.95	+5.60	-9.30	-35.87	+5.57	-30.30

Table 14: Effect of irrigation amounts on wheat yield vulnerability to increased temperature.

1.1.3. Interaction between sowing dates and irrigation amounts

When both delay sowing and increasing irrigation amounts were considered in the predication, prediction equations could be stated as follows:

- Sowing at November, 30 with irrigation amounts included

$$Y` = 13703.85 - 588.94 * \mathrm{Mtemp} + 0.73 * \mathrm{Irri} \qquad [6]$$

- Sowing at December, 10 with irrigation amounts included

$$Y` = 14408.01 - 647.72 * \mathrm{Mtemp} + 0.95 * \mathrm{Irri} \qquad [7]$$

- Sowing at December, 20 with irrigation amounts included

$$Y` = 14771.53 – 658.75 * \mathrm{Mtemp} + 0.63 * \mathrm{Irri} \qquad [8]$$

Both the effect of delay sowing and increasing irrigation amounts were included in the prediction to reduce vulnerability of wheat yield to heat stress (Fig 11 and 12). Results in Table 15, showed that under the condition of temperature increased by + 1.5° C, sowing wheat at December, 20 reduced yield vulnerability by 2.23, 3.29, 4.35, 5.42 %, when the four irrigation amounts were used, respectively. Furthermore, results in Table 16, showed that under the condition of temperature increased by + 3.6° C, sowing wheat at December, 20 reduced yield vulnerability by 4.2, 5.27, 6.33, 7.04 %, when the four irrigation amounts were used, respectively.

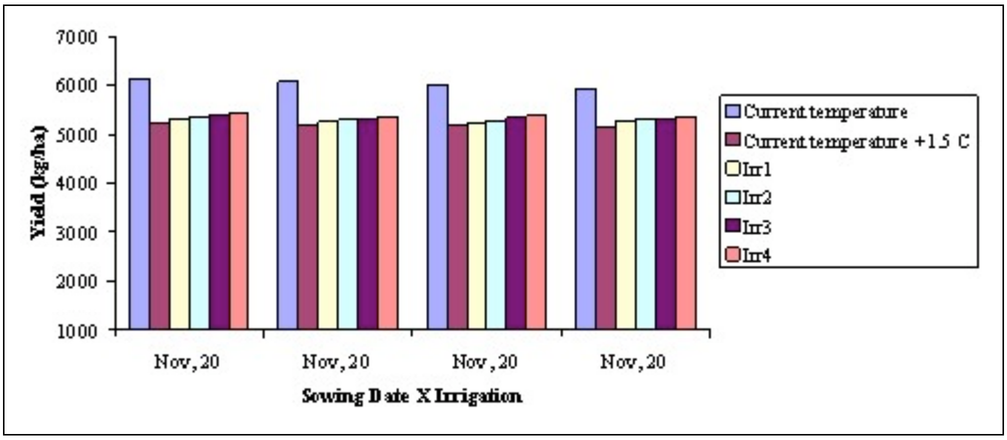


Fig. 11: Predicted wheat yield under current temperature, current temperature +1.5° C and different adaptation techniques

Sowing Date	300 mm/season			400 mm/season			500 mm/season			600 mm/season		
	I	A	V	I	A	V	I	A	V	I	A	V
Nov, 20	-14.95	+1.39	-13.56	-14.95	+2.80	-12.15	-14.95	+4.20	-10.75	-14.95	+5.60	-9.35
Nov, 30	-14.52	+1.93	-12.59	-14.52	+3.46	-11.06	-14.52	+4.99	-9.53	-14.52	+6.52	-8.00
Dec, 10	-13.99	+2.03	-11.96	-13.99	+2.05	-11.94	-13.99	+3.79	-10.20	-13.99	+5.54	-8.45
Dec, 20	-13.34	+2.23	-11.11	-13.34	+3.29	-10.05	-13.34	+4.35	-8.98	-13.34	+5.42	-7.92

I = impact A = adaptation V = vulnerability

Table 15: Effect of interaction between the delay in sowing date and irrigation amounts on wheat yield vulnerability to current temperature and temperature increase by 1.5 ° C.

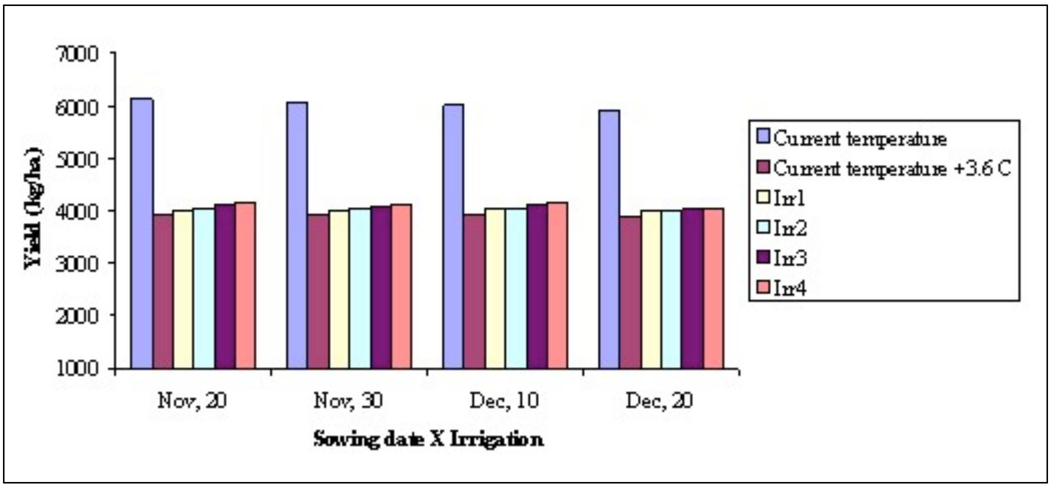


Fig. 12: Predicted wheat yield under current temperature +3.6, and with different adaptation techniques

Sowing Date	300 mm/season			400 mm/season			500 mm/season			600 mm/season		
	I	A	V	I	A	V	I	A	V	I	A	V
Nov, 20	-35.87	+1.36	-34.51	-35.87	+2.79	-33.08	-35.87	+4.17	-31.70	-35.87	+5.57	-30.30
Nov, 30	-35.58	+2.64	-32.94	-35.58	+4.17	-31.41	-35.58	+5.70	-29.88	-35.58	+5.70	-29.88
Dec, 10	-34.45	+4.60	-29.85	-34.45	+6.34	-28.11	-34.45	+8.09	-26.36	-34.45	+9.84	-26.61
Dec, 20	-34.23	+4.20	-30.03	-34.23	+5.27	-28.95	-34.23	+6.33	-26.80	-34.23	+7.04	-26.19

I = impact A = adaptation V = vulnerability

Table 16: Effect of the interaction between the delay in sowing date and irrigation amounts on wheat yield vulnerability under current temperature and temperature increase by 3.6 ° C.

1.2. Evaluation of the inter and intra-annual variability of wheat yield

Riebsame (1989) stated that the simplest climate impact assessment is to compare yields during climate fluctuations to more normal years. Typically, "normal" yields are defined as an average over several years. In our study, wheat yields were compared through the studied twenty-five years to determine normal and abnormal yields. Results presented in Table 17, showed that there is no significant difference in wheat yield, between years having the same letter. Similarly, there is a significant difference between years having the different letter. Yield variability in high latitudes is usually caused by temperature variations (Riebsame, 1989).

For Egyptian wheat varieties, tilleing occurs about 45 days after planting, booting takes about 35-40 after ward. Anthesis takes about 5-10 days and grain filling period takes about 45-60 days.

Three prediction equations were developed for tilleging, booting and anthesis and equation [1] was used to predict wheat yield from planting to the end of grain filling under normal temperature and with a raise in the temperature as follows.

From planting to tillering: Y`= 18259.2 - 835.2 * Mtemp [9]

From planting to booting: Y`= 109411.2 – 993.6 * Mtemp [10]

From planting to anthesis: Y`= 16578.0 – 817.2 * Mtemp [11]

Mean = 4673 ± 229.1

Wheat yield (kg/ha)	Year
3528.0^{B}	1974/75
3420.0^{AB}	1975/76
3405.6^{AB}	1976/77
3531.6^{AB}	1977/78
3322.8^{B}	1978/79
3398.4^{AB}	1979/80
3567.6^{AB}	1980/81
3772.8^{AB}	1981/82
3880.8^{AB}	1982/83
3913.2^{AB}	1983/84
3963.6^{AB}	1984/85
3945.6^{AB}	1985/86
4032.0^{AB}	1986/87
4748.4^{AB}	1987/88
5004.0^{AB}	1988/89
$5637.\ 6^{AB}$	1989/90
5389.2^{AB}	1990/91
5828.4^{AB}	1991/92
5976.0^{AB}	1992/93
5698.8^{AB}	1993/94
5929.2^{AB}	1994/95
6130.8^{AB}	1995/96
5731.2^{AB}	1996/97
6336.0^{AB}	1997/98
6757.2^{A}	1998/99

Table 17: Inter-annual variability for wheat yield from 1975-1999.

Results in Table 18 and Fig 13, showed that booting is the most sensitive stage to heat stress, where reduction in yield was 23.74 and 56.99 % when temperature increased by + 1.5° C and + 3.6° C, respectively.

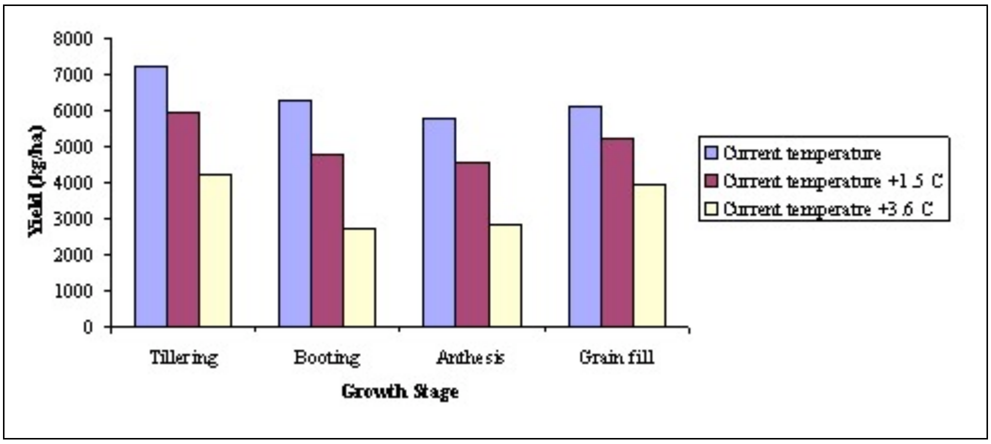


Fig.13: Intra-annual variation in wheat yield under current temperature, and with a rise in temperature

Stage	Predicted yield under current temperature (kg/ha)	Predicted yield under current temperature + 1.5° C (kg/ha)			Predicted yield under current temperature + 3.6° C (kg/ha)		
		Yield	Yield$_{current}$ minus Yield$_{+1.5\,^{\circ}C}$	Impact	Yield	Yield$_{current}$ minus Yield$_{+3.6\,^{\circ}C}$	Impact
Tillering	7217.9	5965.1	-1252.8	-17.35	4211.1	-3006.8	-41.65
Booting	6275.8	4785.4	-1490.4	-23.74	2698.8	-3577.0	-56.99
Anthesis	5774.6	4548.8	-1225.8	-21.22	2832.7	-2941.9	-50.94
Grain Filling	6129.8	5215.5	-914.3	-14.91	3930.8	-2199.0	-35.87

Table 18: Intra-annual variation in wheat yield under current temperature and with temperature increase.

2. Wheat Yield prediction at Marsa Matrouh:

Different prediction equations were developed to assess the impact of temperature increase and change in rain fall (decrease or increase) on wheat yield as followed:

$y` = 2703.24 - 127.67 * Mtemp$ [12]

$y` = -2303.21 + 17.93 * Rain$ [13]

$y` = 679.54 - 79.43 * Mtemp + 7.55 * Rain$ [14]

Mean = 747.93 ± 208.94

2.1. Effect of temperature

Equation [12] was used to predict wheat yield under current temperature, current temperature +1.5° C current temperature +3.6° C (Table 19 and Figure 14). Under a raise in temperature by +1.5 °C, wheat yield was decreased by 25.62 %, whereas it was decreased by 61.5 % when temperature was increased by 3.6 ° C.

Temperature	Predicted yield (kg/ha)	Impact (%)
Current temperature	747.34	0
Current temperature + 1.5° C	555.83	-25.62
Current temperature + 3.6° C	287.72	-61.50

Table 19: Predicted wheat yield under current temperature, and with temperature increase for Marsa Matrouh region.

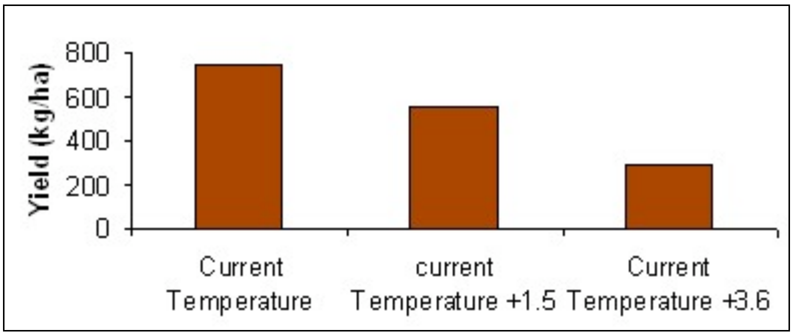


Fig.14: Predicted wheat yield under current temperature, and with temperature increase

<u>*2.2. Effect of rain fall*</u>

Equation [13] was used to predict wheat yield under rain fed conditions, with increase in rain fall and with decrease in rain fall. Under the condition of increase or decrease in the rain fall by either 10 or 20 %, wheat yield was changed by +/- 40.82 and +/- 81.62%, respectively (Table 20, Figure 15 & 16).

Rain fed	Predicted yield (kg/ha)	Impact (%)
Current rain fed	747.58	0
Current rain fed -10%	442.41	-40.82
Current rain fed -20%	137.42	-81.62
Current rain fed +10%	1052.75	+40.82
Current rain fed +20%	1357.74	+81.62

Table 20: Predicted wheat yield under current rain fed, and with rain fed change.

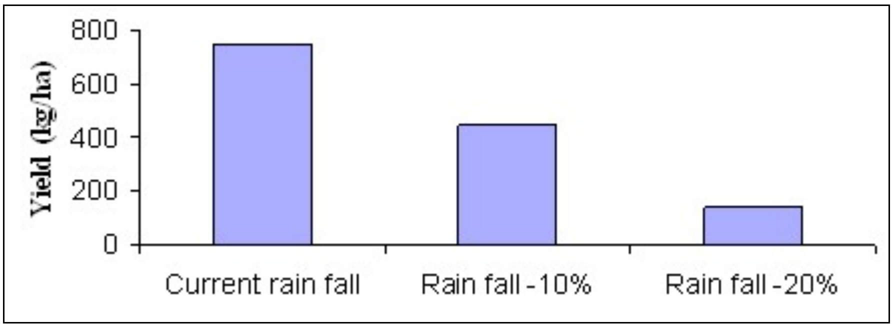


Fig.15: Predicted wheat yield under current rain fall and with rain fall decrease by 10 or 20%

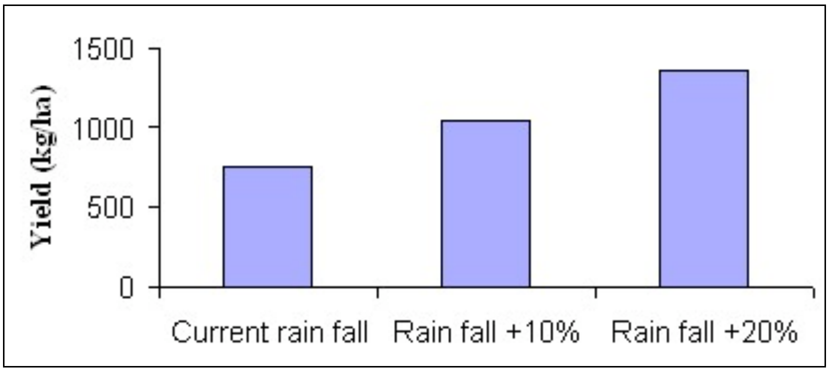


Fig. 16: Predicted wheat yield under current rain fall and with rain fall increase by10 or 20%

<u>*2.3. Interaction between temperature and rain fall*</u>

Equation [14] was used to predict wheat yield as a function of both temperature and rain fall and under climate change conditions. Results in Table (21, Figure 17 & 18) revealed that under the condition of a raise in temperature by 1.5° C, either increase in the rain fall by 10 or 20 %, not only overcome the harm effect of high temperature, but also increase wheat yield by 1.23, 18.41%, respectively.

Current temperature and rain fall	Predicted yield (kg/ha)	Impact (%)
Current temperature and rain fed	747.30	0
Current temperature +1.5° C and rain fed -10%	499.81	-33.11
Current temperature +1.5° C and rain fed -20%	371.46	-50.29
Current temperature +1.5° C and rain fed +10%	756.51	+1.23
Current temperature +1.5° C and rain fed +20%	884.86	+18.41

Table 21: Predicted wheat yield under current temperature +1.5 ° C and rain fall change

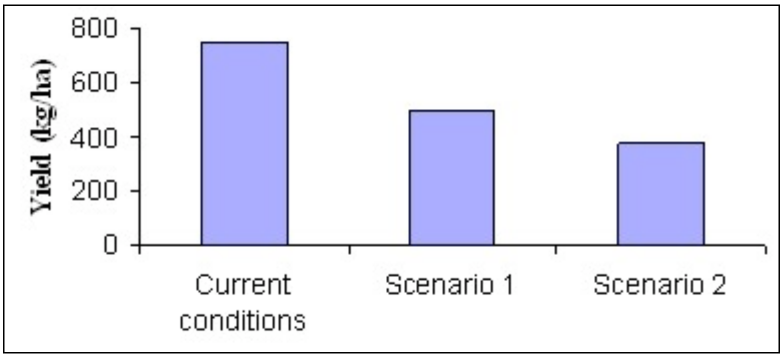


Fig. 17: Predicted wheat yield under temperature +15° C and rain fall decrease

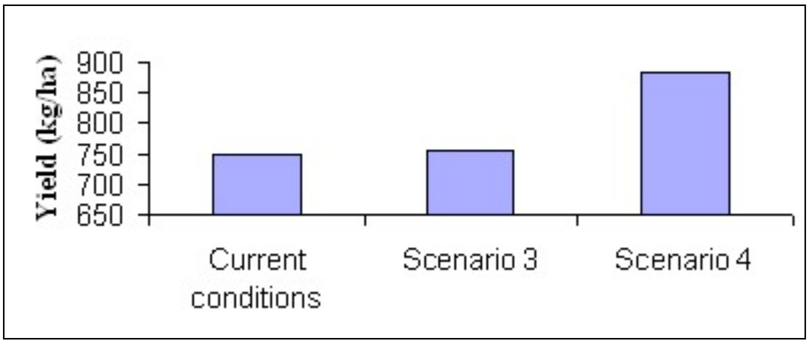


Fig. 18: Predicted wheat yield under temperature +15° C and rain fall increase.

On the contrary, under the condition of a raise in temperature by 3.6° C and rain fall decrease or increase by either 10 or 20 %, wheat yield was decreased (Table 22, Figure 19 & 20).

Current temperature and rain fed	Predicted yield (kg/ha)	Impact (%)
Current temperature and rain fed	747.30	0
Current temperature +3.6° C and rain fed -10%	333.01	-55.44
Current temperature +3.6° C and rain fed -20%	204.66	-72.61
Current temperature +3.6° C and rain fed +10%	589.71	-21.09
Current temperature +3.6° C and rain fed +20%	718.06	-3.91

Table 22: Predicted wheat yield under current temperature +3.6 °C and rain fall change

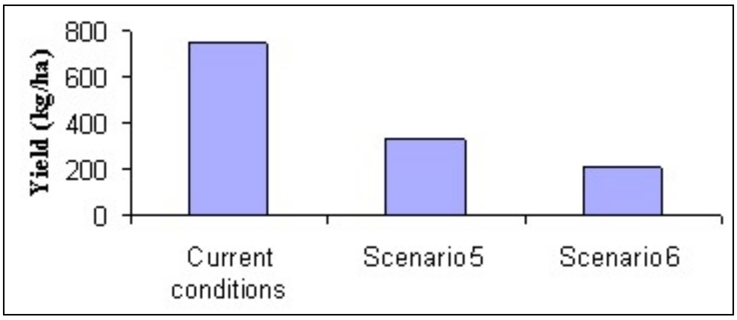


Fig. 19: Predicted wheat yield under temperature +3.6° C and rain fall decrease

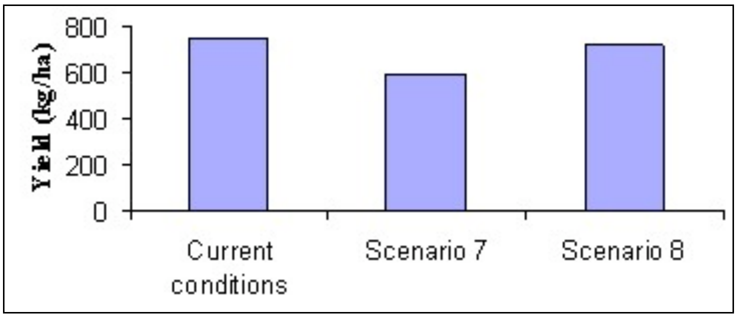


Fig. 20: Predicted wheat yield under temperature +3.6° C and rain fall increase

2.4. Using regression models to evaluate the effect of adaptation strategies

A supplementary irrigation of 60, 130, 230 and 330 mm/season was added to the total rain fall (170 mm/season), then used to predict wheat yield using equation [13] and equation [14]. The addition of supplementary irrigation to wheat plants substantially increased yield. Predicting wheat yield using equation [13] (under current rain fed conditions) resulted in an increase in yield by 791.11 % when 500 mm/season was used (Table 23). The value of that predicted wheat yield is close to what is usually obtained when wheat was planted under irrigation conditions.

Similarly, predicted wheat yield using equation [14] with both temperature and rain fall in addition to supplementary irrigation resulted in an increase in yield by 434.27 % when 500 mm/season was used (Table 23). Figure (21) showed predicted yield using equation [13], whereas Figure (22) showed predicted yield using equation [14].

Irrigation amounts	Predicted yield under current rain fall		Predicted yield under current temperature and rain fall	
	Yield (kg/ha)	Impact %	Yield (kg/ha)	Impact %
Rain fed and/or temperature	747.58	0	747.30	0
Rain fed + 60=230 mm/season	1823.41	+143.54	1200.31	+131.18
Rain fed +130=300 mm/season	3075.79	+311.43	1727.67	+232.21
Rain fed + 230=400 mm/season	4868.79	+551.27	2483.08	+333.24
Rain fed + 330=500 mm/season	6661.79	+791.11	3237.97	+434.27

Table 23: Predicted wheat yield using different supplementary irrigation under current temperature and rain fall.

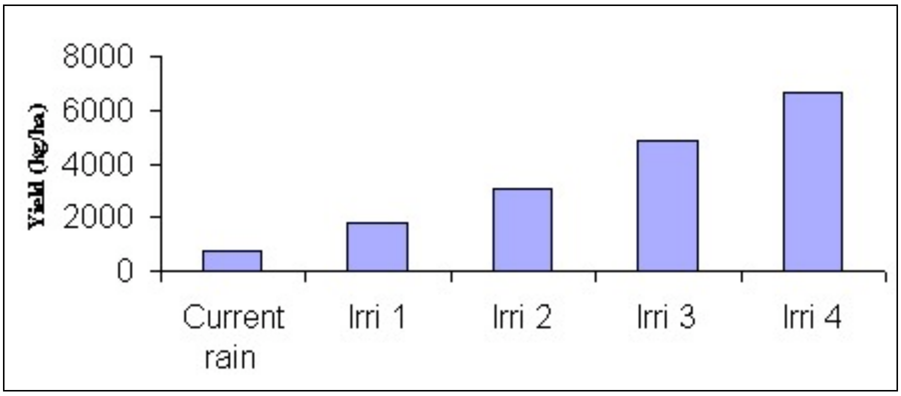


Fig. 21: Predicted wheat yield under different irrigation treatments with rain fall is the only predictor

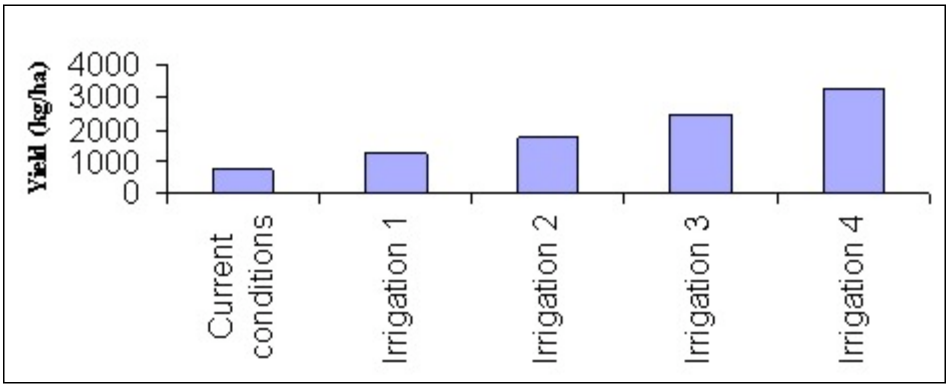


Fig. 22: Predicted wheat yield under different irrigation treatments with both temperature and rain fall included

Furthermore, equation [14] was used to predict the effect of climate change i.e. temperature increase and change in rain fall on wheat yield, when different irrigation amounts were added. Results in Table (24) and Figure 23, 24, 25 and 26, showed that under the condition of temperature increase, rain fall decrease and the addition of irrigation water, large reductions in yield were observed (Table 23 versus Table 24). However, the predicted wheat yield under supplementary irrigations and a raise in temperature still higher than the obtained yield under rain fed only.

Irrigation amounts	Predicted wheat yield (kg/ha)			
	Mtemp +1.5°C -10% rain	Mtemp +1.5°C -20% rain	Mtemp +3.6°C -10% rain	Mtemp +3.6° C -20% rain
Current rain fall	499.81	371.46	333.01	204.66
Rain fall+ 60 =230 mm/season	952.80	824.45	786.00	657.65
Rain fall +130=300 mm/season	1481.31	1352.96	1314.50	1186.15
Rain fall + 230=400 mm/season	2236.31	2107.96	2069.50	1941.15
Rain fall + 330=500 mm/season	2991.31	2862.96	2824.50	2696.15

Table 24: Predicted wheat yield under different irrigation treatments with temperature increase and rain fall decrease

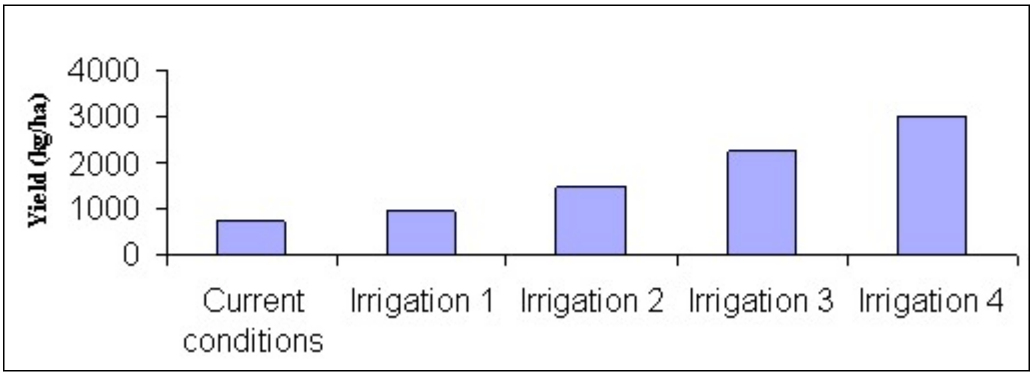


Fig. 23: Predicted wheat yield under a rise in temperature by +1.5° C and decrease in rain fall by 10%

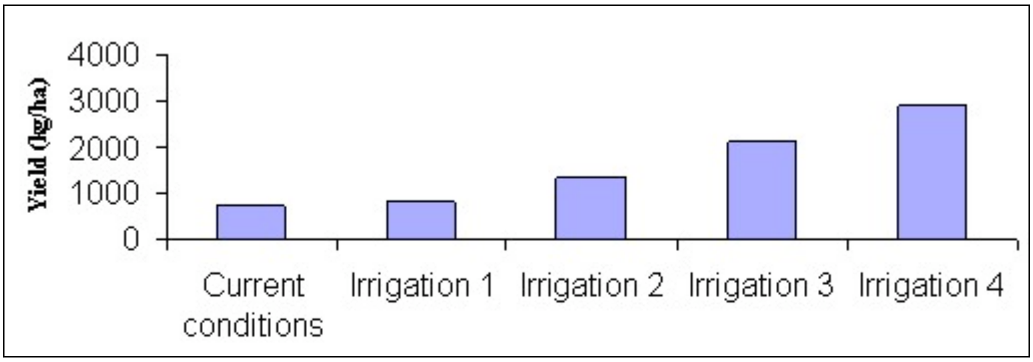


Fig. 24: Predicted wheat yield under a rise in temperature by +1.5° C and decrease in rain fall by 20%

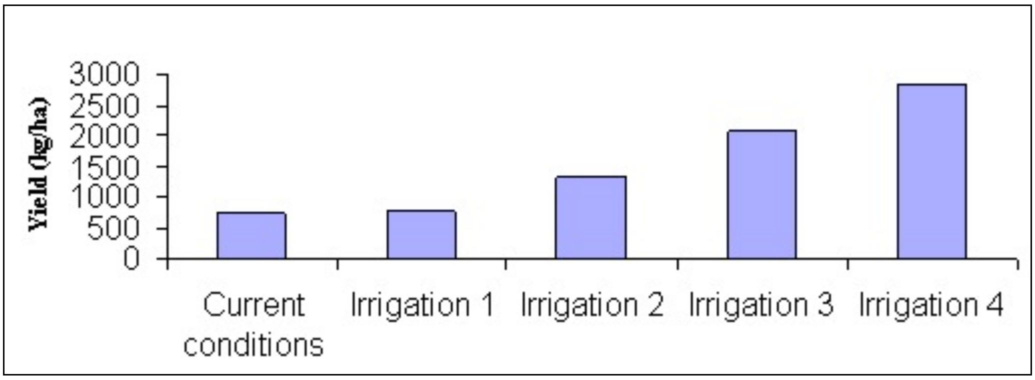


Fig. 25: Predicted wheat yield under a rise in temperature by +3.6° C and decrease in rain fall by 10%

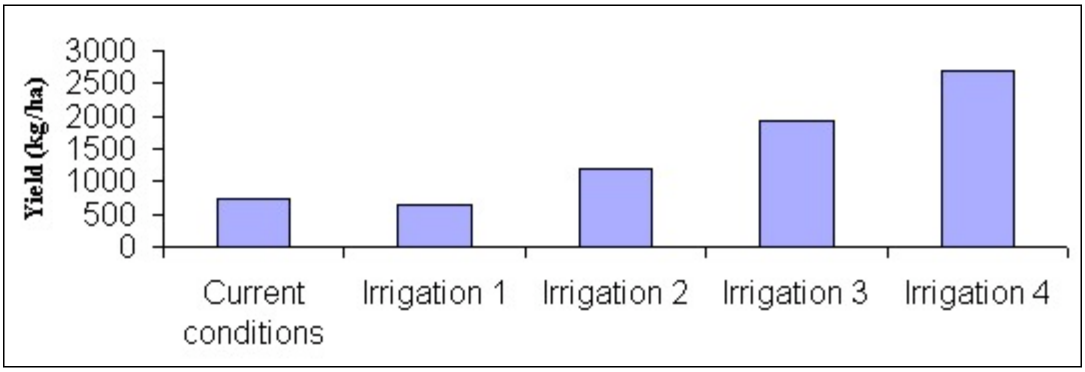


Fig. 26: Predicted wheat yield under a rise in temperature by +3.6° C and decrease in rain fall by 20%

Furthermore, results in Table (25) and Figure 27, 28, 29 and 30, showed that under the condition of temperature increase by 1.5° C, rain fall increase by 10 or 20% and the addition of irrigation water, wheat yield increased (Table 25 versus Table 24). However, when temperature was increased by 3.6° C and rain fall was increased by 10 or 20 %, the addition of irrigation water did not overcome the harm effect of high temperature and wheat yield decreased.

Irrigation amounts	Predicted wheat yield (kg/ha)			
	Mtemp+1.5°C +10% rain	Mtemp+1.5°C +20% rain	Mtemp+3.6°C +10% rain	Mtemp+3.6° C +20% rain
Current rain fall	756.51	884.84	589.71	718.06
Rain fall+ 60 =230 mm/season	1209.51	1337.86	1042.70	1171.05
Rain fall +130=300 mm/season	1738.01	1866.36	1571.20	1699.55
Rain fall + 230=400 mm/season	2493.01	2621.36	2326.20	2454.55
Rain fall + 330=500 mm/season	3248.01	3376.36	3081.20	3209.55

Table 25: Predicted wheat yield under different irrigation treatments with temperature increase and rain fall increase

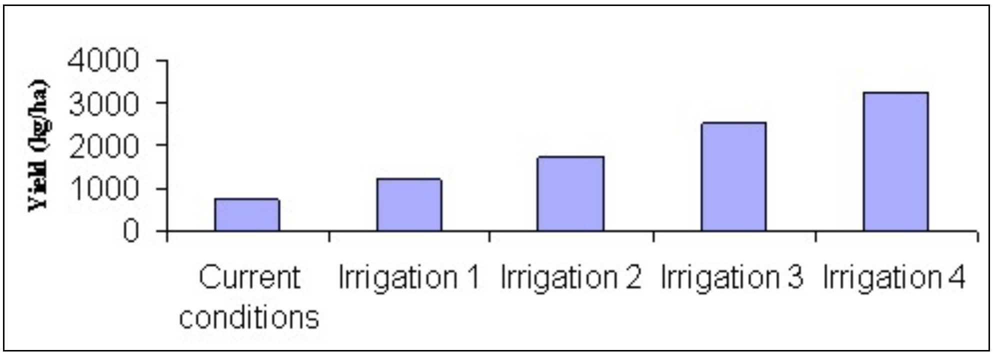


Fig. 27: Predicted wheat yield under a rise in temperature by +1.5° C and increase in rain fall by 10%

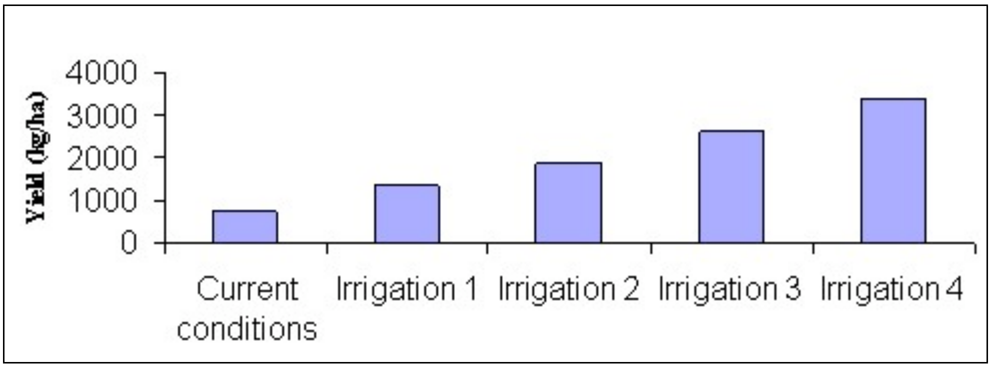


Fig. 28: Predicted wheat yield under a rise in temperature by +1.5° C and increase in rain fall by 20%

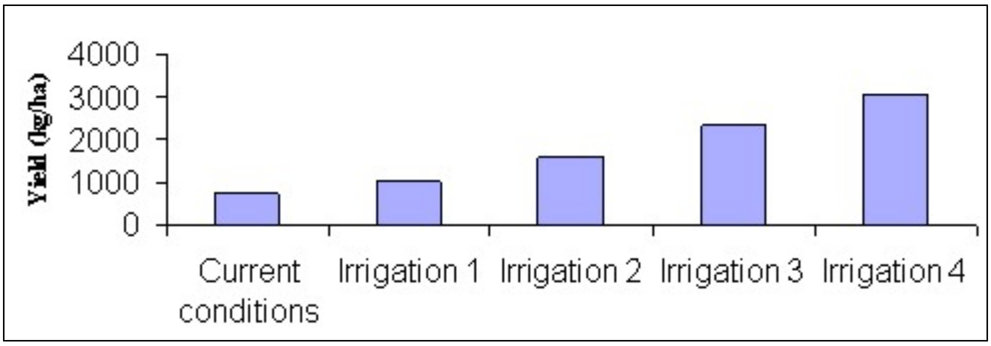


Fig. 29: Predicted wheat yield under a rise in temperature by +3.6° C and increase in rain fall by 10%

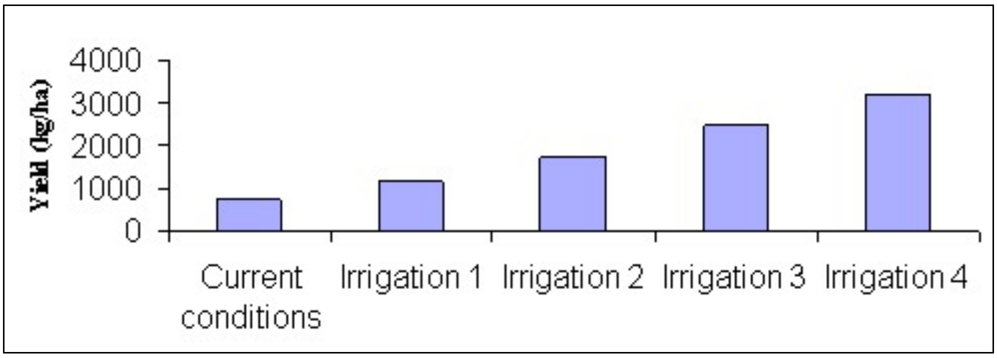


Fig. 30: Predicted wheat yield under a rise in temperature by +3.6° C and increase in rain fall by 20%

Results in Table (26 & 27) indicated that under the condition of temperature increase (+1.5 or +3.6° C) and rain fall decrease (10 or 20 %), increasing irrigation amounts reduced vulnerability of wheat yield. This is an indication of the important role of irrigation as a relief factor for heat stress.

Irrigation amounts	Temperature + 1.5° C and rain -10%			Temperature + 1.5° C and rain -20%		
	Impact	Adaptation	Vulnerability	Impact	Adaptation	Vulnerability
Rain fed+60=230 mm/season	-20.61	0	-20.61	-31.31	0	-31.31
Rain fed+130=300 mm/season	-20.61	+6.30	-14.31	-31.31	+9.57	-21.74
Rain fed+230=400 mm/season	-20.61	+10.65	-9.96	-31.31	+16.18	-15.13
Rain fed+330=300 mm/season	-20.61	+12.97	-7.64	-31.31	+19.71	-11.60

Table 26: Effect of irrigation amounts on wheat yield vulnerability to increased temperature and rain fall decrease.

Irrigation amounts	Temperature + 3.6° C and rain -10%			Temperature + 3.6° C and rain -20%		
	Impact	Adaptation	Vulnerability	Impact	Adaptation	Vulnerability
Rain fed+60mm/season	-34.51	0	-34.51	-45.20	0	-45.20
Rain fed+130mm/season	-34.51	+10.55	-23.96	-45.20	+13.82	-31.38
Rain fed+230mm/season	-34.51	+17.83	-16.67	-45.20	+23.36	-21.84
Rain fed+330mm/season	-34.51	+21.72	-12.79	-45.20	+28.45	-16.75

Table 27: Effect of irrigation amounts on wheat yield vulnerability to increased temperature and rain fall decrease.

Results in Table (28) indicated that under the condition of temperature increase by 3.6° C and rain fall increase (10 or 20 %), increasing irrigation amounts reduced vulnerability of wheat yield by 8.26 and 1.53 %, respectively.

Irrigation amounts	Temperature + 3.6° C and rain +10%			Temperature + 3.6° C and rain +20%		
	Impact	Adaptation	Vulnerability	Impact	Adaptation	Vulnerability
Rain fed+60mm/season	-13.12	0	-13.12	-2.43	0	-2.43
Rain fed+130mm/season	-13.12	+4.01	-9.11	-2.43	+0.74	-1.69
Rain fed+230mm/season	-13.12	+6.78	-6.34	-2.43	+1.25	-1.17
Rain fed+330mm/season	-13.12	+8.26	-4.86	-2.43	+1.53	-0.90

Table 28: Effect of irrigation amounts on wheat yield vulnerability to increased temperature and rain fall

2.5. Evaluation of the intra-annual variability of wheat yield grown under rainfed

Three prediction equations were developed to predict wheat yield under climate change conditions for three growth stages (from planting to tillering, from planting to booting, and from planting to anthesis) and equation [14] was used for growth stage from planting to the end of grain filling as follows.

From planting to end of tillering: $Y` = 2334.42 - 117.94 * Mtemp + 5.08 * Rain$ [15]

From planting to end of booting: $Y` = 2141.53 - 93.7 * Mtemp + 1.65 * Rain$ [16]

From planting to end of anthesis: $Y` = 2674.1 - 133.62 * Mtemp + 3.8 * Rain$ [17]

Mean = 747.93 ± 208.94

Results in Table (29) indicated that tillering is the most sensitive stage to temperature increase by 1.5°C and rain fall decrease by 10 %, where the impact was the highest (-33.54 %). However, under temperature increase by 1.5°C and rain fall decrease by 20 %, the whole growing season was sensitive to climate change.

Stage	Predicted wheat yield (kg/ha)				
	Under current temperature and rain fall	Under current temperature + 1.5° C and current rain fall -10 %		Under current temperature + 1.5° C and current rain - 20 %	
		Yield	Impact %	Yield	Impact %
Tillering	627.68	417.14	-33.54	383.51	-38.90
Booting	748.02	591.84	-20.87	576.28	-22.95
Anthesis	794.90	558.4	-29.75	522.3	-34.29
Grain Filling	747.30	499.80	-33.11	371.45	-50.29

Table 29: Intra-annual variation in wheat yield predicted under current temperature and with temperature increase by 1.5 ° C and rain fall decrease.

Stage	Predicted wheat yield (kg/ha)				
	Under current temperature and rain fall	Under current temperature + 1.5° C and current rain fall +10 %		Under current temperature + 1.5°C and current rain +20 %	
		Yield	Impact %	Yield	Impact %
Tillering	627.68	512.71	-18.31	518.03	-17.46
Booting	748.02	623.09	-16.70	638.65	-14.62
Anthesis	794.90	657.32	-17.30	666.70	-16.12
Grain Filling	747.30	756.51	+1.23	884.86	+18.41

Table 30: Intra-annual variation in wheat yield predicted under current temperature and with temperature increase by 1.5 ° C and rain fall increase.

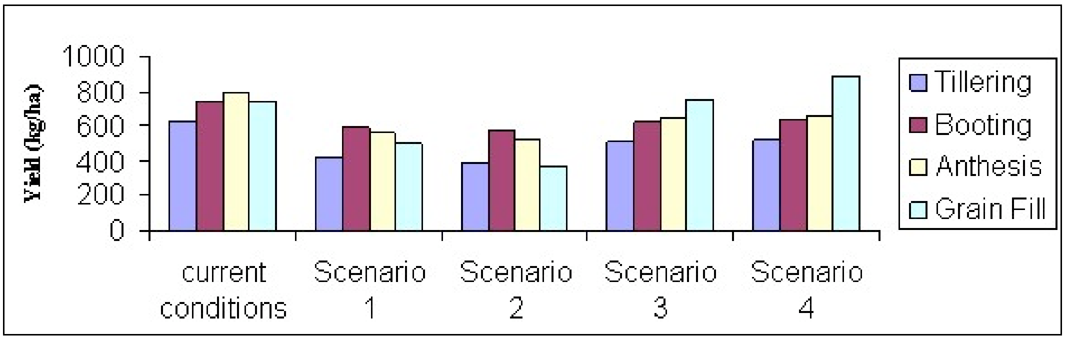


Fig. 31: Predicted wheat yield under a rise in temperature by +1.5° C and change in rain fall at four growth stages

Under temperature increase by 1.5° C and rain fall increase by 10 or 20 %, tillering was also the most sensitive stage to climate change (impact were -18.31 and -17.46 %, respectively; Table 30).

Scenario 1 = 1.5 ° C increase in temperature and 10% decrease in rain fall

Scenario 2 = 1.5 ° C increase in temperature and 20% decrease in rain fall

Scenario 3 = 1.5 ° C increase in temperature and 10% increase in rain fall

Scenario 4 = 1.5 ° C increase in temperature and 20% increase in rain fall

Results in both Table (31) and (32) revealed that tillering was also the most sensitive stage under temperature increase by 3.6 ° C and rain fall decrease or increase.

Stage	Predicted wheat yield (kg/ha)				
	Under current temperature and rain fall	Under current temperature + 3.6° C and current rain fall -10 %		Under current temperature + 3.6° C and current rain - 20 %	
		Yield	Impact %	Yield	Impact %
Tillering	627.68	169.47	-73.00	135.84	-78.35
Booting	748.02	395.07	-47.18	379.50	-49.26
Anthesis	794.90	277.84	-65.04	241.74	-69.58
Grain Filling	747.30	333.00	-55.43	204.65	-72.61

Table 31: Intra-annual variation in wheat yield prediction under current conditions and with temperature increase by 3.6 ° C and rain fall decrease.

Stage	Predicted wheat yield (kg/ha)				
	Under current temperature and rain fall	Under current temperature + 3.6° C and current rain fall +10 %		Under current temperature + 3.6° C and current rain + 20 %	
		Yield	Impact %	Yield	Impact %
Tillering	627.68	236.73	-62.28	270.3	-56.92
Booting	748.02	426.32	-43.00	441.88	-40.92
Anthesis	794.90	350.04	-55.96	386.14	-51.42
Grain Filling	747.30	589.70	-21.08	718.05	-3.91

Table 32: Intra-annual variation in wheat yield prediction under current conditions and with temperature increase by 1.5 ° C and rain fall increase.

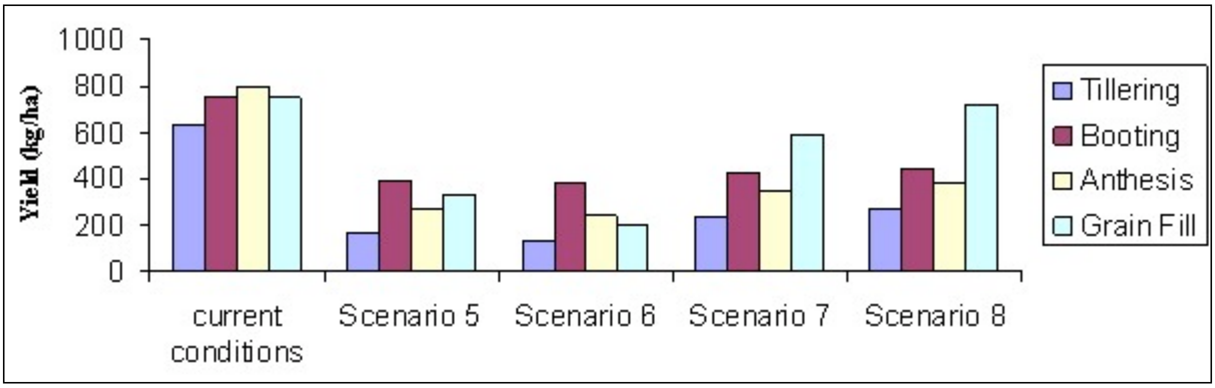


Fig. 32: Predicted wheat yield under a rise in temperature by +3.6° C and change in rain fall at four growth stages

Scenario 5 = 3.6° C increase in temperature and 10% decrease in rain fall.

Scenario 6 = 3.6° C increase in temperature and 20% decrease in rain fall.

Scenario 7 = 3.6° C increase in temperature and 10% increase in rain fall.

Scenario 8 = 3.6° C increase in temperature and 20% increase in rain fall.

3. Tomatoes yield prediction at Kafer Elsheikh

Tomatoes yield was predicted using equation [18] as followed:

$Y` = 72.95 - 2.28 * Mtemp$ [18]

Different adaptation techniques, such as delay sowing, altering irrigation amounts, and increasing nitrogen rate were tested and used to reduce vulnerability. Three sowing dates (July, 1; July, 15; and August, 1), and/or four irrigation amounts (400, 500, 600, and 700 mm/season) were included in the prediction and new prediction equations were developed. Afterward, three nitrogen rates (170, 200, 230 kg/ha) were included in the prediction and new prediction equations were developed. The percent of yield quantity improvement as a result of these adaptation techniques was then determined. Results in Table 33, showed that a raise in temperature by 1.5° C could reduce yield by 15.68 %, whereas a raise in temperature by 3.6° C could reduce yield by 37.63 %.

Temperature	Predicted yield	Impact %
Current temperature	21.80	0
Current temperature +1.5° C	18.38	- 15.68
Current temperature +3.5° C	13.60	- 37.63

Table 33: Predicted tomatoes yield under current temperature, and with temperature increase

3.1. Using regression models to evaluate the effect of adaptation strategies

3.1.1. Effect of sowing date

Prediction equations that include different sowing dates could be stated as follows:

- Sowing at July, 15: $Y` = 71.90 - 2.23*Mtemp$ [19]
- Sowing at August, 1: $Y` = 58.90 - 1.70*Mtemp$ [20]

Tomatoes yield was predicted using equations [1], [2], and [3], where the differences in yield, as a result of a raise in temperature were found to be decreasing when sowing was delayed (Table 34 & Figure 33).

Sowing Date	Predicted yield under current temperature (ton/ha)	Predicted yield under current temperature + 1.5° C (ton/ha)		Predicted yield under current temperature + 3.6° C (ton/ha)	
		Yield	Yield $_{current}$ minus Yield $_{+1.5^{\circ} C}$	Yield	Yield $_{current}$ minus Yield $_{+3.6^{\circ} C}$
July, 1	21.80	18.38	-3.42	13.60	-8.20
July, 15	21.08	18.02	-3.05	13.05	-8.03
Aug, 1	20.76	17.82	-2.94	14.02	-6.74

Table 34: Predicted tomatoes yield using different sowing dates under current temperature, and with a raise in temperature

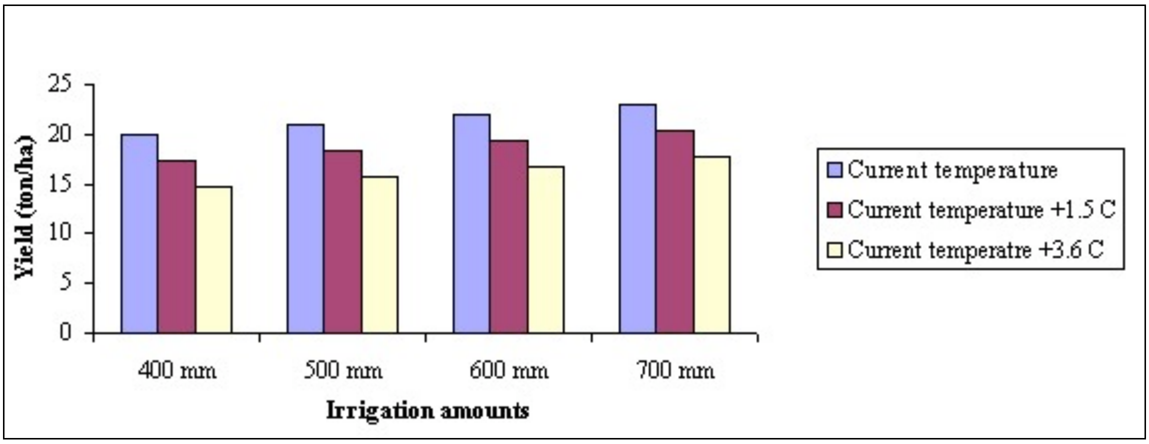


Fig. 33: Predicted tomatoes yield under using different irrigation amounts under current temperature, and with a raise in temperature

Results in Table 35, showed that sowing tomatoes at August 1, reduced vulnerability by 1.48 % and 5.18 % under a raise in temperature by 1.5° C and 3.6° C, respectively.

Sowing dates	Current temperature + 1.5° C			Current temperature + 3.6° C		
	Impact %	Adaptation %	Vulnerability %	Impact %	Adaptation %	Vulnerability %
July, 1	-15.68	0	15.68	-37.63	0	37.63
July, 15	-14.49	+1.18	13.31	-34.28	+3.35	30.93
August, 1	-14.19	+1.48	12.71	-32.45	+5.18	27.27

Table 35: Effect of delay sowing on tomatoes yield and vulnerability to high temperature

3.1.2. <u>*Effect of irrigation amounts*</u>

Prediction equations that include different irrigation amounts (Irr) could be stated as follows:

$$Y` = 47.87 - 1.42*Mtemp + 0.01*Irri \qquad [21]$$

Tomatoes yield was predicted using equation [21]. Results in Table 36 and Figure 34, showed that increasing irrigation amount could sever as a relief factor to overcome heat stress. Irrigation with 700 mm/season reduced tomatoes yield vulnerability by 4.09 % and 14.56 % when a raise in temperature by 1.5° C and 3.6° C occurred, respectively.

Irrigation amounts	Current temperature + 1.5° C			Current temperature + 3.6° C		
	Impact	Adaptation	Vulnerability	Impact	Adaptation	Vulnerability
400 mm/season	-15.68	+2.34	13.33	-37.63	+11.10	26.63
500 mm/season	-15.68	+2.98	12.70	-37.63	+12.36	25.27
600 mm/season	-15.68	+3.56	12.12	-37.63	+13.51	24.12
700 mm/season	-15.68	+4.09	11.59	-37.63	+14.56	23.07

Table 36: Effect of irrigation amounts on tomatoes yield and vulnerability to high temperature

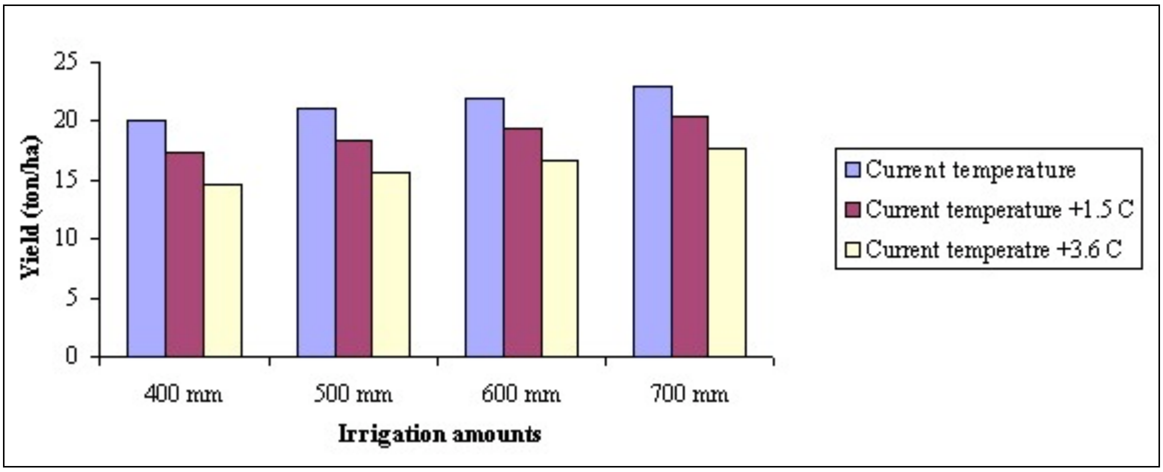


Fig. 34: Predicted tomatoes yield under using different irrigation amounts under current temperature, and with a raise in temperature

3.1.3. Interaction between sowing dates and irrigation amounts

Delay sowing and increasing irrigation amounts were considered in the predication and new prediction equations could be stated as follows.

- Sowing at July, 15 with irrigation amounts included

$$Y` = 24.21 - 0.59 * Mtemp + 0.02 * Irri \quad [22]$$

- Sowing at August, 1 with irrigation amounts included

$$Y` = 25.06 - 0.58 * Mtemp + 0.01 * Irri \quad [23]$$

Results in Table 37 and Figure 35, showed that under the condition of temperature increased by +1.5° C, sowing tomatoes at August,1 reduced yield vulnerability by 7.6 %, 8.1 %, 8.5 %, 8.8 %, when the four irrigation amounts were used, respectively.

Treatments	400 mm/season			500 mm/season			600 mm/season			700 mm/season		
	I %	A %	V%	I%	A%	V%	I%	A%	V%	I%	A%	V%
SD1	-15.6	+2.3	13.3	-15.6	+2.9	12.7	-15.6	+3.5	12.1	-15.6	+4.1	11.5
SD2	-14.4	+6.7	7.7	-14.4	+7.4	7.0	-14.4	+8.1	6.3	-14.4	+8.5	5.9
SD3	-14.1	+7.6	6.5	-14.1	+8.1	6.0	-14.1	+8.5	5.6	-14.1	+8.8	5.3

SD = Sowing dates I = impact A = adaptation V = vulnerability

Table 37: Effect of the interaction between delay sowing and increasing irrigation amounts under current temperature + 1.5 ° C on yield vulnerability

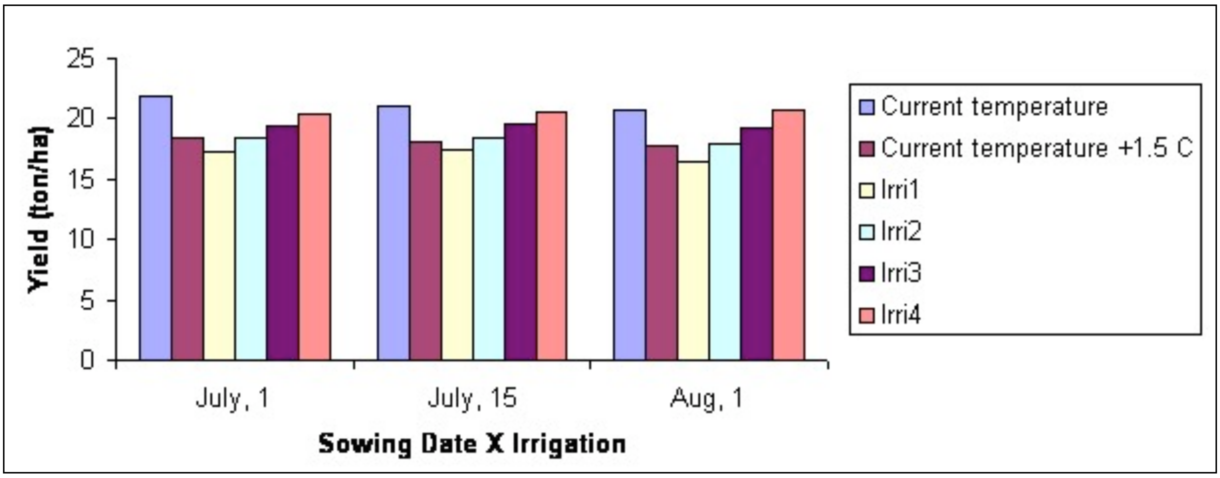


Fig. 35: Predicted tomatoes yield under current temperature, current temperature +1.5° C and different adaptation techniques

Furthermore, results in Table 38 and Fig 36, showed that under the condition of temperature increased by +3.6° C, sowing tomatoes at August 1 reduced yield vulnerability by 24.6 %, 25.2 %, 25.7 %, 26.1 %, when the four irrigation amounts were used, respectively.

Treatments	400 mm/season			500 mm/season			600 mm/season			700 mm/season		
	I	A	V	I	A	V	I	A	V	I	A	V
SD1	-37.6	+11.1	26.5	-37.6	+12.3	25.3	-37.6	+13.5	24.1	-37.6	+14.5	23.1
SD2	-34.2	+19.9	14.3	-34.2	+21.3	12.9	-34.2	+22.4	11.8	-34.2	+23.4	10.8
SD3	-32.4	+24.6	7.8	-32.4	+25.2	7.2	-32.4	+25.7	6.7	-32.4	+26.1	6.3

SD= Sowing dates I = impact A = adaptation V = vulnerability

Table 38: Effect of the interaction between delay sowing and increasing irrigation amounts under current temperature + 3.6 ° C on yield vulnerability

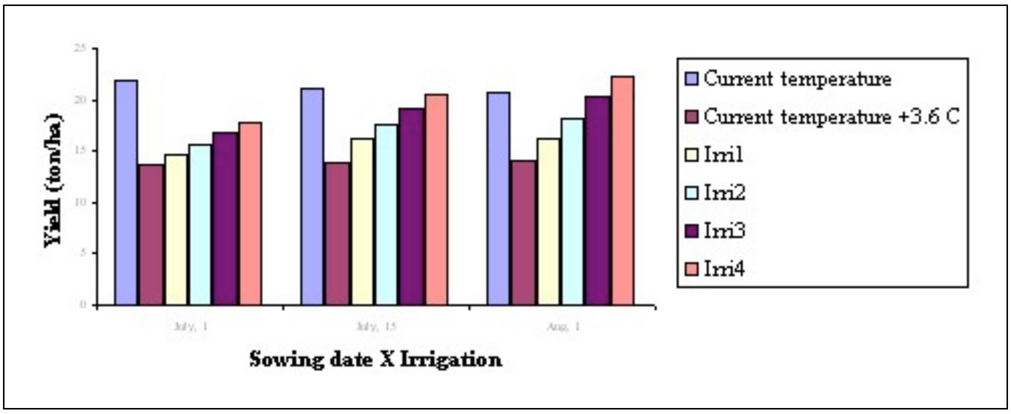


Fig. 36: Predicted tomatoes yield under current temperature, current temperature +3.6° C, and different adaptation techniques

3.1.4. <u>*Interaction between sowing dates, irrigation amounts and nitrogen amounts:*</u>

Delay sowing, increasing irrigation amounts, and increasing amount of nitrogen fertilizer were considered in the predication and the new prediction equations could be stated as follows.

- Sowing at July, 1 with irrigation amounts and nitrogen fertilizer included

Y` = 39.79 - 1.22 * Mtemp + 0.04 * Irri + 0.02 * N [24]

- Sowing at July, 15 with irrigation amounts and nitrogen fertilizer included

Y` = 28.65 - 0.64 * Mtemp + 0.01 * Irri + 0.01* N [25]

- Sowing at August, 1 with irrigation amounts and nitrogen fertilizer included

Y` = 25.57 - 0.66 * Mtemp + 0.01 * Irri + 0.01 * N [26]

Results in Table 39, Figure 37, 38, and 39, showed that sowing tomatoes at August, 1, with 700 mm/season and 230 kg N/ha reduced yield vulnerability by 12.55% under the condition of temperature rise by 1.5° C.

Treatments	July, 1			July, 15			August, 1		
	I	A	V	I	A	V	I	A	V
N1Irri1	-15.68	+6.54	9.13	-14.49	+9.69	4.80	-14.19	+12.19	2.00
N1Irri2	-15.68	+7.05	8.62	-14.49	+9.76	4.73	-14.19	+12.30	1.88
N1Irri3	-15.68	+7.52	8.16	-14.49	+9.83	4.66	-14.19	+12.41	1.78
N1Irri4	-15.68	+7.93	7.74	-14.49	+9.91	4.57	-14.19	+12.50	1.69
N2Irri1	-15.68	+6.63	9.04	-14.49	+9.98	4.50	-14.19	+12.23	1.96
N2Irri2	-15.68	+7.13	8.54	-14.49	+10.04	4.44	-14.19	+12.34	1.85
N2Irri3	-15.68	+7.59	8.08	-14.49	+10.12	4.36	-14.19	+12.44	1.75
N2Irri4	-15.68	+8.00	7.68	-14.49	+10.18	4.30	-14.19	+12.52	1.66
N3Irri1	-15.68	+6.72	8.95	-14.49	+10.24	4.24	-14.19	+12.26	1.93
N3Irri2	-15.68	+7.21	8.46	-14.49	+10.31	4.17	-14.19	+12.37	1.82
N3Irri3	-15.68	+7.66	8.01	-14.49	+10.37	4.12	-14.19	+12.46	1.73
N3Irri4	-15.68	+8.06	7.61	-14.49	+10.42	4.06	-14.19	+12.55	1.64

I = impact A= adaptation V = vulnerability

Table 39: Effect of the interaction between delay sowing, increasing irrigation amounts and increasing nitrogen application under current temperature + 1.5 ° C on tomatoes yield vulnerability

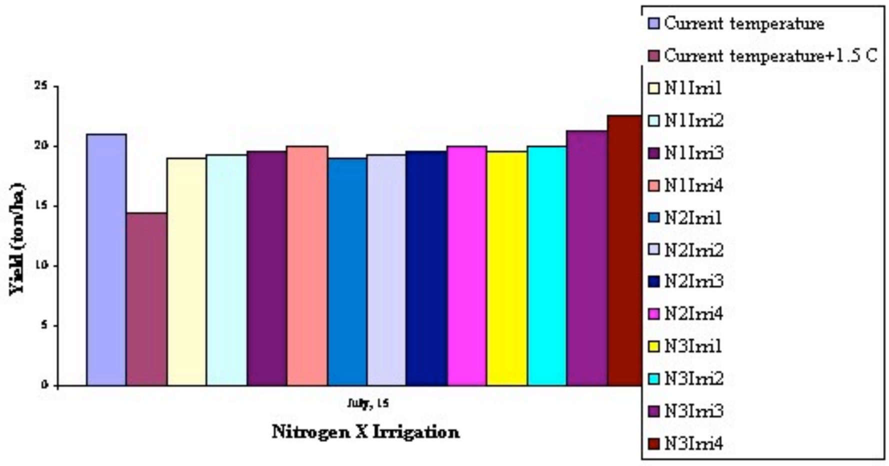


Fig. 37: Predicted tomatoes yield under current temperature, current temperature +1.5° C, and different adaptation techniques

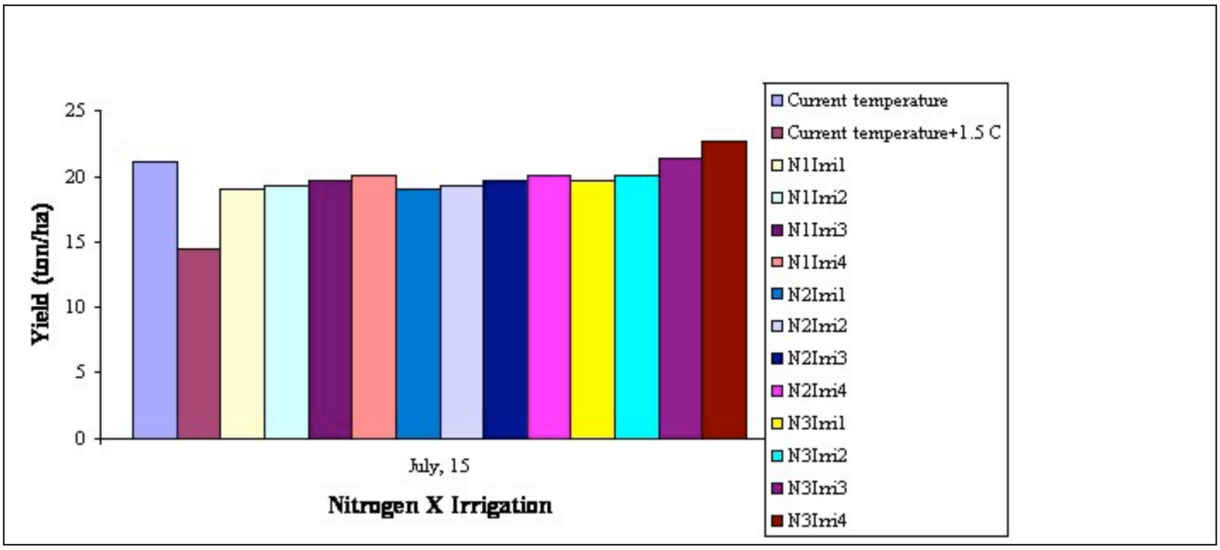


Fig. 38: Predicted tomatoes yield under current temperature, current temperature +1.5° C, and different adaptation techniques

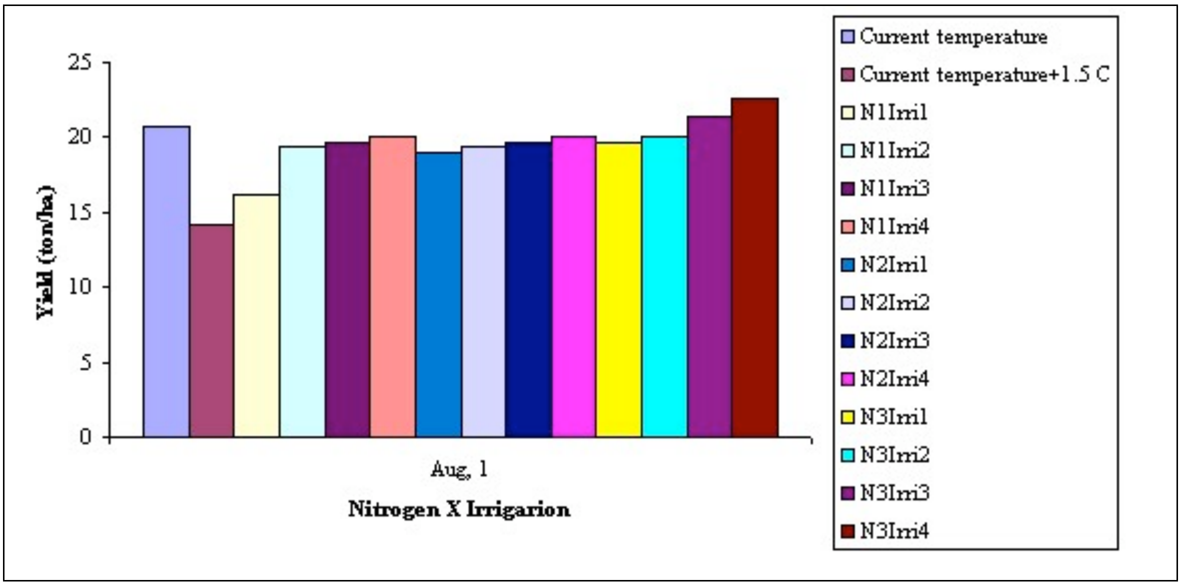


Fig. 39: Predicted tomatoes yield under current temperature, current temperature +1.5° C, and with different adaptation techniques

Results in Table 40, Figure 40, 41, and 42, showed that sowing tomatoes at August, 1, with 700 mm/season and 230 kg N/ha reduced yield vulnerability by 28.88% under the condition of temperature rise by 3.6° C.

Treatments	July, 1			July, 15			August, 1		
	I	A	V	I	A	V	I	A	V
N1Irri1	-37.63	+15.70	21.93	-34.28	+22.76	11.52	-32.45	+28.10	4.34
N1Irri2	-37.63	+16.94	20.69	-34.28	+22.93	11.35	-32.45	+28.35	4.09
N1Irri3	-37.63	+18.04	19.58	-34.28	+23.09	11.18	-32.45	+28.57	3.87
N1Irri4	-37.63	+19.04	18.59	-34.28	+23.31	10.97	-32.45	+28.77	3.67
N2Irri1	-37.63	+15.91	21.71	-34.28	+23.46	10.81	-32.45	+28.18	4.27
N2Irri2	-37.63	+17.13	20.49	-34.28	+23.61	10.66	-32.45	+28.42	4.03
N2Irri3	-37.63	+18.22	19.41	-34.28	+23.81	10.47	-32.45	+28.63	3.81
N2Irri4	-37.63	+19.20	18.43	-34.28	+23.95	10.33	-32.45	+28.82	3.62
N3Irri1	-37.63	+16.13	21.50	-34.28	+24.08	10.19	-32.45	+28.25	4.19
N3Irri2	-37.63	+17.32	20.30	-34.28	+24.26	10.01	-32.45	+28.48	3.96
N3Irri3	-37.63	+18.39	19.24	-34.28	+24.39	9.89	-32.45	+28.69	3.75
N3Irri4	-37.63	+19.35	18.28	-34.28	+24.52	9.76	-32.45	+28.88	3.56

N= nitrogen Irri = irrigation I = impact A = adaptation V = vulnerability

Table 40: Effect of the interaction between delay sowing, increasing irrigation amounts and increasing nitrogen application under current temperature + 3.6 ° C on tomatoes yield vulnerability

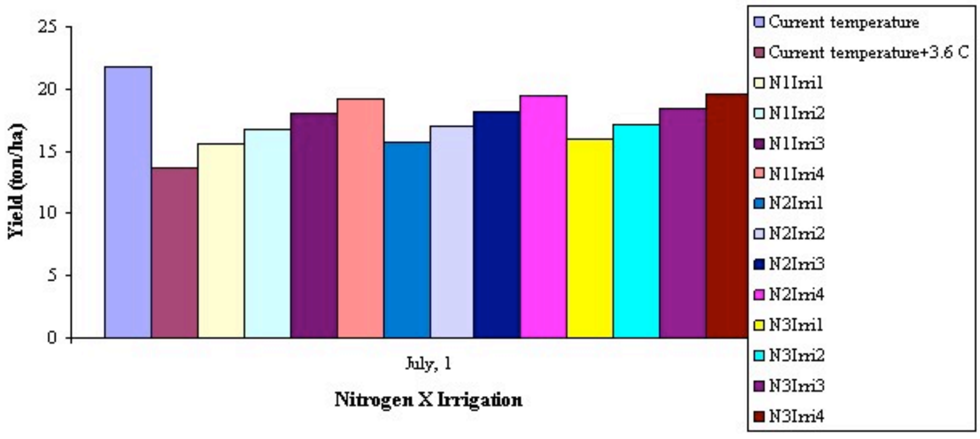


Fig. 40: Predicted tomatoes yield under current temperature, current temperature +3.6° C, and different adaptation techniques

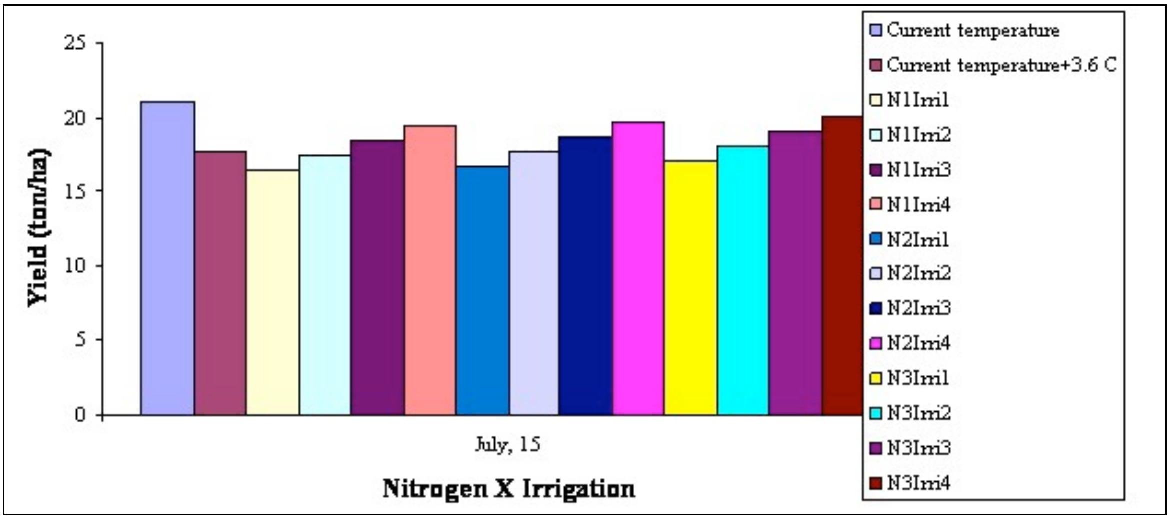


Fig. 41: Predicted tomatoes yield under current temperature and climate change (+3.6° C), under different adaptation techniques

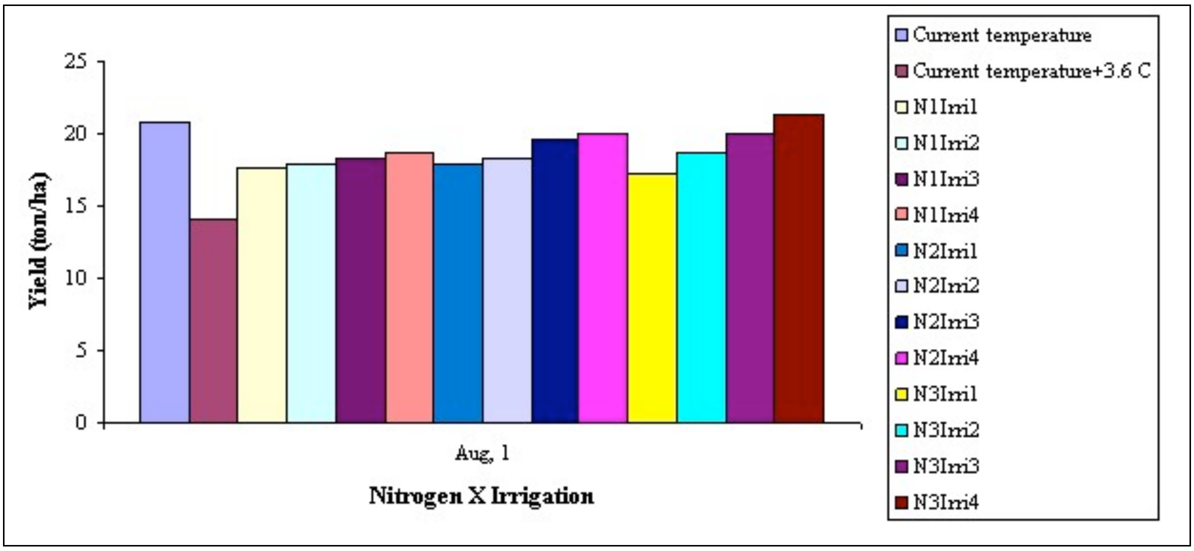


Fig. 42: Predicted tomatoes yield under current temperature and climate change (+3.6° C), under different adaptation techniques

5.2.2 Process-based crop agricultural models and decision support systems

Methodology and data requirements

Crop yields and demand for irrigation water were estimated with CERES-Wheat model for wheat and Tom-Gro for tomatoes included in the DSSAT 3.5 (1998) developed by the International Benchmark Sites Network for Agrotechnology Transfer. Daily maximum and minimum temperatures, precipitation, and solar radiation data were obtained for Sakha from 1975 to 1999. Typical soils at Sakha (clay loam soils) are montmorillonitic, thermic, slightly calcareous, and deep (Abdel-Wahed 1983). The texture, albedo, and water-related specific characteristics of these soils are adequately represented by the generic soil (Medium silt clay) provided for the study.

Wheat and tomatoes are grown using flood irrigation. Data of one experiment at the site (Sakha) were used in the present study (Eid, 1994). For the simulations, the field schedule irrigation option was chosen to provide the crop with water as field schedule; the model includes an option that simulates flooding. Wheat and tomatoes are fertilized in the region in this study, and therefore the simulation considered water and nitrogen balances.

5.2.2.1 Impacts and adaptation on wheat crop at Sakha region:

CERES-Wheat model was validated by comparing observed data on biomass, yield, and maturity date to simulated values (Table 41 and Figs 43& 44). The results of the validation experiment indicated that CERES-Wheat crop model can be used successfully at the selected site in Egypt. The observed data on grain yield and season length were very close to the corresponding simulated values. The observed total biomass was slightly smaller than the simulated one. According to these results, the model was considered validated for the conditions of the study.

Variable	MEASURED	PREDICTED
Flowering Date (dap)	124	122
Physiological Maturity (dap)	165	163
Grain Yield (kg/ ha; dry)	4769	4754
Wt. per Grain (g; dry)	0.03	0.038
Grain Number (grain/ m^2)	12400	12229
Maximum LAI (m^2/ m^2)	5.6	5.02
Biomass (kg/ ha) at Harvest Mat.	14229	16942

Table 41: Calibration and validation test for wheat (Sakha-8 CV) at Sakha region.

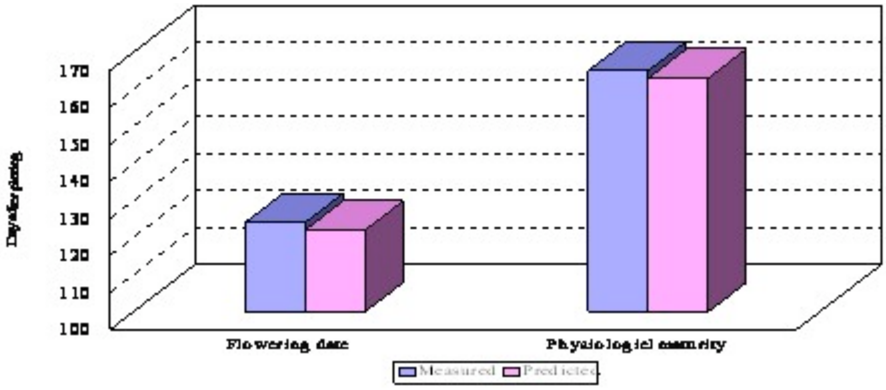


Fig. 43: Calibration and validation test for wheat (Sakha-8 CV) at Sakha region

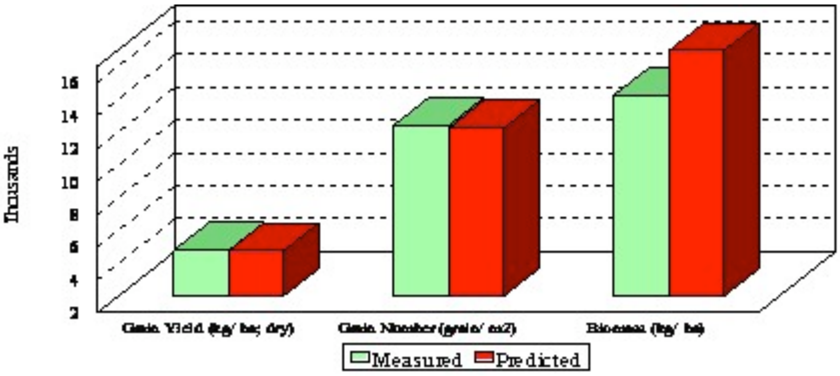


Fig. 44: Calibration and validation test for wheat (Sakha-8 CV) at Sakha region

<u>*Adaptation to Climate Variability and Change:*</u>

Studies on adaptation strategies evaluation of climate variability were carried out using the following methods: Simulation runs on different cultivars, water amounts and sowing dates through DSSAT 3.5 model on wheat. Adaptation options to climate under climate change (GCMs/ MAGICC/SCENGEN) are shown in (Tables 42-59 and Fig. 45-62). The simulation studies were carried out for the validation test as well as 25 succeeding years.

Character	Cultivars			
	Sakha-8	Giza-168	Sakha-69	Average
Grain yield, kg/ ha (Base)	4712	6797	6068	5859
Grain yield, kg/ ha (Base+1.5 ° C)	4500	4769	4387	4552

Table 42: Simulation of grain YIELD FOR different wheat cultivars under current and climate change conditions (+1.5° C) at Sakha region (Kafr EL- Shaikh Governorate).

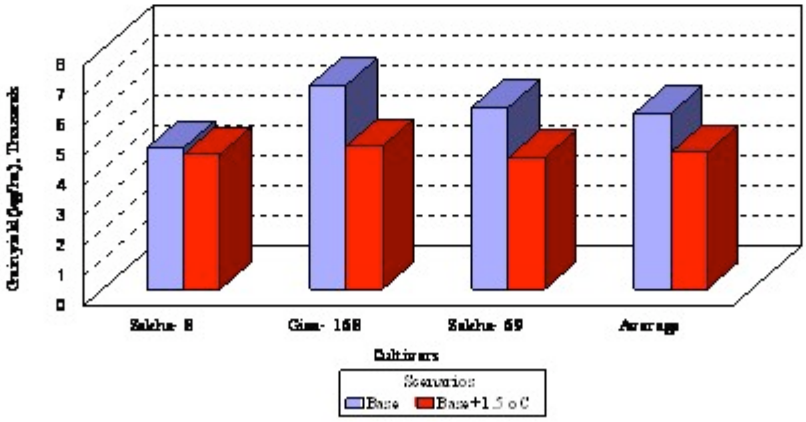


Fig. 45: simulation of grain yield for some wheat cultivars under current (base) and climate change conditions (+1.5 ° C) at Sakha region (Kafer El-Shakh Governorate)

Character	Water amounts (mm/ season)			
	300 mm	400 mm	500 mm	600 mm
Grain yield, kg/ ha (Base)	3560	4479	4712	4744
Grain yield, kg/ ha (Base+1.5 ° C)	2992	4227	4500	4518

Table 43: Simulation of grain yield at different water AMOUNTS FOR wheat crop (Sakha-8 CV.) under current and climate change conditions (+1.5 ° C) at Sakha region (Kafr EL- Shaikh Governorate).

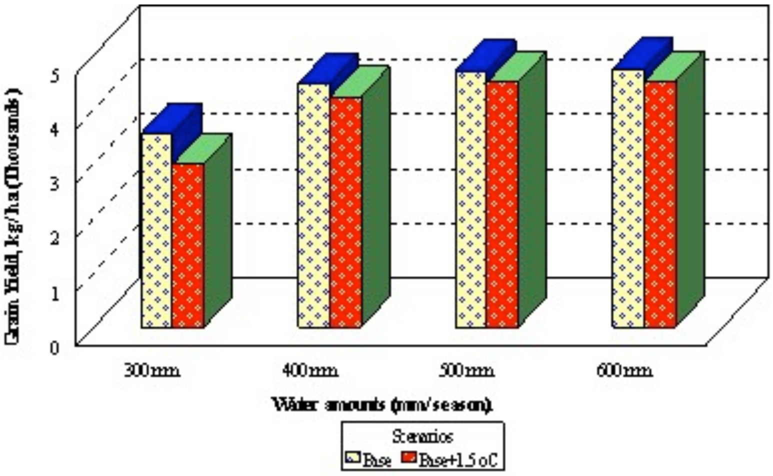


Fig. 46: simulation of grain yield under different water amounts for wheat crop (Sakha-8 CV) under climate change conditions (+1.5 ° C) at Sakha region (Kafer El-Shakh Governorate)

Character	Sowing dates			
	Nov. 20	Dec. 01	Dec. 10	Dec. 20
Grain yield, kg/ ha (Base)	4750	4736	4699	4689
Grain yield, kg/ ha (Base+1.5 ° C)	4484	4506	4497	4451

Table 44: Simulation of grain yield under different sowing dates for wheat crop (Sakha-8 CV.) under current and climate change conditions (+1.5 ° C) at Sakha region (Kafr EL- Shaikh Governorate).

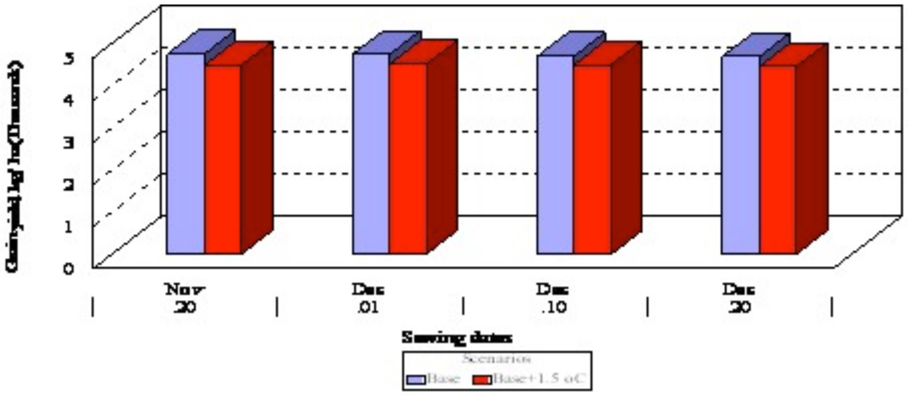


Fig. 47: simulation of grain yield under different growing dates for wheat crop (Sakha-8 CV) under climate change conditions (+1.5 ° C) at Sakha region (Kafer El-Shakh Governorate)

Character	Cultivars			
	Sakha-8	Giza-168	Sakha-69	Average
ET crop (Base)	464	354	352	390
ET crop (Base+1.5 ° C)	489	357	358	401

Table 45: Simulation of ET (mm) FOR some wheat cultivars under current and climate change conditions (+1.5 ° C) at Sakha region (Kafr EL- Shaikh Governorate).

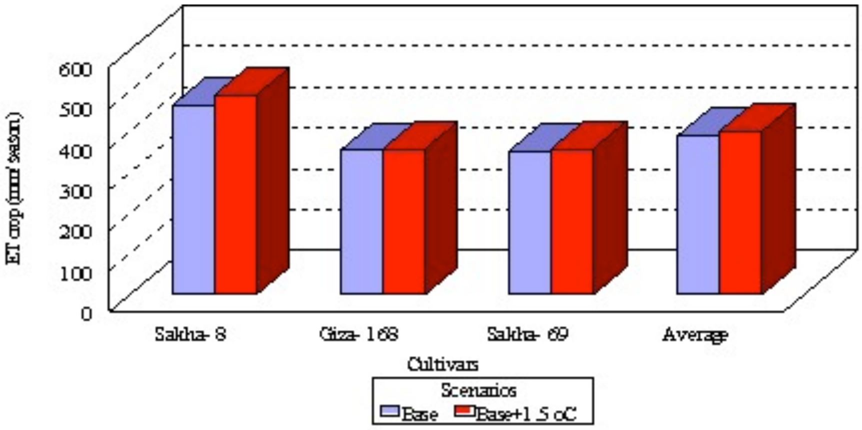


Fig. 48: Simulation of Et (mm) for some wheat cultivars under climate change conditions (+1.5 ° C) at Sakha region (Kafer El-Shakh Governorate)

Character	Water amounts (mm/season)			
	300 mm	400 mm	500 mm	600 mm
ET crop (Base)	313	403	464	476
ET crop (Base+1.5 ° C)	316	409	489	513

Table 46: Simulation of ET (mm) under different water AMOUNTS FOR wheat crop (Sakha-8 CV.) under current and climate change conditions (+1.5 ° C) at Sakha region (Kafr EL- Shaikh Governorate).

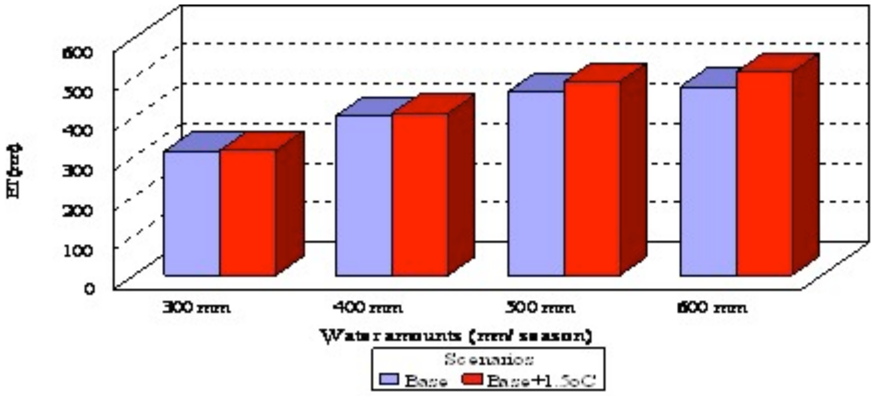


Fig. 49: Simulation of Et (mm) under different water amounts for wheat crop (Sakha-8 CV) under climate change conditions (+1.5 ° C) at Sakha region (Kafer El-Shakh Governorate)

Character	Sowing dates			
	Nov. 20	Dec. 01	Dec. 10	Dec. 20
ET crop (Base)	469	462	467	476
ET crop (Base+1.5 ° C)	498	490	490	491

Table 47: Simulation of ET (mm) under different sowing dates for wheat crop (Sakha-8 CV.) under current and climate change conditions (+1.5° C) at Sakha region (Kafr EL- Shaikh Governorate).

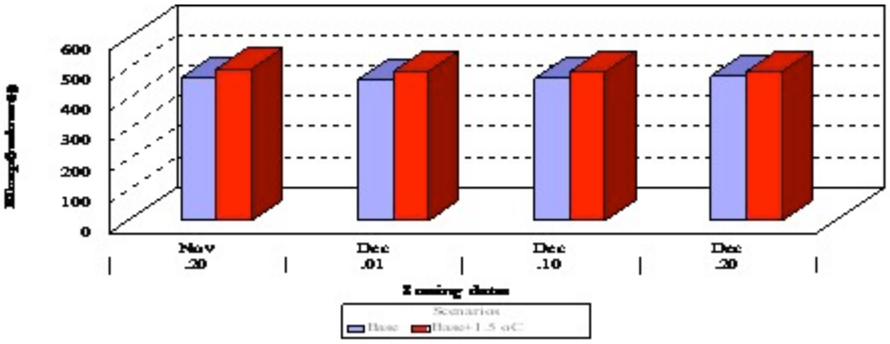


Fig. 50: Simulation of Et (mm) under different sowing dates for wheat crop (Sakha-8 CV) under climate change conditions (+1.5 ° C) at Sakha region (Kafer El-Shakh Governorate)

Character		Cultivars		
		Sakha-8	Giza-168	Average
	Grain yield, kg/ ha (Base)	4680	6929	5805
Scenarios	Grain yield, kg/ ha (CCCM)	3350	4172	3761
	Grain yield, kg/ ha (GFD3)	3610	4380	3995
	Average 2 scenarios	3480	4276	3878

Table 48: Simulation of grain YIELD FOR some wheat cultivars under current (Base) and climate change conditions (+3.7° C) at Sakha region (Kafr EL- Shaikh Governorate).

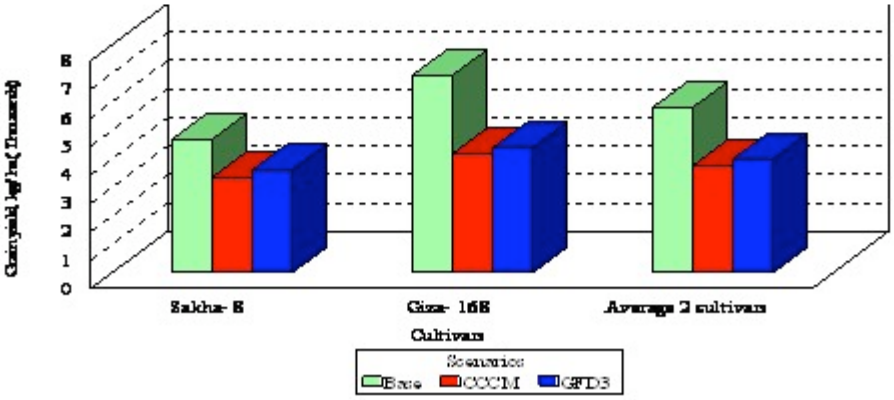


Fig. 51: Simulation of grain yield for some wheat cultivars under current (Base) and climate change conditions (+3.7 ° C) at Sakha region (Kafer El-Shakh Governorate)

Character	Change %				Average 2 scenarios		Average 2 cultivars
	CCCM		GFD3				
	Sakha-8	Giza-168	Sakha-8	Giza-168	Sakha-8	Giza-168	
Grain yield	-28	-40	-23	-37	-26	-38	-32

Table 49: Change percent of grain YIELD FOR some wheat cultivars under climate change (+3.7 °C) COMPARED to current conditions at Sakha region.

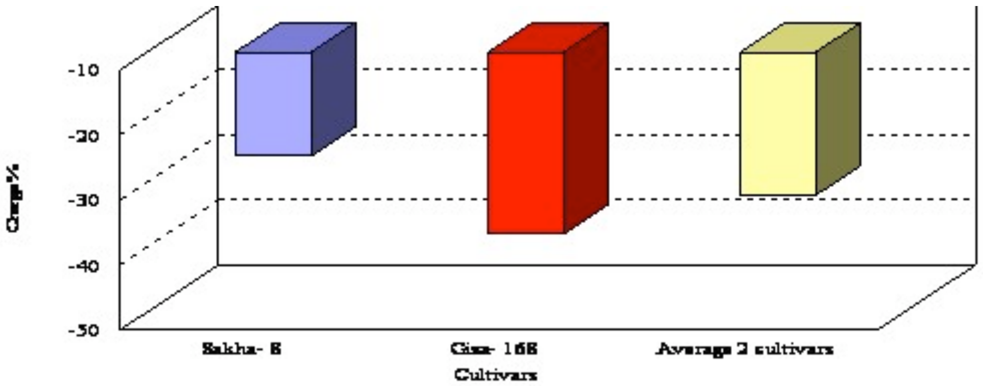


Fig. 52: change percent of grain yield for some wheat cultivars under climate change (+3.7° C) compared to current conditions at Sakha region.

Character		Sowing dates			
		Nov. 20	Dec. 01	Dec. 10	Dec. 20
	Grain yield, kg/ ha (Base)	4726	4723	4702	4672
Scenarios	Grain yield, kg/ ha (CCCM)	2810	2825	3034	3093
	Grain yield, kg/ ha (GFD3)	3332	3461	3723	3724
	Average 2 scenarios	3071	3143	3379	3409

Table 50: Simulation of grain YIELD FOR different sowing dates under current (Base) and climate change conditions (+3.7 ° C) at Sakha region (Kafr EL- Shaikh Governorate).

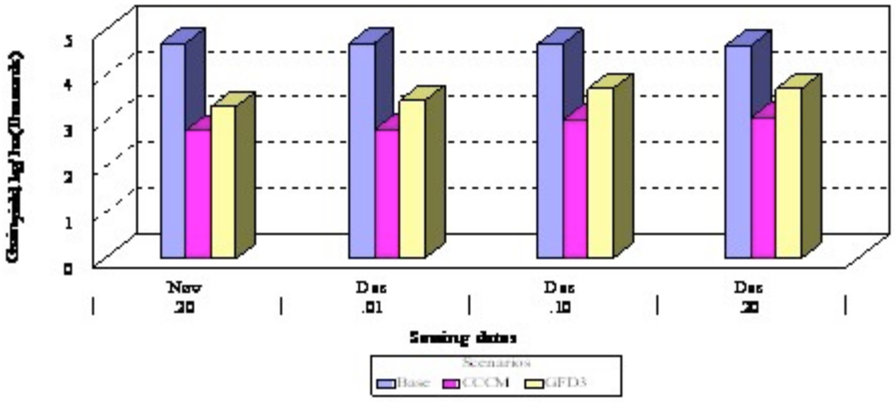


Fig. 53: Simulation of grain yield for different sowing dates under climate change conditions (+3.7° C) at Sakha region (Kafer El-Shakh Governorate)

Character	Change %											
	CCCM				GFD3				Average 2 scenarios			
	Nov. 20	Dec. 01	Dec. 10	Dec. 20	Nov. 20	Dec. 01	Dec. 10	Dec. 20	Nov. 20	Dec. 01	Dec. 10	Dec. 20
Grain yield	-41	-41	-36	-34	-30	-27	-21	-20	-35	-34	-28	-27

Table 51: Change percent of grain YIELD FOR different sowing dates under climate change (+3.7 ° C) compared to current conditions at Sakha region

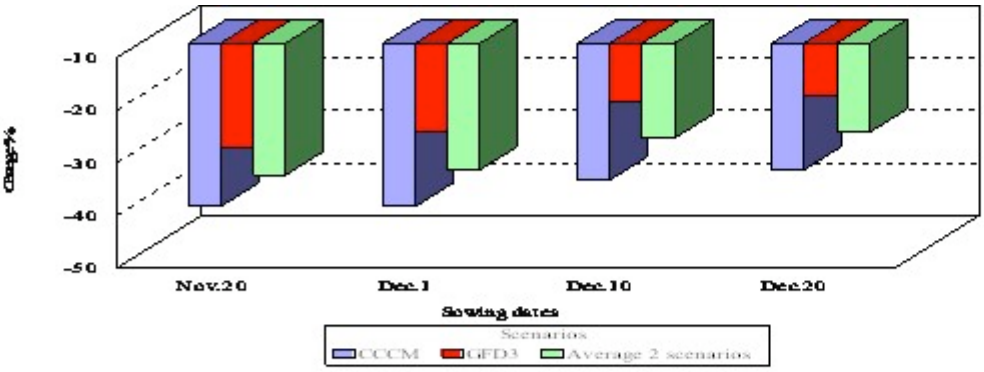


Fig. 54: change percent of grain yield for different sowing dates under climate change compared to current conditions at Sakha region.

Character		Water amount (mm/ season)			
		300 mm	400 mm	500 mm	600 mm
Grain yield, kg/ ha (Base)		3522	4491	4680	4711
Scenarios	Grain yield, kg/ ha (CCCM)	2190	2932	3410	3806
	Grain yield, kg/ ha (GFD3)	2416	3142	3695	3991
	Average 2 scenarios	2303	3037	3553	3899

Table 52: Simulation of grain YIELD FOR different water amounts under current (Base) and climate CHANGE (+3.7° C) conditions at Sakha region (Kafr EL- Shaikh Governorate).

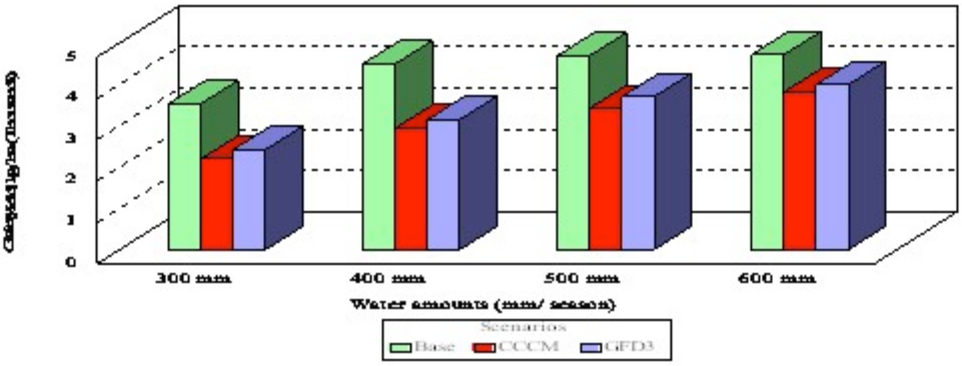


Fig. 55: Simulation of grain yield for different water amounts under climate change conditions at Sakha region (Kafer El-Shakh Governorate)

Character	Change %											
	CCCM				GFD3				Average 2 scenarios			
	300 mm	400 mm	500 mm	600 mm	300 mm	400 mm	500 mm	600 mm	300 mm	400 mm	500 mm	600 mm
Grain yield	-38	-35	-27	-19	-31	-30	-21	-15	-34	-32	-24	-17

Table 53: Change percent of grain YIELD FOR different water amounts under climate change (+3.7 ° C) compared to current conditions at Sakha region.

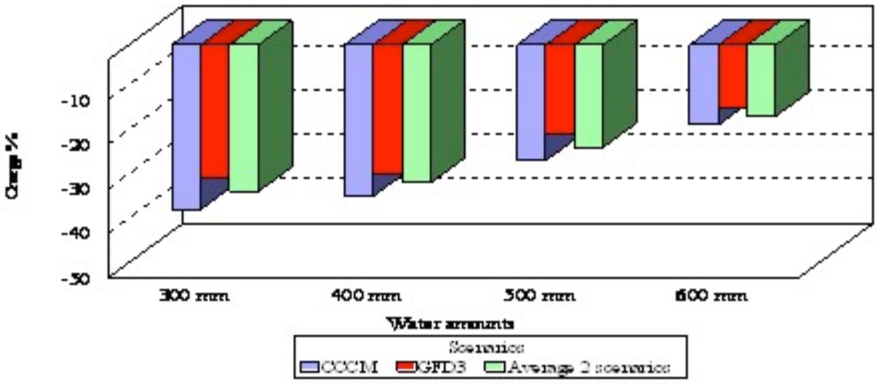


Fig. 56: change percent of grain yield for different water amounts under climate change compared to current conditions at Sakha region.

	Character	Cultivars		
		Sakha-8	Giza-168	Average
	ET crop, mm/ season (Base)	465	515	490
Scenarios	ET crop, mm/ season (CCCM)	492	500	496
	ET crop, mm/ season (GFD3)	504	505	505
	Average 2 scenarios	498	503	500

Table 54: Simulation of ET (MM) FOR some wheat cultivars under current (Base) and climate change conditions (+3.7 ° C) at Sakha REGION (Kafr EL- Shaikh Governorate).

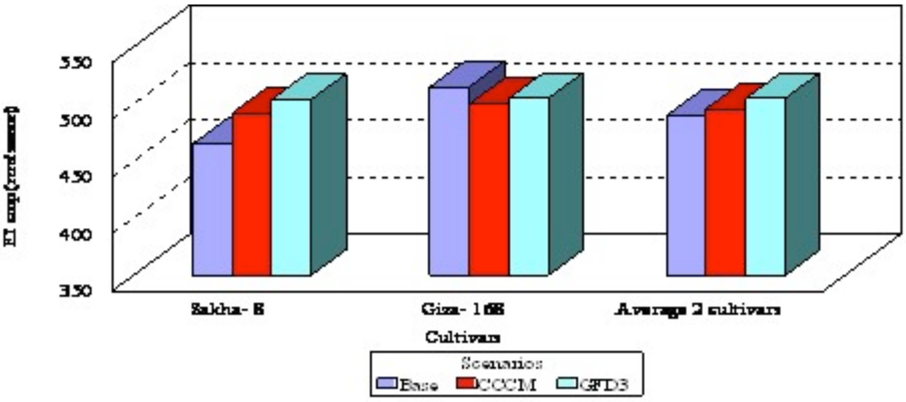


Fig. 57: Simulation of Et (mm) for some wheat cultivars under current (Base) and climate change conditions (+3.7 ° C) at Sakha region (Kafer El-Shakh Governorate)

Character	Change %						
	CCCM		GFD3		Average 2 scenarios		Average 2 cultivars
	Sakha-8	Giza-168	Sakha-8	Giza-168	Sakha-8	Giza-168	
ET crop	6	-3	8	-2	7	-2	2.5

Table 55: Change percent of ET FOR some wheat cultivars under climate change (+3.7 ° C) compared to current conditions at Sakha region.

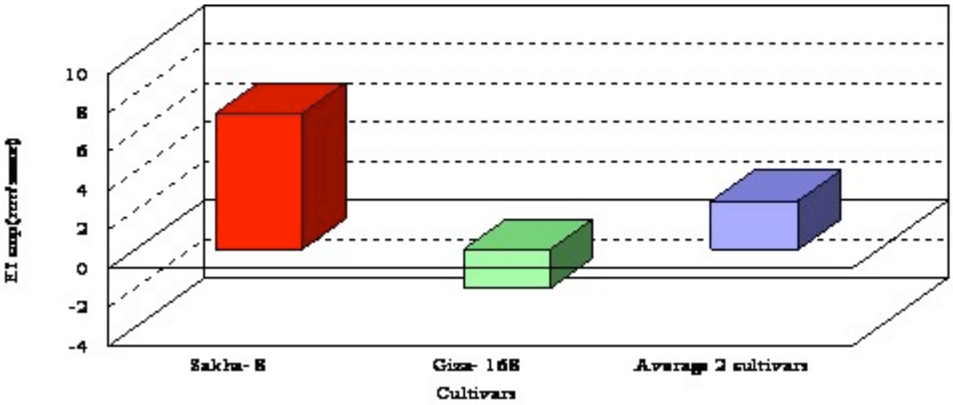


Fig. 58: Change percent of Et (mm) for some wheat cultivars under current (Base) and climate change conditions (+3.7 ° C) at Sakha region (Kafer El-Shakh Governorate)

Character		Sowing dates			
		Nov. 20	Dec. 01	Dec. 10	Dec. 20
ET crop, mm/ season (Base)		470	463	466	472
Scenarios	ET crop, mm/ season (CCCM)	499	494	492	490
	ET crop, mm/ season (GFD3)	514	508	503	498
	Average 2 scenarios	507	501	498	494

Table 56: Simulation of ET (MM) FOR different sowing dates under current (Base) and climate change (+3.7° C) conditions at Sakha region (Kafr EL- Shaikh Governorate).

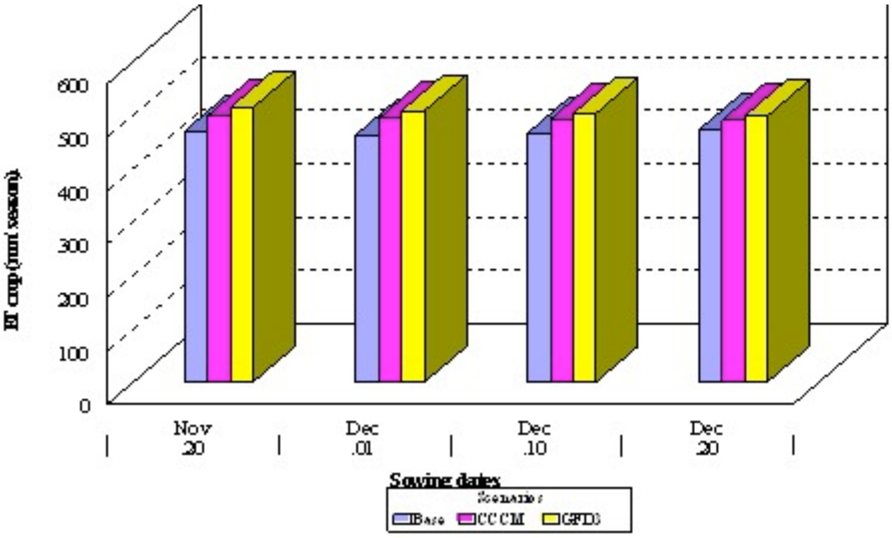


Fig. 59: simulation of Et (mm) for different sowing dates under climate change conditions at Sakha region (Kafer El-Shakh Governorate)

Character	Change %											
	CCCM				GFD3				Average 2 scenarios			
	Nov. 20	Dec. 01	Dec. 10	Dec. 20	Nov. 20	Dec. 01	Dec. 10	Dec. 20	Nov. 20	Dec. 01	Dec. 10	Dec. 20
ET crop	6	7	6	4	9	10	8	6	8	8	7	5

Table 57: Change percent in ET (MM) FOR different sowing dates under current (Base) and climate change conditions (+3.7 ° C) at Sakha region (Kafr EL- Shaikh Governorate).

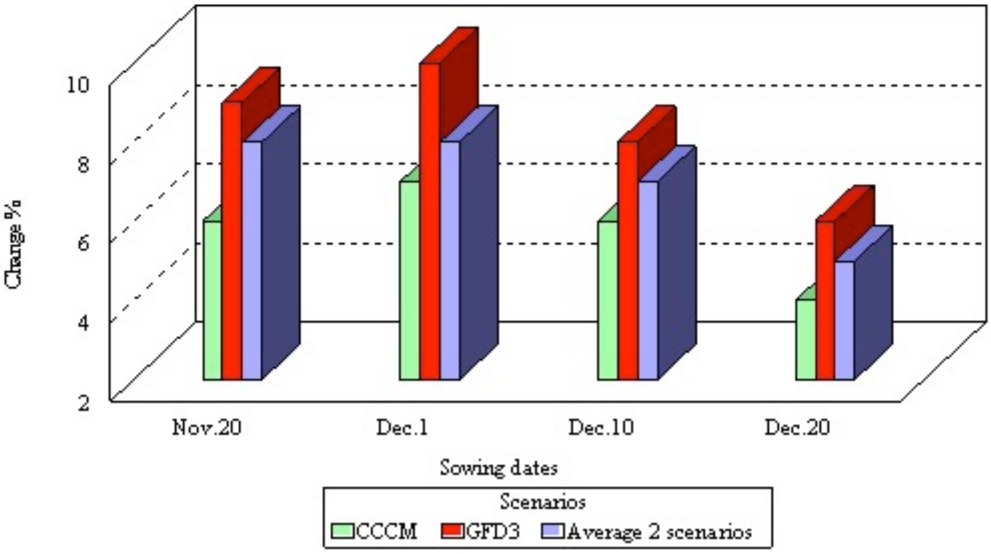


Fig. 60: change percent of Et (mm) for different sowing dates under climate change compared to current conditions at Sakha region.

Character		Water amount (mm/ season)			
		300 mm	400 mm	500 mm	600 mm
ET crop, mm/ season (Base)		314	403	465	476
Scenarios	ET crop, mm/ season (CCCM)	302	398	492	574
	ET crop, mm/ season (GFD3)	318	412	504	584
	Average 2 scenarios	310	405	498	579

Table 58: Simulation of ET (MM) FOR different water amounts under current (Base) and climate change conditions (+3.7 ° C) at Sakha region (Kafr EL- Shaikh Governorate).

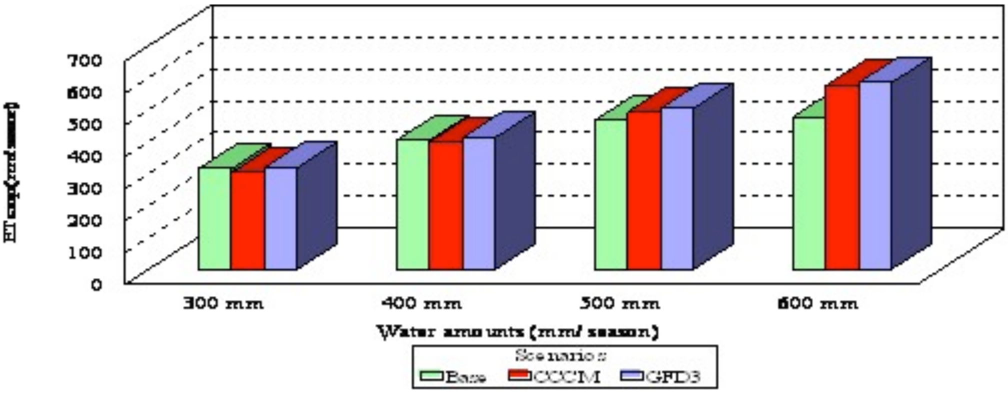


Fig. 61: simulation of Et (mm) for different water amounts under climate change conditions at Sakha region (Kafer El-Shakh Governorate)

Character	Change %											
	CCCM				GFD3				Average 2 scenarios			
	300 mm	400 mm	500 mm	600 mm	300 mm	400 mm	500 mm	600 mm	300 mm	400 mm	500 mm	600 mm
ET crop	-3	-1	6	21	1	2	9	23	-1	1	7	22

Table 59: Change percent of ET (MM) for different water amounts under climate change conditions (+3.7 ° C) at Sakha region (Kafr EL- Shaikh Governorate).

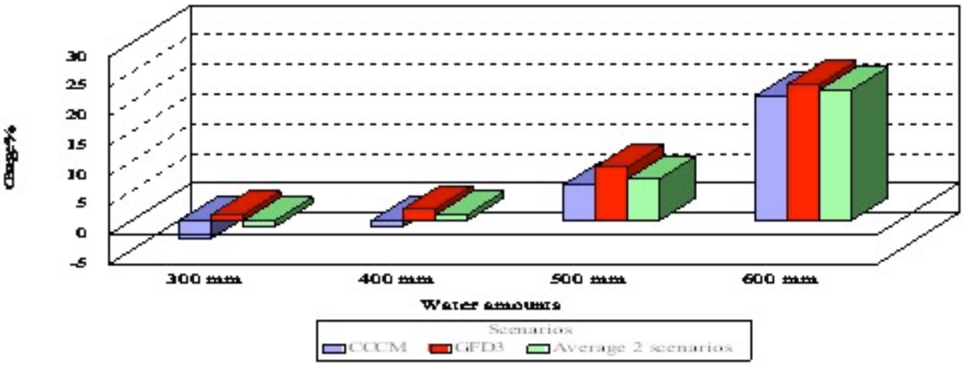


Fig. 62: change percent of Et (mm) for different water amounts under climate change compared to current conditions at Sakha region.

<u>From the previous results, it could be concluded that:</u>

<u>Under climate change +1.5 °C:</u> the variety of Sakha-8 is more tolerance to high temperature as compared with Giza-168 and Sakha-69. Regarding to water amount, the treatment of 500 mm/season is the most efficient as compared with 300, 400 and 600 mm/ season. At the same time, sowing on 1st to 10th of Dec. is more suitable to wheat cultivation at Sakha region, which gave maximum yield and minimum ET under climate change conditions as compared with the others.

With respect to water consumptive use (ET), it was increased by 5.4, 0.85 and 1.7% for Sakha-8, Giza-168 and Sakha-69, respectively as compared with those under current conditions.

<u>*Under climate change +3.7 °C:*</u> the reduction of grain yield reached about 26 and 38% for Sakha-8 and Giza- 168, respectively, as compared with the yield of these varieties under current conditions. Regarding to sowing dates, the change percent reached about -35, -34, -28 and -27% for Nov. 20, Dec. 01, Dec. 10 and Dec. 20, respectively as compared with the current conditions. Increasing water amount under climate change will decrease the adverse impacts on yield. The change percent of grain yield for different water amounts under climate change compared to current conditions was -34, -32, -24 and -17% for 300, 400, 500 and 600 mm/season, respectively. Finally, Sakha-8 is more tolerance to high temperature (+3.7 °C) as compared with Giza-168. The most suitable date for wheat cultivation at Sakha region under climate change from 10th to 20th Dec., which gave maximum yield and minimum ET.

<u>*Impacts and adaptation on tomatoes crop at Sakha region:*</u>

The TOM- GRO model was validated by comparing observed data on biomass, yield, and maximum Leaf area index (LAI) to simulated values (Table 60 and Fig.63). The results of the validation experiment indicate that the Tom-Gro crop model can be used successfully in Egypt. The observed data on tomatoes yield, LAI and biomass were very close to the corresponding simulated values. The observed total biomass was slightly smaller than the simulated one. According to these results, the model was considered validated for the conditions of the study. The simulation studies were carried out for the validation test as well as 25 succeeding years.

Variable	MEASURED	PREDICTED
Tomatoes Yield (kg/ ha; dry)	8333	8350
Maximum LAI (m^2/ m^2)	6.00	6.32
Biomass (kg/ ha) at Harvest Mat.	12214	14333

Table 60: Calibration and validation test for tomatoes crop at Sakha region.

Fig. 63: Calibration validation test for tomato crop at Sakha region

<u>*Adaptation to Climate Change under GCMs/:*</u>

<u>*1- Adaptation under (MAGICC/SCENGEN, +1.5 ° C)*</u>

Studies of adaptation strategies evaluation to climate variability were carried out using the following method: Simulation runs on different water amounts and sowing dates through DSSAT 3.5 model on tomatoes. Adaptation options to climate under climate change (+1.5 ° C) are shown in Tables (61-64) and Figs. (64 -67).

Conditions	Water amounts	Tomatoes yield (kg/ ha, dry)
Current	Base (700 mm / season)	7568
Climate change (+1.5 ° C)	500 mm/ season	4727
	600 mm/ season	5764
	700 mm/ season	6497
	800 mm/ season	6861
	900 mm/ season	6927

Table 61: Simulation of tomatoes yield at different water amounts under current and climate change conditions (+1.5° C) at Sakha region (Kafr EL- Shaikh Governorate).

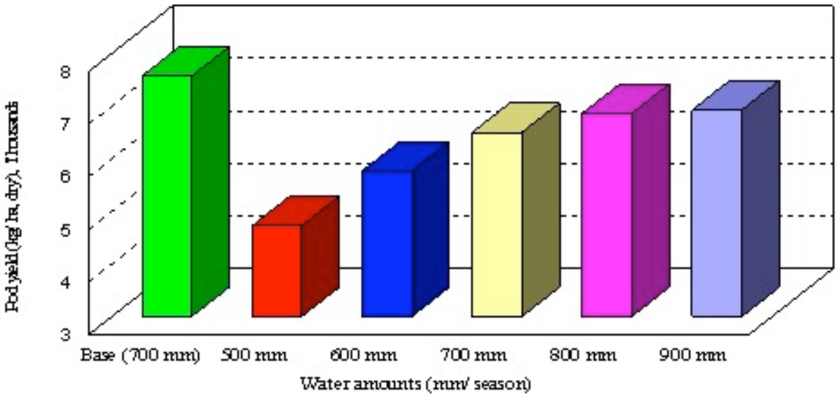


Fig. 64: Simulation of tomato fruit yield at different water amounts (mm/ season) under current (Base) and climate change conditions (+1.5° C) at Sakha region (Kafer El-Shakh Governorate)

Conditions	Water amounts	Tomates yield (kg/ ha, dry)
Climate change (+1.5 ° C)	500 mm/ season	-37.5
	600 mm/ season	-23.8
	700 mm/ season	-14.1
	800 mm/ season	-9.3
	900 mm/ season	-8.5

Table 62: Change percent of tomatoes yield at different water amounts under climate change conditions (+1.5 ° C) at Sakha region.

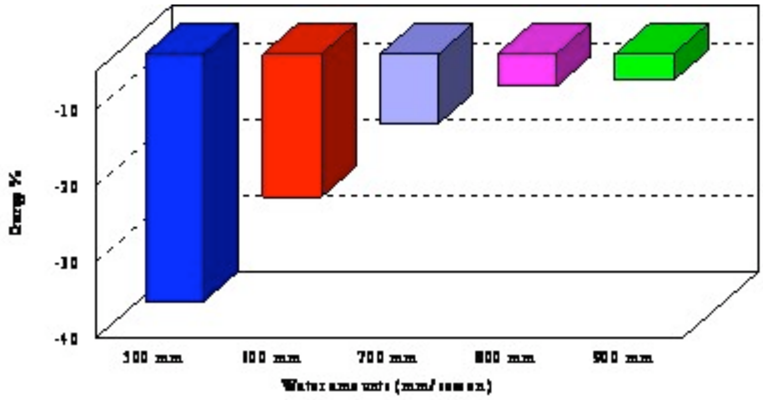


Fig. 65: Change percent of tomato fruit yield at different water amounts under climate change conditions (+1.5° C) at Sakha region (Kafer El-Shakh Governorate)

Conditions	Sowing dates	Tomatoeses yield (kg/ ha, dry)
Current	Base (Mar. 01)	7568
Climate change (+1.5 ° C)	Feb. 01	4886
	Feb. 10	5699
	Feb. 20	6321
	Mar. 01	6543
	Mar. 10	6819

Table 63: Simulation of tomatoes yield at different sowing dates under current and climate change conditions (+1.5° C) at Sakha region (Kafr EL- Shaikh Governorate).

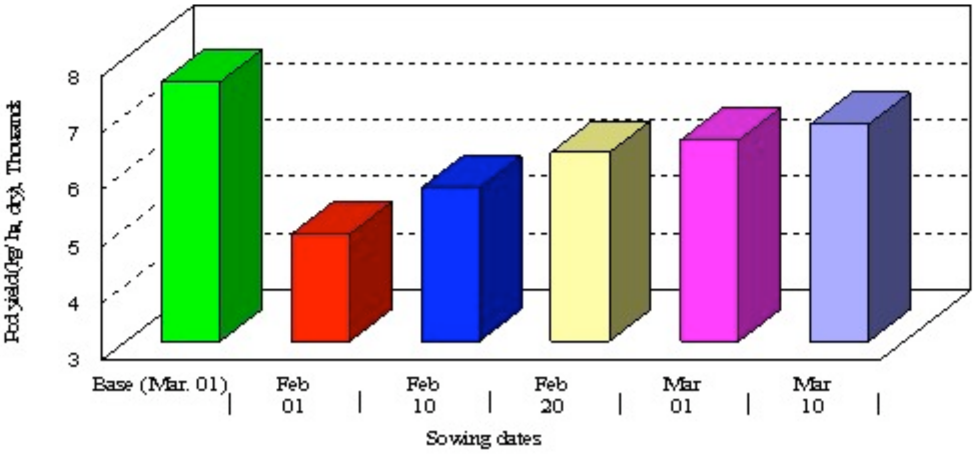


Fig. 66: Simulation of tomato fruit yield at different sowing dates under current (base) abd climate change conditions (+1.5° C) at Sakha region (Kafer El-Shakh Governorate)

Conditions	Sowing dates	Tomatoes yield (kg/ ha, dry)
Climate change (+1.5 ° C)	Feb. 01	-40
	Feb. 10	-26
	Feb. 20	-17
	Mar. 01	-51
	Mar. 10	-73

Table 64: Change percent of tomatoes yield at different sowing dates under climate change conditions (+1.5° C) at Sakha region.

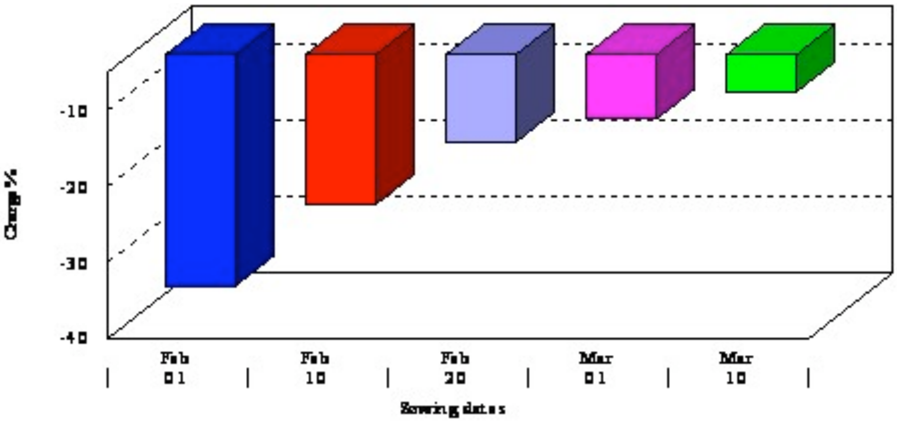


Fig. 67: Change percent of tomato fruit yield at different sowing dates under climate change conditions (+1.5° C) at Sakha region (Kafer El-Shakh Governorate)

2- Adaptation under (climate change at +3.7 ° C)

Studies of adaptation strategies evaluation to climate variability were carried out using the following method: Simulation runs on different water amounts and sowing dates through DSSAT 3.5 model on tomatoes. Adaptation options to climate under climate change (+3.7 ° C) are shown in Tables (65-68) and Figs. (68- 71).

Conditions	Water amounts	Tomatoes yield (kg/ ha, dry)
Current	Base (700 mm / season)	7940
Climate change (+3.7 ° C)	500 mm/ season	2404
	600 mm/ season	3248
	700 mm/ season	3898
	800 mm/ season	4244
	900 mm/ season	4260

Table 65: Simulation of tomatoes yield at different water amounts under current and climate change conditions (+3.7° C) at Sakha region (Kafr EL- Shaikh Governorate.

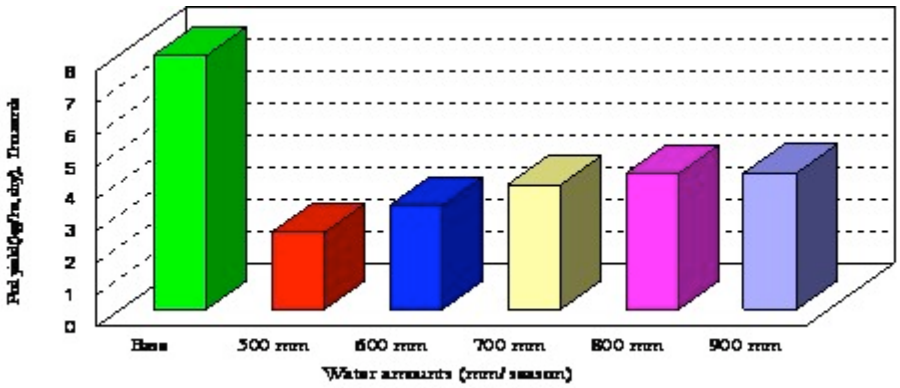


Fig. 68: Simulation of tomato fruit yield at different water amounts (mm/season) under current (base) at climate change conditions (+3.7° C) at Sakha region (Kafer El-Shakh Governorate)

Conditions	Water amounts	Tomatoes yield (kg/ ha, dry)
Climate change (+3.7 °C)	500 mm/ season	-70
	600 mm/ season	-59
	700 mm/ season	-51
	800 mm/ season	-47
	900 mm/ season	-46

Table 66: Change percent of tomatoes yield at different water amounts under climate change conditions (+3.7 ° C) at Sakha region.

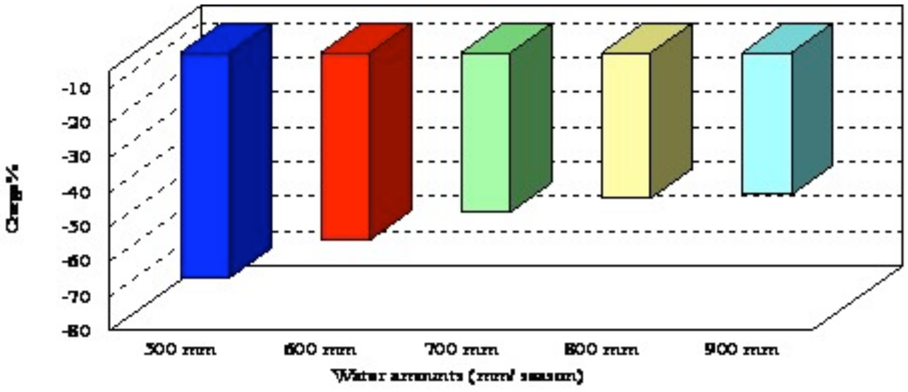


Fig.69: Change percent of tomato fruit yield at different water amounts under climate change conditions (+3.7° C) at Sakha region (Kafer El-Shakh Governorate)

Conditions	Sowing dates	Tomatoes yield (kg/ ha, dry)
Current	Base (Mar. 01)	7940
Climate change (+3.7 ° C)	Feb. 01	4794
	Feb. 10	5880
	Feb. 20	6587
	Mar. 01	3898
	Mar. 10	2165

Table 67: Simulation of tomatoes yield at different sowing dates under current and climate change conditions (+3.7° C) at Sakha region (Kafr EL- Shaikh Governorate).

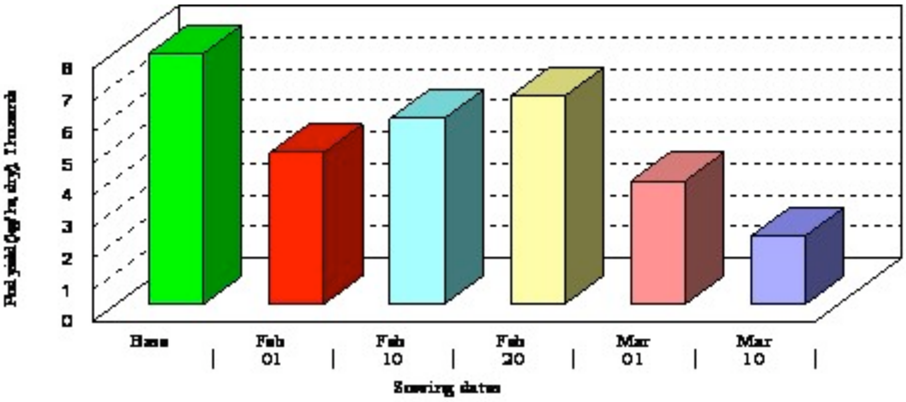


Fig. 70: Simulation of tomato fruit yield at different sowing dates under current (base) at climate change conditions (+3.7° C) at Sakha region (Kafer El-Shakh Governorate)

Conditions	Sowing dates	Tomatoes yield (kg/ ha, dry)
Climate change (+3.7 ° C)	Feb. 01	-40
	Feb. 10	-26
	Feb. 20	-17
	Mar. 01	-51
	Mar. 10	-73

Table 68: Change percent of tomatoes yield at different sowing dates under climate change conditions (+3.7 o C) at Sakha region.

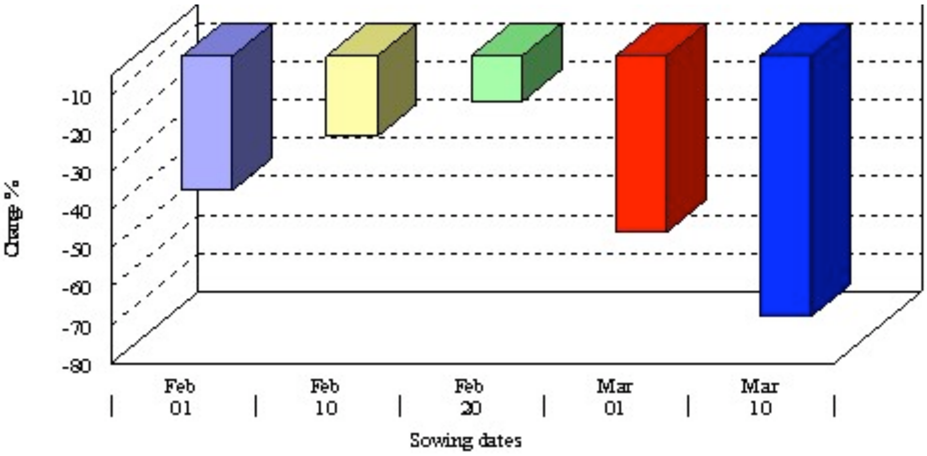


Fig. 71: Change percent of tomato fruit yield at different sowing dates under climate change conditions (+3.7° C) at Sakha region (Kafer El-Shakh Governorate)

Finally, it could be concluded that:

<u>Adaptation to climate change under Gems:</u>

1. *Adaptation under (MAGICC/ SCENGEN, +1.5 ºC):* tomatoes yield was very sensitivity to high temperature specially under decreasing water amount. Decreasing water amount from 700 mm/season (under current conditions) to 500 or 600 mm/ season (under climate change conditions) decreased tomatoes yield by -37.5 and -23.8%, respectively. While, increasing water amount to 800 and 900 mm/ season slightly decreased tomatoes yield (-9.3 and -8.5%, respectively). Regarding to different sowing dates, tomatoes yield was decreased by -35.4, -24.7, -16.5, -1.35 and -9.9% when sown on Feb. 01, Feb. 10, Feb. 20, Mar. 01 and Mar. 10, respectively, as compared with the current conditions (Mar. 01). So, cultivation of tomatoes crop through March is more suitable under climate change (+1.5 ºC) at Sakha region.
2. *Under climate change +3.7 ºC:* the reduction of tomatoes yield reached about -70, -59, -51, -47 and -46% for water amounts of 500, 600, 700, 800 and 900 mm/season, respectively, as compared with water amount of 700 mm/season under current conditions. So, tomatoes crop will need more water to compensate the reduction in yield as a result of high temperature. With respect to sowing dates, the reduction of yield reached about -40, -26, -17, -51 and -73% for Feb. 01, Feb. 10, Feb. 20, Mar. 01 and Mar. 10, respectively. Sowing tomatoes on Feb. 20 is more efficient for this crop at Sakha region under +3.7 raise in temperature.

5.2.2.2 Impacts and adaptation on wheat crop at Mersa Matruh region

CERES- Wheat model was validated by comparing observed data on flowering and maturity dates, grain and biomass yields, grain weight and maximum leaf area index to simulated values (Table 69 and Fig. 72 & 73). It is clear that CERES-Wheat crop model can be used successfully at the selected site in Egypt. The observed data on all variables were very close to the corresponding simulated values. The simulated maximum leaf area index (LAI) was slightly smaller than the observed one. According to these results, the model was considered validated for the conditions of the study.

Variable	MEASURED	PREDICTED
Flowering Date (dap)	112	112
Physiological Maturity (dap)	160	163
Grain yield (kg/ ha; dry)	2506	2555
Wt. per grain (g; dry)	0.035	0.037
Maximum LAI (m2/ m2)	3.60	2.31
Biomass (kg/ ha) at Harvest Mat.	9670	9222
Stalk (kg/ ha) at Harvest Mat.	7164	6666

Table 69: Calibration and validation test for wheat crop (Sakha-8 CV) at Mersa Matruh region.

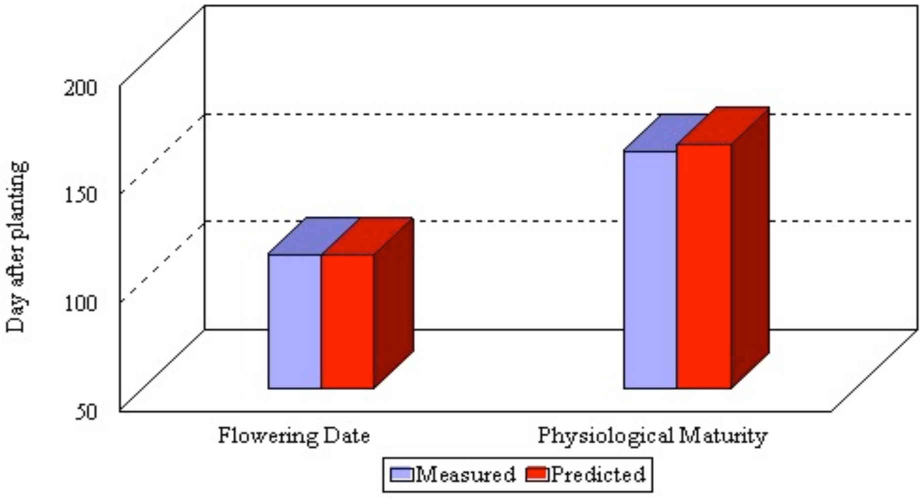


Fig. 72: Calibration and validation test for wheat crop (Sakha-8 CV) at Marsa Matruh region

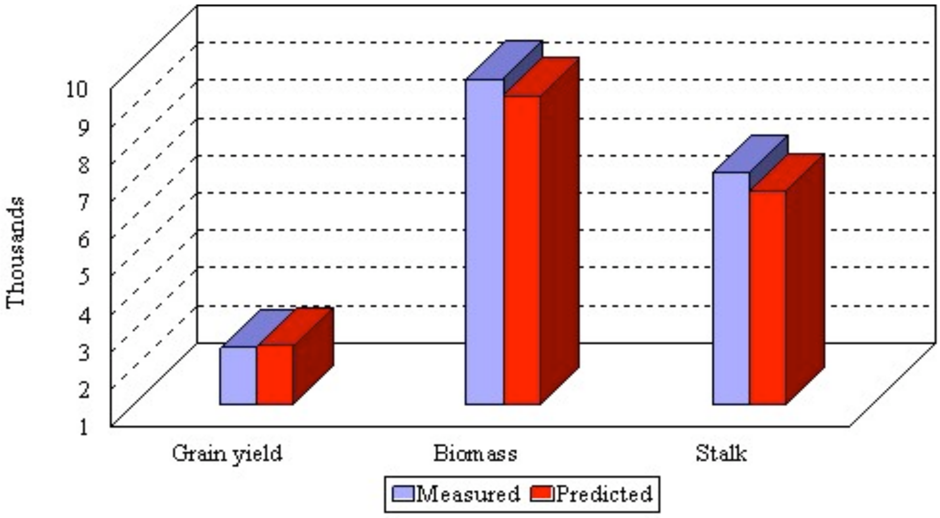


Fig. 73: Calibration and validation test for wheat crop (Sakha-8 CV) at Marsa Matruh region

Adaptation to Climate Variability and Change:

Studies of adaptation strategies evaluation to climate variability were carried out using the following method: Simulation runs on different water amounts and sowing dates through DSSAT 3.5 model on wheat. Adaptation options to climate under climate change (MAGICC/SCENGEN, +1.5 ºC) are shown in (Tables 70-73 and Fig. 74 -81). The simulation studies were carried out for the validation test as well as 14 succeeding years.

Sowing dates	Grain yield	Change %
Base (Nov. 01)	2325	…
Nov. 10	2560	10.1
Nov. 20	2799	20.4
Dec. 01	2909	25.1
Dec. 10	3067	31.9
Dec. 20	2969	27.7

Table 70: Simulated wheat crop productivity (kg/ ha) under current conditions at different sowing dates for Mersa Matruh region.

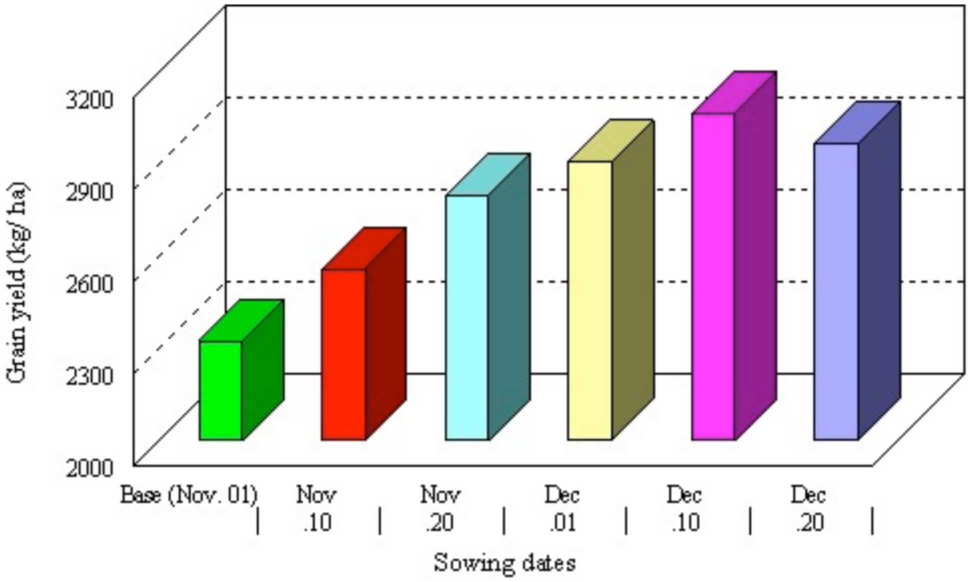


Fig. 74: Simulation wheat grain yield (kg/ha) under current conditions at different dates at Marsa Matruh region

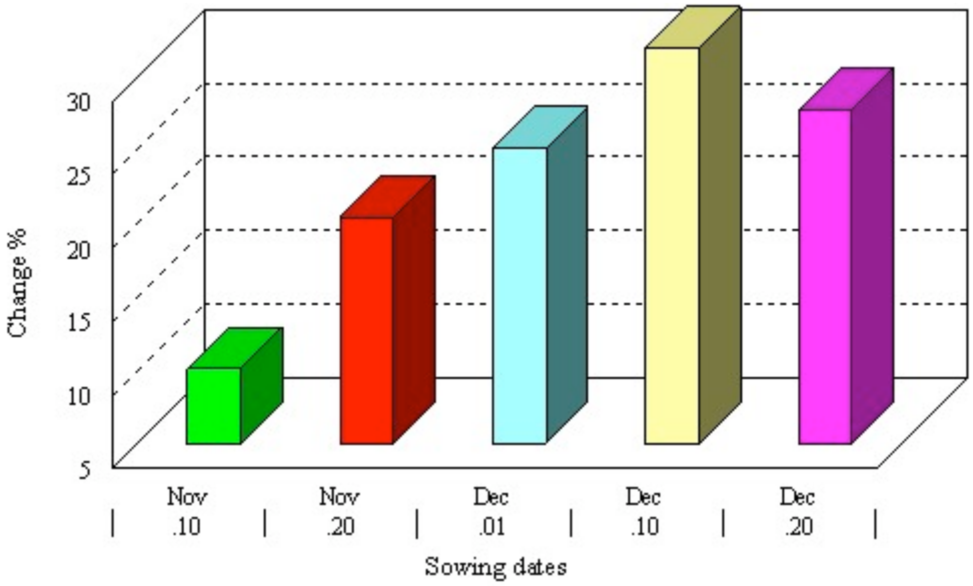


Fig. 75: Change percent of wheat grain yield under current conditions at different sowing dates at Marsa Matruh region

Water amounts	Grain yield	Change %
Base (240 mm/ season)	2325	…
Base -10%	1728	-25.7
Base -20%	1201	-48.3
Base +10%	2519	8.3
Base +20%	2576	10.8

Table 71: Simulated wheat crop productivity (kg/ha) under current conditions at different water amounts for Mersa Matruh region.

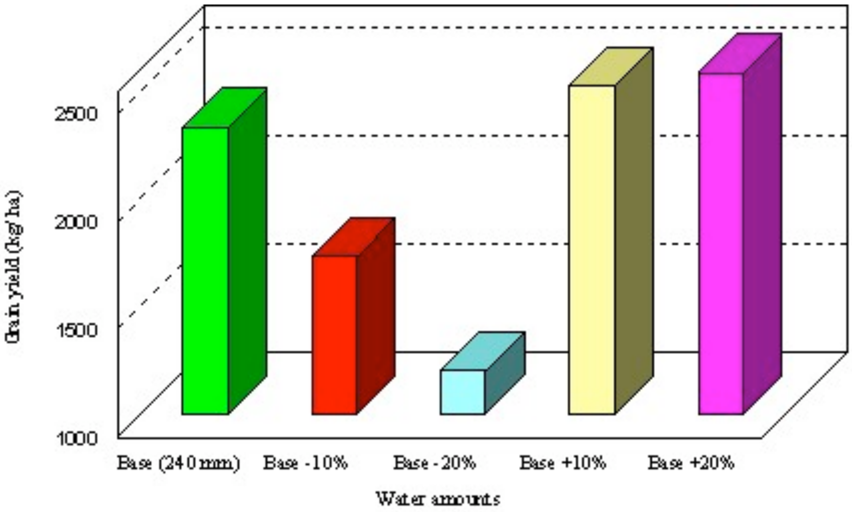


Fig. 76: Simulated Wheat grain yield (kg/ha) under current conditions at different water amounts at Marsa Matruh region

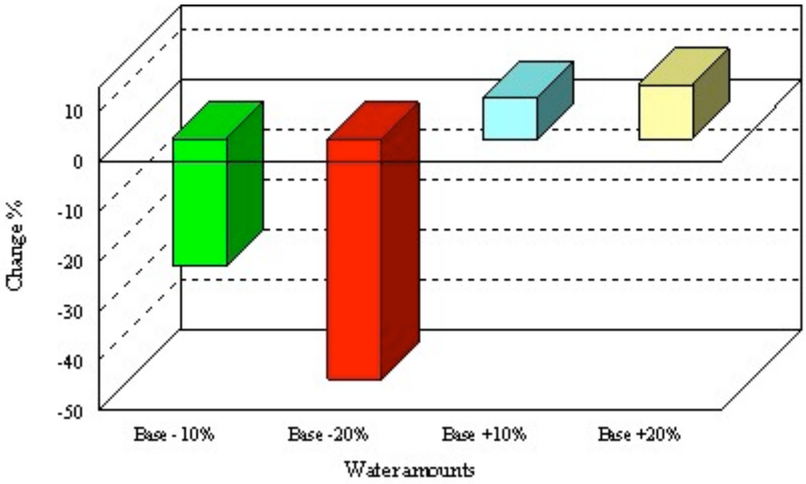


Fig. 77: Change percent of wheat grain yield under current conditions at different water amounts at Marsa Matruh region

Sowing dates	Grain yield	Change %
Base (Nov. 01)	2325	…
Nov. 01	2124	-8.6
Nov. 10	2362	1.6
Nov. 20	2631	13.2
Dec. 01	2759	18.7
Dec. 10	2872	23.5
Dec. 20	2817	21.2

Table 72: Simulated wheat crop productivity (KG/HA) under climate change conditions (+1.5 ° C) at different sowing dates for Mersa Matruh region.

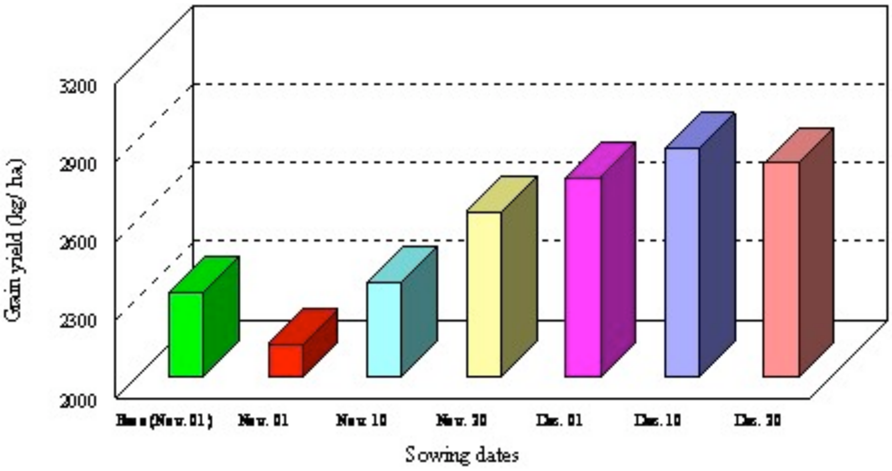


Fig. 78: Simulated Wheat grain yield (kg/ha) under climate change conditions (+1.5° C) at different sowing dates at Marsa Matruh region

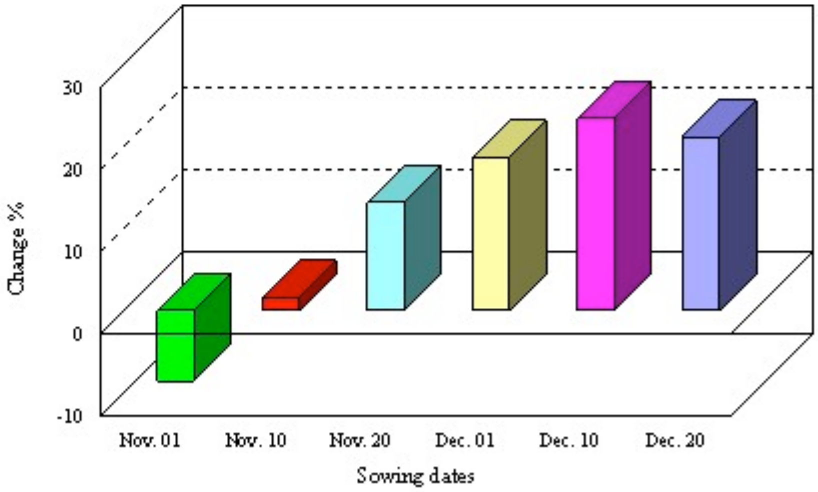


Fig. 79: Change percent of wheat grain yield under climate change conditions (+1.5° C) at different sowing dates at Marsa Matruh region

Water amounts	Grain yield	Change %
Base (240 mm/ season)	2325	…
Base -10%	1547	-33.5
Base -20%	1038	-55.3
Base +10%	2335	0.4
Base +20%	2396	3.1

Table 73: Simulated wheat crop productivity (KG/HA) under climate change conditions (+1.5 ° C) at different water amounts for Mersa Matruh region.

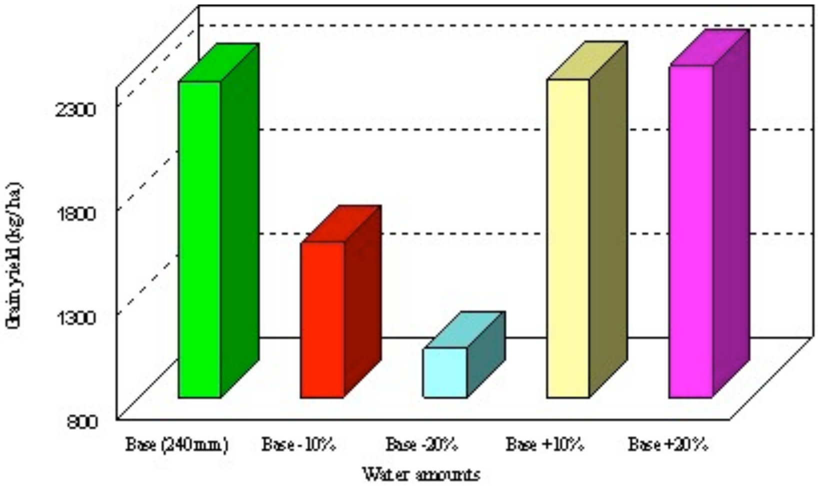


Fig. 80: Simulated Wheat grain yield (kg/ha) under climate change conditions (+1.5° C) at different water amounts at Marsa Matruh region

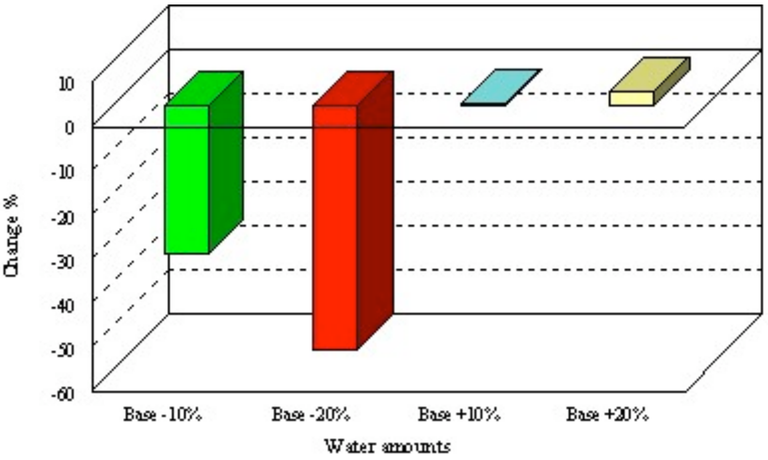


Fig. 81: Change percent of wheat grain yield under climate change conditions (+1.5° C) at different water amounts at Marsa Matruh region

From these results it could be concluded that:

Under current conditions:

Delaying **sowing date** is more efficient to wheat cultivation at Mersa Matruh region. The increase in grain yield when sowing was delayed reached 10.1, 20.4, 25.1, 31.9 and 27.7% for Nov. 10, Nov. 20, Dec. 01, Dec. 10 and Dec. 20, respectively as compared with Nov. 01 (base treatment). So, the best sowing date for wheat crop in this region through December.

With respect to **water amounts**, decreasing water amount by 10 and 20% compared to the base treatment decrease grain yield by 25.7 and 48.3%, respectively. While increasing water amount 10 and 20% above the base treatment increased grain yield by 8.3 and 10.8% respectively.

Under climate change conditions (+1.5 ºC):

Since the crop models can be used to identify appropriate crops, varieties and management strategies to maximize benefits and minimize risks associated with future climate change, further simulation studies would be valuable in assessing the risks associated with given production strategies. Studies on the effect of different sowing dates on the yield cleared that increasing temperature about 1.5 ºC as a result of climate change conditions will decrease the yield about of 8.6%. On the other hand, delaying sowing date under the future conditions will produce higher grain yield compared with early sowing under the same climate conditions. So, the select of optimum sowing date will increase crop production and this will reduce the adverse impact of expected climate change on crop production. Also, increasing water amount by 10- 20% above the used amount under current conditions will increase crop production by 0.4-3.1%.

5.3 Conclusion

From the study sample, farmers with their own experiences and/or with the help of the agricultural extension personnel apply some tactics and adaptation options to face changes in temperature or rain fall. The most mentioned options were change crop sowing dates, use heat tolerant varieties, increase number of irrigation, increase irrigation amounts, apply irrigation early in the morning or late in the evening and avoid irrigation in the afternoon, use intercropping, fruit mulching in vegetables, manage pesticide and fertilizer applications, use underground and drainage water for irrigation and change varieties.

On the other hand, the results show that there is an overall reduction in crop wheat and tomato yields under climate change even when adaptation is taken into account. Whereas, under climate change conditions, wheat variety, irrigation amount, sowing dates and water consumptive use (ET) have to be changed according to the growing area to overcome the reduction in yield.

6. Tunisian case studies

Tunisia belongs to the Maghreb countries. It is a hydraulic poor country. In Tunisia arid to semi-arid climate represent 75% of the total area. It shall be noted that the key position of Tunisia between the tempered regions of the Northern Hemisphere and the inter-tropical regions grant its climate a special variability. Such a characteristic makes Tunisia particularly vulnerable to climate change (Ministry of Environment and land planning, 2001).

Hard climatic conditions which could negatively influence socio-economic development pushed the Tunisian government to set up a management strategy of available resources. The strategies consist in managing in an optimal way all available resources in order to allow for a sustainable development.

Three sectors are mainly vulnerable to predicted climate change: water sector, agriculture sector and costal zone (Anonymous, 2002). The agriculture sector has been identified as the most vulnerable sector to climatic change in the all Maghreb countries where it plays an important economic and social role. In addition to the problem of the scarcity of water, Tunisia is confronted to a problem of quality since the most of water resources have medium to mediocre quality and salinity is often high. Indeed, more than 30% of available water contain more than 3g/l salt. This salinity varies from year to year depending on rainfall.

The irrigated areas occupy only 10% of total cultivated areas and water deficit and drought represent a permanent risk for rainfed agriculture that occupies the majority of agricultural area. Rainwater cereals and fruit trees occupy respectively about 97% and 93% of cultivated areas and therefore are vulnerable to climate variability. The production is very variable because it depends essentially on rainfall.

In 2025, the population in Tunisia will reach 13.5 Millions and we could have a downturn in natural resource: water, soil, and forest. This limitation will have a big repercussion on the agricultural production. Among reasons of the natural resource limitation, we can mention the predicted climatic change to which the Tunisian agriculture is very vulnerable (Mtimet, 1999).

In Tunisia, rainfed system is very vulnerable to current climate variability and drought episodes. In this study, we evaluate the interactions between climate and rainfed agricultural production and the vulnerability of the system to climate change.

The main speculations undertaken under rainfed conditions are mainly cereals and fruit crops including olive trees. In Tunisia, 97% of cereals are cultivated under rainfed conditions and they represent one of the most important sectors in Tunisia economy. Areas cultivated in cereals cover 30% of the total cultivated areas.

For the government policy, cereals and mainly wheat production are considered as a vital production. Based on general agreement, that effective adaptation strategies should reduce present vulnerability as well as future vulnerability to climate change (Downing et al., 1997; Adger, 2001), the principal objective for Tunisian government is to reduce the impact of climate variability and climate change by using new agricultural technologies and by a better understanding of wheat response to environmental variability (Latiri, 1994).

The expected climatic changes, especially precipitation decreases, further increases in variability and an increase in drought episodes in addition to population increase, urbanization and industrial development as well as the intensification of irrigation constantly increase water demand and agricultural production variability and consequently the country vulnerability. All this factors could lead to direct and indirect consequences.

6. 1 The Selected Case Studies: Wheat and Olive Trees in the Center Region.

In Tunisia, the centre region is a climatic transition zone between Mediterranean zone and the Sahara region. It is the most vulnerable region because of high climatic variability.

In this region, water deficit and drought represent a permanent risk for rainfed agriculture. Rainfall is characterized by a very important year to year variability and by its scarcity; consequently, production is variable.

The several dry years (deficit > 50%) and drought persistence are more frequent in the south and the center than in the North.

The temperature is moderate; however, very hot conditions are frequent and may occur from May to September. The average temperature in August is about 30°C and a maximum temperature can reach 45°C. Maximum temperature reaches 40.7°C in May and in February.

The high temperature may affect cereal production when they occur in the growing season by increasing the evaporation rate.

An efficient management of water resources, a genetic selection of adapted varieties, the improvement of new agricultural technologies and the implementation of efficient agronomy practices could contribute to reduce a negative effect of climate variability and climate change. Rainfed cereals are a major agricultural sector in the Kairouan region and about 88 percent of the total cereal production in the region is rainfed. Rainfed cereals

Olive tree has a great adaptation capacity to different climates and may also valorize dry regions. However, prolonged drought is damaging to this crop. The olive tree can support about 50% of yearly water deficit; if the deficit is maintained for a second year, the olive tree endures the drought essentially in marginal zones.

Olive tree is more sensible to drought in the center and the south of the country. Olive production for olive oil in Tunisia has a long history and has determined the history of rural populations. The area of production accounts for 1.6 million ha, that is 79% of the total tree area and 33.7% of the farmland (DGPDIA, 1996). This crop is the main activity of a diverse range of farm structures and represents 57% of the total farm revenues. The olive oil production is also the basis for an industrial in the Sfax region.

6.2 Case Studies

6.2.1 Kairouan case study

Climate characterization of Kairouan region climate

In Tunisia the severely dry years (deficit > 50%) and drought persistence are more frequent in the south and the center than in the North (Louati et al. 1999). Climate in the center of Tunisia and especially in Kairouan region is characterized by a very important year to year and intra year variability. This variability in addition to rainfall scarcity; has as consequence a variable agricultural production. In this region, water deficit and drought represent a permanent risk for agriculture and especially for rainfed agriculture.

A- Rainfall variability

The Rainfall data related to Kairouan station from 1951 to 2002 (Figure 82) show an important year to year variation with a standard deviation of 114 mm. The normal annual rainfall is 298 mm, the maximum and minimum recorded for the studied period are respectively 624 and 111 mm.

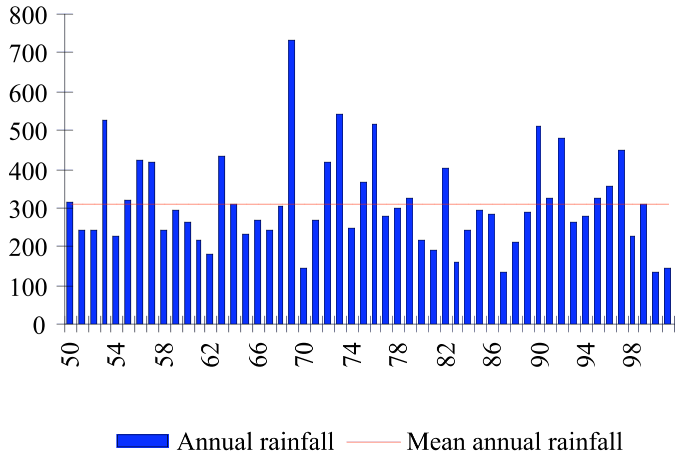


Fig. 82: Annual rain distribution in Kairouan (1950-2001)

For Kairouan, monthly rain distribution (Figure 83) shows that low precipitations are recorded during summer "June, July and August". In the region in addition to intra and inter-annual rainfall variability a high monthly, a monthly variability is recorded like in all Tunisia regions.

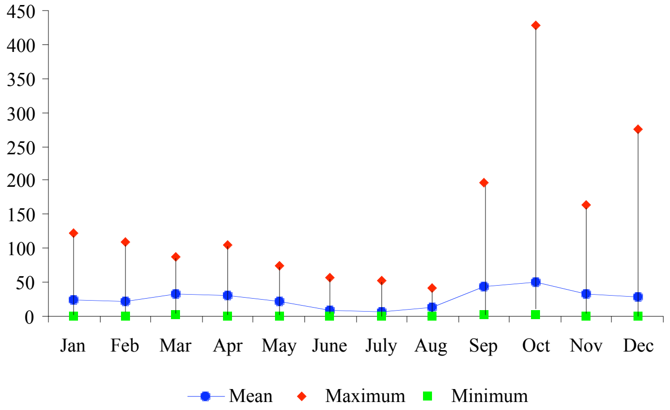


Fig. 83: Monthly rain distribution in Kairouan (1950-2002).

<u>B- Temperature variability</u>

The temperatures are moderate; however, very hot conditions are frequent and may occur from May to September. The average temperature in August is about 30°C and a maximum temperature can reach 45°C. Maximum temperature reaches 40.7°C in May and in February.

These high temperatures may affect cereal production when they occur in the growing season by increasing the evaporation rate.

High temperature can occur during the grain filling period affecting crop growth and development. A major risk to the crop is the very dry wind blowing from the Sahara known as "Sirocco". Sirocco occurs between May and September and the phenomena could be important in the beginning of the spring season (Mougou and Henia, 1998). If Sirocco occurs during the grain filling stage of cereals, an irreversible lost of water from the crop can take place mainly in non-irrigated cereal crops.

In Kairouan the effect of high temperature is intensified by a high solar radiation (Maximum daily solar radiation: 1965hours/year) and high evaporation (Average annual evaporation: 1390 mm).

Among climatic parameters that could be intensified by a climate change and affect negatively the yield in Kairouan region is sirocco. The mean number of sirocco days per year recorded between 1975 and 1995 is 41. The minimum and maximum days are respectively 13 and 60 (Mougou et Henia. 1998).

Sirocco occurs between May and September and the phenomena could be important in the beginning of the spring season. When sirocco happens at the grains growth stage of cereals, an irreversible lost of water can be produced in non irrigated conditions.

In Kairouan average annual solar radiation is high; the maximum can reach 1965 hours/year during (1960 to 1990). Average annual evaporation is also very high (average annual evaporation is 1390 mm/year).

The study of minimum, maximum and average temperature data related to Kairouan station from 1951 to 2002 shows that the increase of temperature during the last 50 years seems clear. It was shown that the increase of minimum temperature is highly significant contrary to the maximum temperature.

Previous studies in Tunisia showed that the tendency does not exist when we analyse a long period data. The study of a long period temperature data (1901-1990) for some stations in Tunisia showed that there is no dominant, statistically significant tendency (Laben Y.1996).

The same application by various methods and made according to rainfall data for a long period (1901 in 1990) and for great geographic regions of Tunisia (Sakis.1994, Benzarti, 1994) does not let appear any significant tendency, either in the rise or in the decline.

All this parameters and their variability affect agricultural production, mainly for rainfed agriculture, by affecting photosynthesis, vegetative development of the plant, cycle length and consequently yield. The whole plant metabolism could change. For agronomists it is important to analyze the impact of temperature increase and to consider this information for genetic selection of cultivars and development of new agricultural technologies.

In the Kairouan region, the possible increase in temperature and solar radiation, and as consequence the increase in evaporation, will result in a worsening of the stress conditions for the crops, mainly the rainfed crops.

Vulnerability of dryland agricultural to current climate variability in the Kairouan Region

The Tunisian component of this project was to evaluate the impact of the current climate variability on wheat production in a semi arid region of Tunisia. As a first step, the results of Tunisian studies on the assessment of cultivated areas and production variability according to climate variability have been considered. Then, a statistical study was used considering monthly rainfall data over 50 years, yield data and wheat production data over 20 years. This has permitted to quantify the effect of rainfall variability on yield. Also monthly air temperatures data from 1950 to 2001 were analysed.

The statistical analysis confirms that the amount of rainfall and its distribution are important factors that determine yield and wheat production. A high significant linear relation (R^2=0.51) has been found between rainfall during the growing season (from November to April) and wheat yield. Also, a significant linear relation (R^2=0.39) has been found between March rainfall (critical growing phase) and yield. Early soon areas are not totally harvested, the ratio between harvested and total soon areas shows a high significant linear relation (R^2=0.44) with rainfall during growing season.

A- Identification of current water deficit and stress for agricultural production in Kairouan.

An analysis of rainfall and evapotranspiration data has been used to evaluate the water balance and to show the sheer scale of water deficit for Kairouan station. Using daily evapotranspiration (Penman Monteith formula), monthly evapotranspiration data from Kairouan was evaluated, in order to calculate the water balance (Figure 84a, 84b).

The Water balance date related to Kairouan station from 1979 to 2000 shows an important water deficit. From March to August, the water balance was always negative. The water deficit reached 200 mm during the summer. During the start of agricultural season until February, the water balance was also negative during almost all months with however less raised values. However the monthly deficit value reached to about 150 mm. The water deficit can affect the harvested areas if it occurs when the cereal water needs are higher.

These results concerning the water balance confirm the importance of amount and distribution of rainfall and the high evapotranspiration are factors, to determine yield and cereal production.

The predicted climate change will increase the water deficit by increasing temperature and rainfall variability and consequently can worsen the situation. Therefore, due to the variability of rainfall, the high evapotranspirarion increase the need of new adaptation methods as a selection of new cultivars, change of planting date, increasing of agriculture area and use of new agronomic practices.

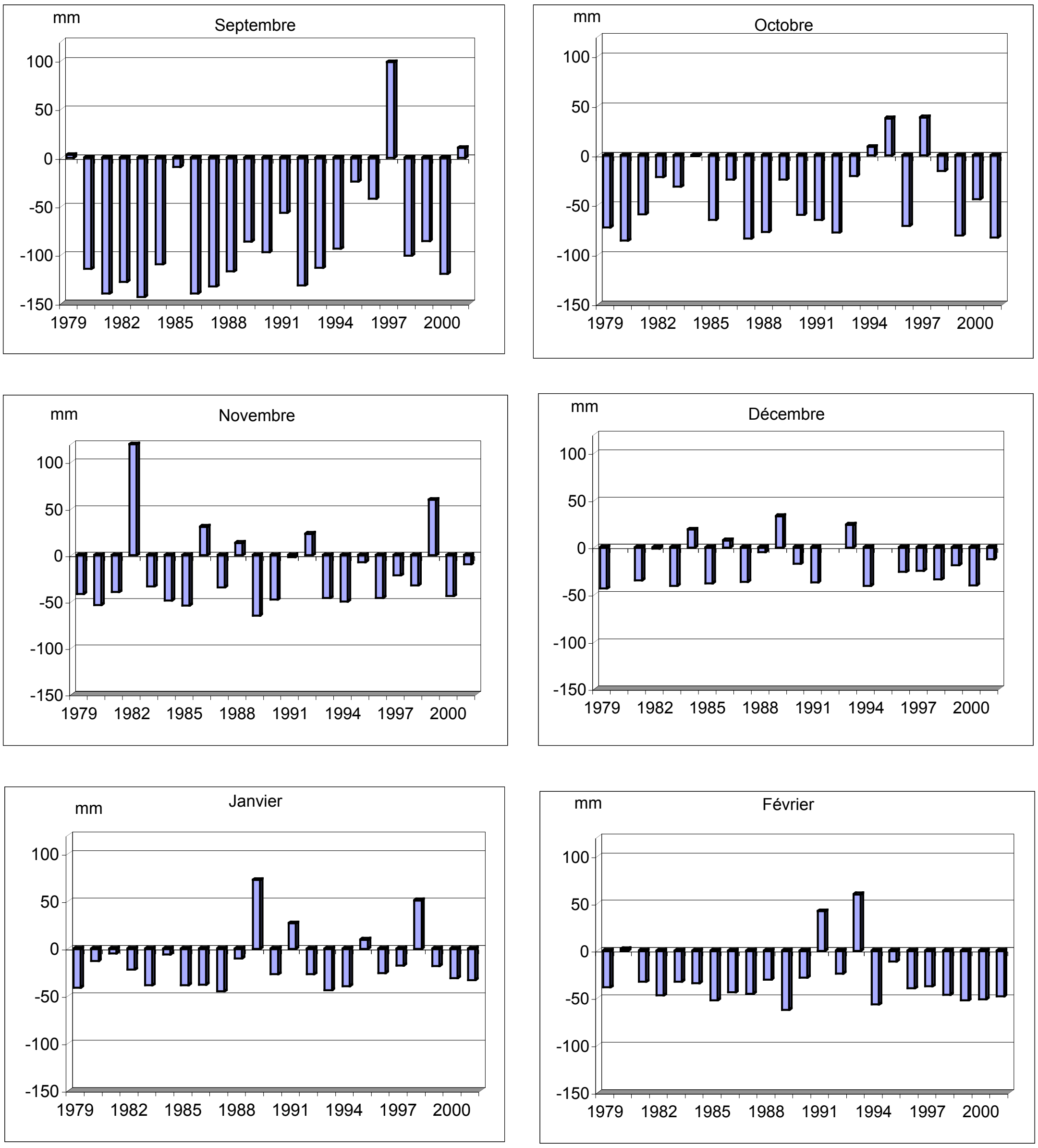


Fig. 84a: Monthly agrometeorological water balance (P- PET) for Kairouan station (1979/2000) during September to February

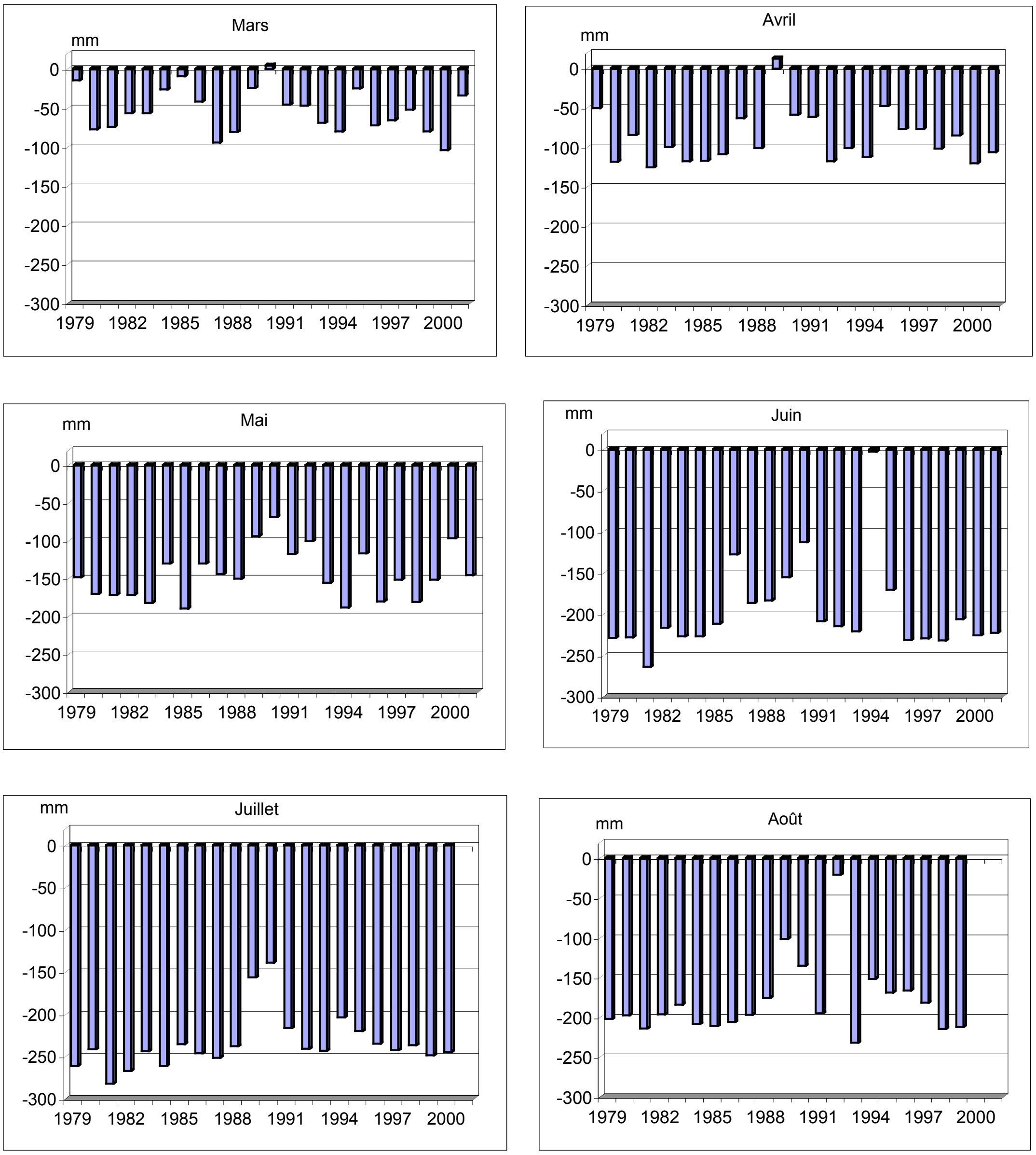


Fig. 84b: Monthly agrometeorological water balance (P- PET) for Kairouan station (1979/2000) during March to August.

B- Characterization of Agro-climatic drought episodes that affect wheat in Kairouan region

Previous studies (Mougou, 2003) have analysed the daily water balance (precipitation vs. evapotranspiration) in Kairouan, along the period 1979-2000, using Penman-Monteith method for calculation of evapotranspiration. In this region, the water balance showed a deficit over 200 mm form March to August, and over 150 mm during September to February in all years. But these important water balance deficits were not uniform across the entire Kairouan region and, therefore, there were large variations in the crop growing conditions in the different areas within the region. In the most stressed areas, water balance deficits resulted in crop failures during the most severe drought years. This part of study analyzed the water balance in four points within the Kairouan region: Ouslatia, Sbikha, Haffouz and Kairouan "Delegations" (administrative units).

The water balance integrates the rainfall and the wheat water requirements which represent optimal water needs calculated experimentally (Figure 85). It was considered that precipitation is intended for satisfaction of water needs and that the excess (surplus) of rainfall water is lost (infiltration and runoff). The water balance was calculated for the period from November to April, which corresponds to the wheat crop growing season.

Water balance was calculated according to the equation below:

Water Balance = Rainfall - ETw

Results

The calculation of the water balance showed that wheat is always grown under drought conditions in the Kairouan region. The wheat water requirements were almost never satisfied in rainfed agriculture. Wheat suffered an important water deficit balance during almost all growing period in the four "delegations" (Kairouan, Haffouz, Ouslatia and Sbikha). In all cases, the water deficit occurred from December to April, and the water balance was only positive in November because the water requirement was satisfied by soil water (Figure 86).

The results showed that the months with water deficit range from 57 to 100 % during the 1979 to 2000 period (Figure 87). The largest annual water deficit during the wheat crop growing season was -218 mm (64 % of the total wheat water needs) for the Haffouz delegation (Figure 88).

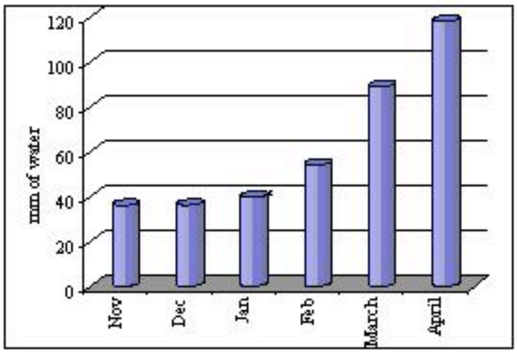


Fig. 85: Experimental values of monthly water needs for wheat in Tunisia

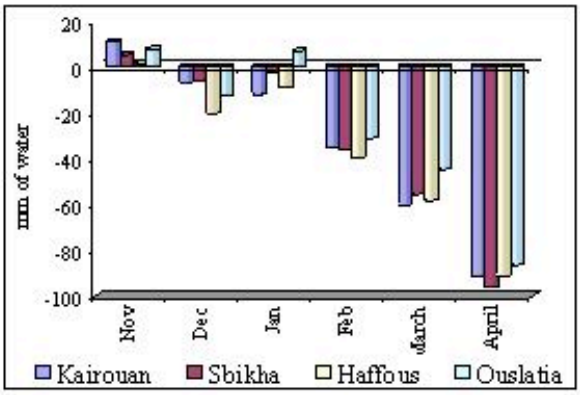


Fig. 86: Mean monthly what water balance (1979-2000)

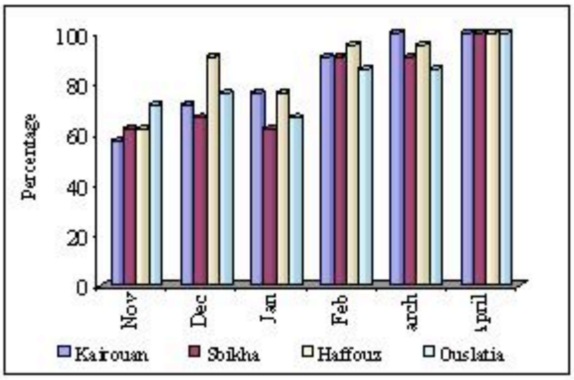


Fig. 87: Percentage of dry months with water deficits for wheat (1979-2000)

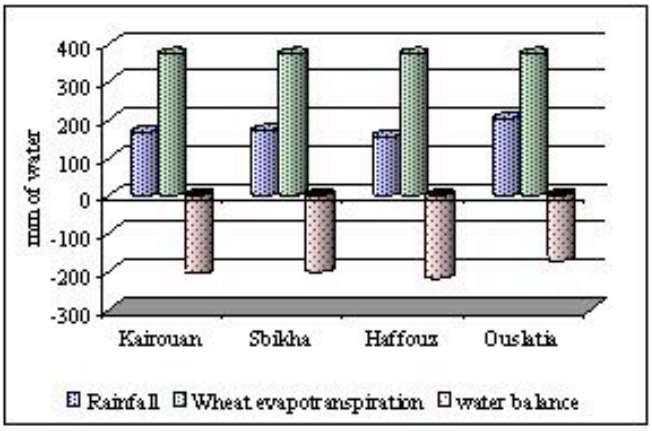


Fig. 88: Annual what water balance during the wheat growing season (1979-2000)

C- Impacts of rainfall variability in wheat production

The analysis that was carried out in the Ouslatia, Sbikha, Haffouz and Kairouan Delegations (Figure 89) represented durum wheat yields and harvested areas according to total rainfall (1995 – 2003). Both yields and harvested areas are correlated to rainfall. The regression coefficients (Table 74) were highly significant for the four sites but they were different from site to site.

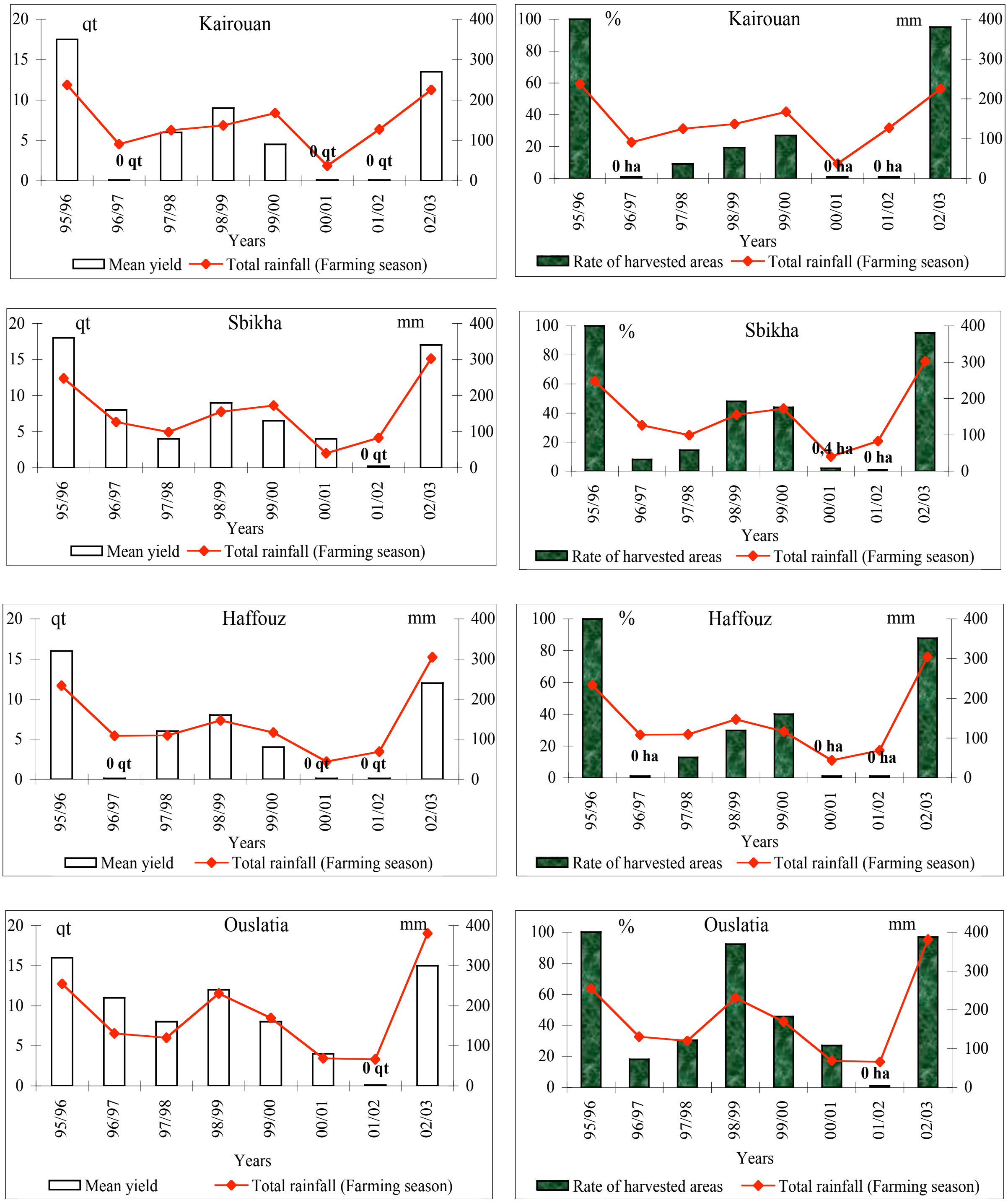


Fig. 89: Durum wheat yields (left panel) and harvested areas (right panel) according to total rainfall for the 1995 to 2003 period in Kairouan, Sbikha, Haffouz and Ouslatia

1995/2003	REGRESSION COEFFICIENTS		
	Rate harvested areas/Total rainfall	**Yield/ Total Rainfall**	**Yield/Rainfall March**
Kairouan	0.92	0.84	0.87
Sbikha	0.95	0.92	0.65
Haffouz	0.92	0.81	0.80
Ouslatia	0.87	0.85	0.67

Table 74: Regression coefficients of durum wheat yields and harvested areas according to total rainfall for the 1995 – 2003 period in Kairouan, Sbikha, Haffouz and Ouslatia.

Table (2) shows that wheat yield during rainy years (1995/1996 and 2002/2003) were high compared to dry years (1996/1997 to 2001/2002). The yield increased during the rainy years, and ranged between 178 % (Ouslatia) and 80 % (Ouslatia) of dry years yields (Table 75).

	Rainy years (1995/1996 and 2002/2003)		Dry years (1996/1997 to 2001/2002)		Yield increase during rainy years in relation to dry years (%)
	Mean rainfall (mm)	Mean yields (qt)	Mean rainfall (mm)	Mean yields (qt)	
Kairouan	231,55	15,5	114,2	6,5	138
Sbikha	275,2	17,5	112,6	6,3	178
Haffouz	269,15	14	99,1	6	133
Ouslatia	317,7	15,5	130,9	8,6	80

Table 75: Mean yield during rainy and dry year abd yield increase during rainy years (1995 to 2003) in Kairouan, Sbikha, Haffouz and Ouslatia.

A simple linear regression was used to quantify the variability of cereal yields in relation to rainfall variability in Kairouan area during the last two decades. For monthly rainfall data it was considered only the farming season period, i.e. the period from September to April. For yield data it was considered the average annual yield in the region. And the following regression equation was obtained:

$$Y = 0.0287\,X - 0.0289; \quad R^2 = 0.5612$$

Y: Average cereal yield

X: Monthly rainfall data

R^2: Regression coefficient

The rainfall variability explains the variability of cereal yield with a rate of 56 %.

Vulnerability of Kairouan region to predicted climate change.

A- Agroclimatic characterization in climate change conditions

A.1- Climate index in climate change conditions

Climate index is used to establish criteria to compare between and to classify climate. It was used to classify climates according to their aridity. For the agroclimatic characterization in actual and climate change conditions it was calculated and compared the actual and the predicted climatic index. Standard daily Meteorological data were used; 1950-2001 period for temperature and rainfall, 1974-2001 for humidity, sunshine and wend speed. And it evaluated in climate change conditions as following:

(1) The *Martonne Aridity index*: ,

(2) The *Emberger coefficient,* ,

(3) The *Gaussen Ombrothermic Index (1952) and graph.*

P: annual average rainfall (mm),

T: annual average temperature (°C),

M: mean maximal temperature of the hottest month (°K),

m: mean minimal temperature of the coldest month (°K).

To evaluate the climate indexes in climate change conditions, IPCC scenarios for the temperature were used, besides the scenarios mentioned in the report of the Regional Coordination of the UNDP/GEF RAB 94/G31 Project (Anonymous, 2002) for rainfall.

A.1.1- Martonne Aridity index and Emberger index

The application of climate scenario to evaluate the Martonne Aridity index and the Emberger index in climate change conditions showed an evolution trend from the semi-arid to the arid climate in Kairouan region (Table 76, 77**).** This tendency towards the dry was remarkable from a rainfall decrease of -5mm, if the temperature increase is equal to 2°C or more.

Martonne Aridity index	Temperature increase				
	Mean Temperature	+ 1.3°C	+ 2 °C	+2.5°C	+4°C
Mean actual rainfall	10 Semi-arid	10 Semi-arid	10 Semi-arid	10 Semi-arid	9 arid
Rainfall decrease: (–5%)	10 Semi-arid	10 Semi-arid	9 arid	9 arid	9 arid
Rainfall decrease: (–20%)	8 arid	8 arid	8 arid	8 arid	8 arid

Table 76: Martonne Aridity index evolution in climate change conditions

Emberger quotient	Temperature increase				
	Mean Temperature	+ 1.3°C	+ 2 °C	+2.5°C	+4°C
Mean actual rainfall	34 Semi-arid	34 Semi-arid	34 Semi-arid	34 Semi-arid	34 Semi-arid
Rainfall decrease: (–5%)	33 Semi-arid	32 arid	32 arid	32 arid	32 arid
Rainfall decrease: (–20%)	27 arid	27 arid	27 arid	27 arid	27 arid

Table 77: Emberger index variation according to climate scenarios

A.1.2- Ombrothermic diagram

According to Gaussen, the month is considered dry, if the coefficient of monthly rainfall ($P_{[mm]}$) by the average temperature (C°) is lower than 2 values. The ombrothermic diagraph is a graph (months in abscissa, rainfall and temperature in ordered) which highlights the dry and the rainy periods. Kairouan region under actual climate conditions (1962 to 2002) (figure 90) showed a dry periods ranged from 15 January to 15 February and from 15 March to 15 September.

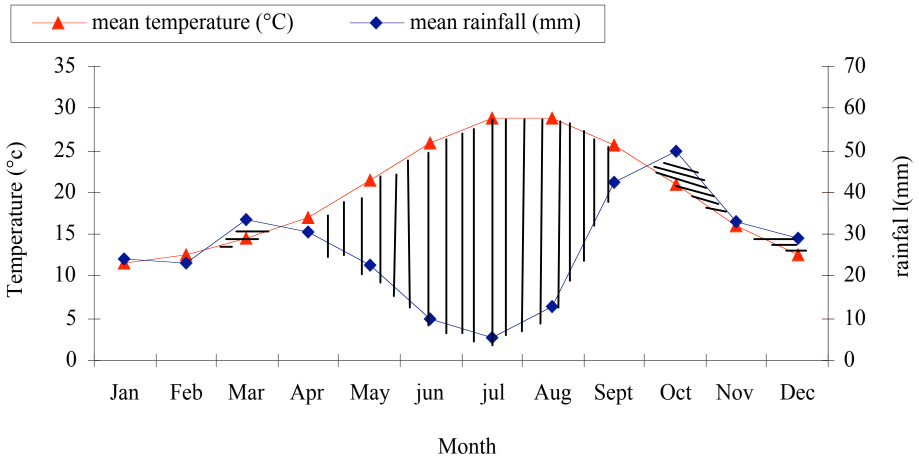
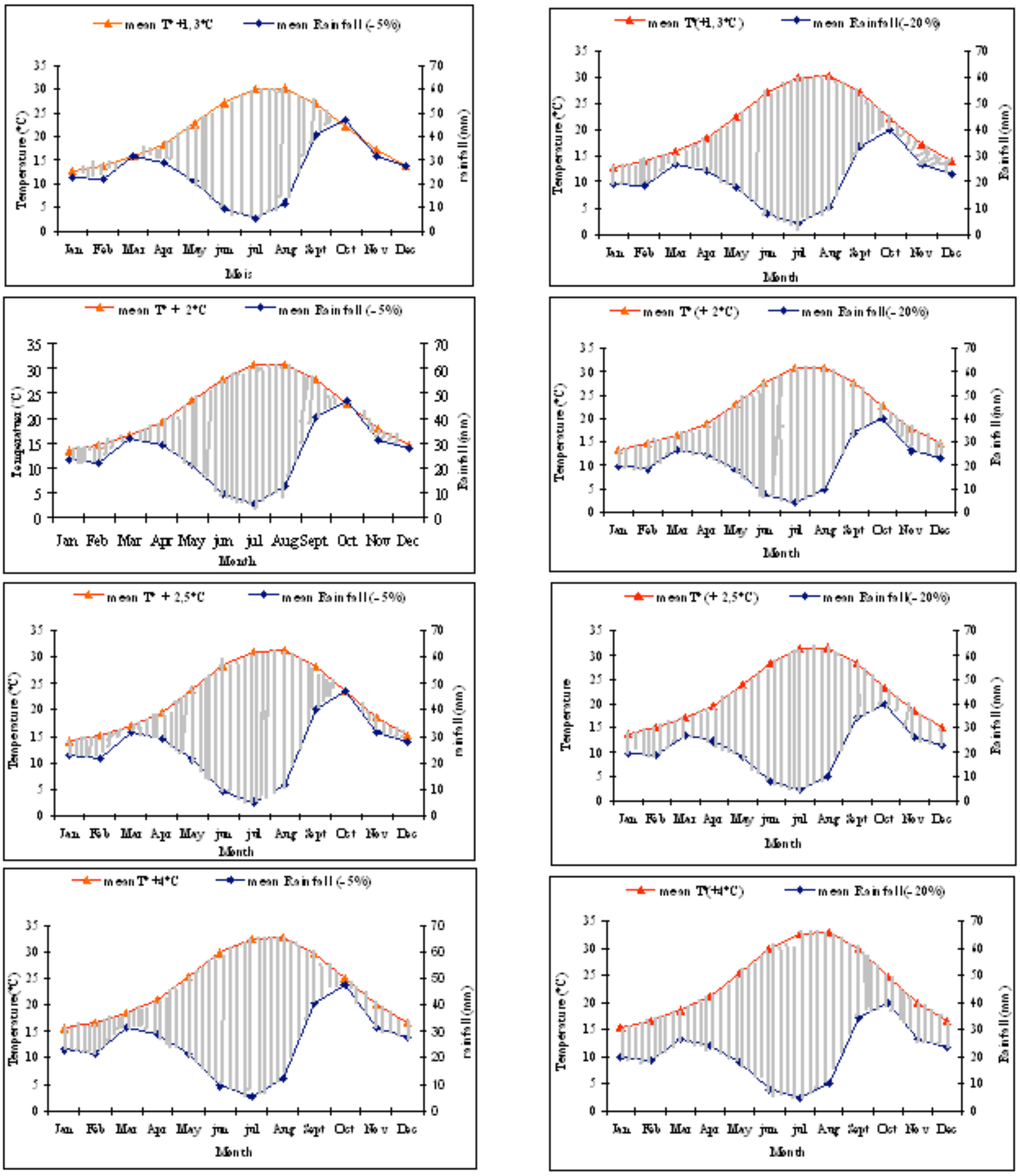


Fig. 90: Gaussen Ombrothermic diagram in actual conditions for Kairouan region

Under climate change conditions (temperature increase and rainfall decrease), the Ombrothermic Diagrams showed a lengthening of the dry period. Dry period became more and longer than scenario became warm and the rainfall decrease. For the pessimistic scenarios temperature increase and 20% decrease on rainfall, the dry period spreaded out over all year (Figure 91).



▥ Dry period

Fig.91: Gaussen Ombrothermic diagram in climate change conditions for Kairouan region.

A.2- Evapotranspiration increase in climate change conditions

Daily maximum and minimum temperature, maximum and minimum humidity, global radiation and wind speed data was used to evaluate reference evapotranspiration (RET) for Kairouan site current and future climate conditions according to IPCC scenarios (+1.3°C, +2.0°C, +2.5°C, and SRES scenarios (+4°C), in order to show the rate of evapotranspiration increase by year 2100.

By using these scenarios, the rate of RET increased by year 2100 compared to actual values (1872mm). It was 3.1% for the optimistic scenario (+1.3°C), 4.5% for 1.3°C and 9.4 % for the pessimistic scenarios (+ 4°C) (Figure 92).

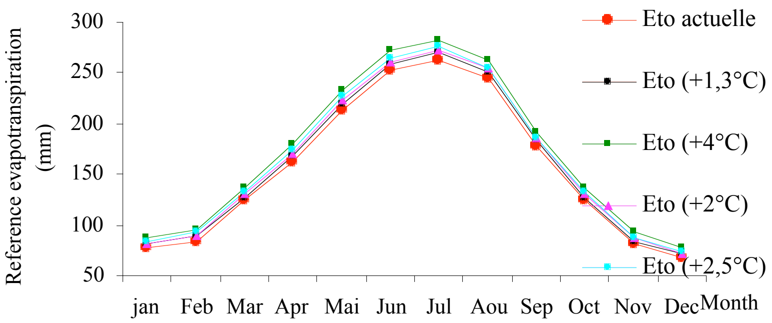


Fig. 92: Reference evapotranspiration evolution in actual and climate change conditions (Kairouan region).

To emphasize the impact of RET increase on water availability in the region, the RET increases had compared to the mean total annual rainfall in the Kairouan region (312.2mm). This analysis showed that the increase of water losses by evapotranspiration in temperature increase conditions represented 18% of the mean total annual rainfall for 1.3°C temperature increase and it reached 57% if the temperature increase is equal to 4.0°C.

In previous analysis it was shown that the water demand projections for agriculture in the centre region (taking into account the improvement in irrigation efficiency) up to 2030 was equal to 3435 m^3/ha (Lebdi 2002). The rate of evapotranspiration increase was compared to this value to underline the RET increase impact on availability of water for irrigation.

The evaporation increase will aggravate the water deficit for rainfed and irrigated agriculture in Tunisia. In fact, the available water will be insufficient for the irrigated areas even if they are increasing at a slow growth rate (Lebdi 2002). For the rainfed cereals, climate change will increase the water deficit by increasing temperature, evaporation and consequently water requirement.

In the Kairouan region, by year 2100, the rate of increase of maximum wheat evapotranspiration (MET_W) will represent 11.3% of the actual wheat water requirement (705mm, calculated using the cultural coefficients in Zaîri 2003). The water deficit increase will represent 15.2% of the actual wheat water deficit (523.6mm) for the pessimistic scenario (+4°C). Table (78) summarize the temperature increase impacts on evapotranspiration (RET and MET_W) and the impact of evaporation increase on wheat water consumption.

	Temperature increase			
	+1.3°C	+2.0°C	+2.5°C	+4.0°C
Annual RET increase	3,1	4,4	5,7	8,9
Annual RET increase / Mean annual rainfall	18,4	27,3	36,0	56,5
Annual RET increase / Water demand projection	16,8	24,8	32,8	51,4
MET_W increase (wheat growing season)	3,8	5,2	7,7	11,3
Water deficit increase (wheat growing season)	5,2	7,1	10,4	15,2

Table 78: Rate of RET, METw and wheat water deficit increase (%) in climate change conditions (Kairouan)

A.3- Agricultural production in climate change conditions

A.3.1- Climate change impact on wheat production by the DSSAT model.

To evaluate the climate impact on agricultural production, DSSAT model were used (Rosenzweig and Iglesias, 1998; Iglesias et al., 2000). Field experiment data of wheat yield and growth stage were used. The experiment carried out in 1996-1997 concerned the effect of two irrigation methods on the yield and growth of a local wheat cultivar in Kairouan region.

For the yield simulation 10% rainfall decrease and 1.5°C temperature increase scenario was used. The simulation by the DSSAT model showed that 10% rainfall decrease can generate 12% yield decrease. If we consider in the same simulation rainfall decrease and 1.5 °c temperature increase the wheat yield decrease will be equal to 48%.

A.3.2- Climate change impact on wheat growing season duration

Previous studies showed the climate change impacts on trees and grapes. It concluded that there is a shortening of three weeks in a period of thirty years of trees flowering dates in the Rhône valley (Domerge, 2001). Ganichot (2002) found a shortening in the grape harvests dates from one month in fifty years period in the same region.

In order to evaluate the impact of climate scenarios on cereals production, it is difficult to dissociate the impacts of used techniques and climate conditions.

Domerge (2003) founded that for wheat, for example, it is possible to discern a slight upward trend of the leaf area index (LAI) and of the yield; nevertheless the biomass could decrease. It is important to point out that for cereals, the growth speed would be moderated as a consequence of slightest satisfaction in cold requirement during winter.

For Kairouan case study, projected climate change impacts on wheat production had assessed according to the IPCC (Inter governmental Panel on Climate Change) scenarios. (Anonymous, 2000).

The same time series of 1996- 1997 field data were used to compare the experimental growing season duration of wheat with the simulated duration under temperature increase predicted by the IPCC scenarios (1.3°C *temperature increase* (Scenario IS92c), 2°C (Scenario IS92a), 2.5 °C (Scenario IS92e), and 4°C (Catastrophic scenario). Heat requirement for the different growing stage was evaluated in experimental conditions and temperature increase conditions.

The evaluation of growing season duration in climate temperature increase conditions (IPCC scenarios), showed a growing season shortening. The shortening varies from 10 to 30 days and increased with the temperature increase (Table 79 and Figure 93a, 93b, 93c, 93d).

Scenarios	**Cycle duration (Degree day)**	**Cycle shortening (Day)**
Normal condition	193	
Temperature increase (+.1.3°C)	183	10
Temperature increase (+.2°C)	177	16
Temperature increase (+2.5°C)	173	20
Temperature increase (+4°C)	163	30

Table 79: Increase temperature affect on wheat cycle duration in Kairouan region.

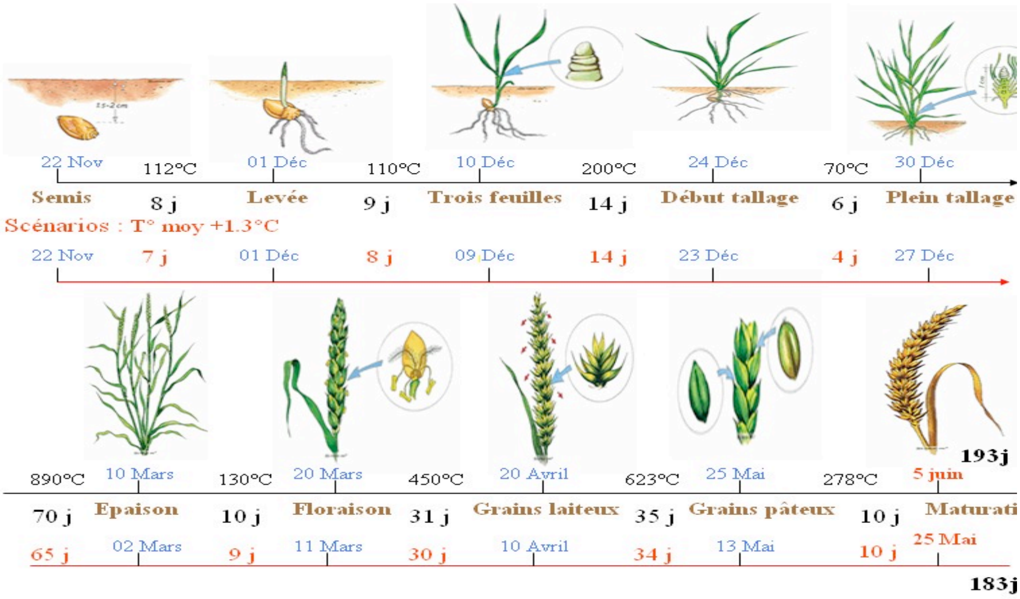


Fig. 93a: Shortening wheat cycle from 193 to 183 days for 1.3°C temperature increase

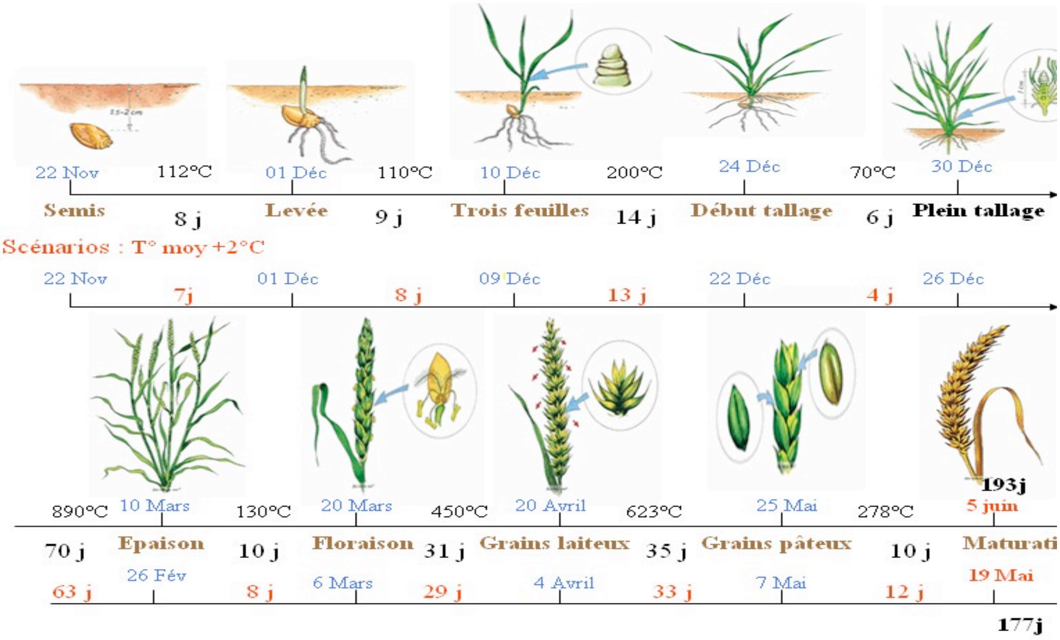


Fig. 93b: Shortening wheat cycle from 193 days to 177 days for 2°C temperature increase

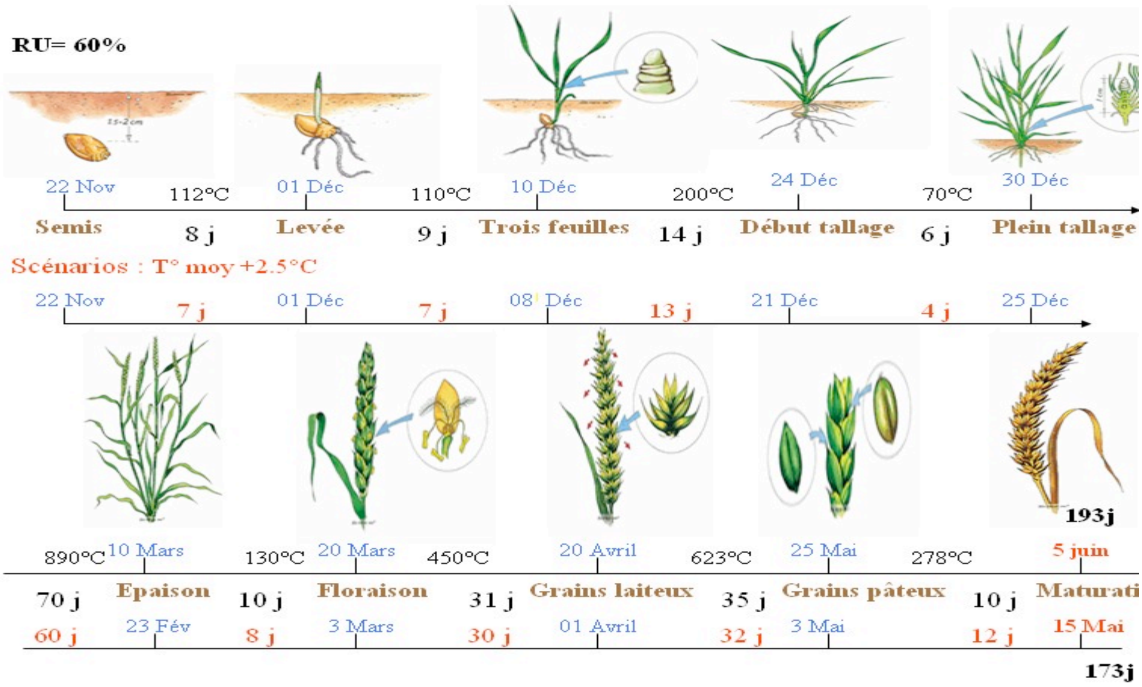


Fig. 93c: Wheat shortening cycle from 193 days to 173 days for 2.5°C temperature increase

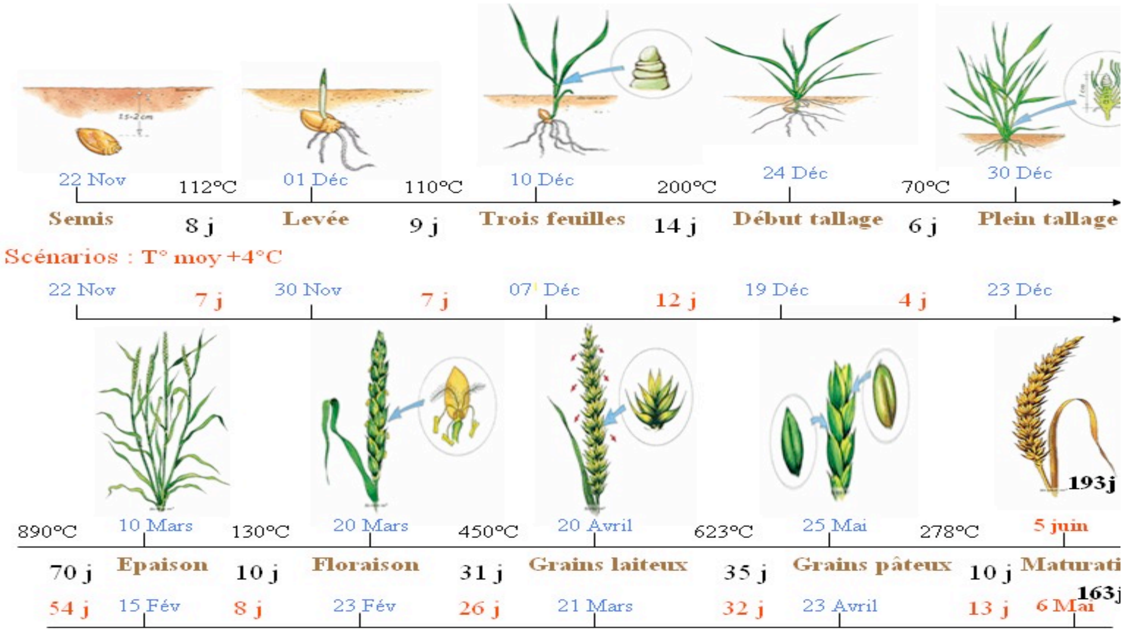


Fig. 93d: Shortening wheat cycle from 193 days to 163 days for 4°C temperature increase

Stakeholders survey analysis

A prototype survey was prepared in the previous stages of the project (Mougou et al., 2003). This survey was given on farmers in the Kairouan region. Figure (94) shows the method of survey development in Tunisia. In step one, the INRGREF (Institut National de Recherche en Génie Rural, Eaux et Forêts) team, central and regional technical staff involved in the project, prepared conjointly the survey. The farmers were selected conjointly by the regional technical staff taking into account their initial response and willingness to participate in the study. In the second step farmers were questioned jointly by the research and extension teams. In the third step, the research team analysed the results of the survey.

The survey general objectives were:

- Determine the rate of rainfed cereals in the farms;
- Define the farmers behaviour toward the effect to climate variability on agricultural production;
- Define the current and future vulnerability of rainfed cereals;
- Analyze the capability of the farmers to adapt to climate variability;
- Define the "know how" of the farmers in relation to predicted climate change;
- List the adaptation methods already used in the farms;
- Specify the reason that prevents the farmers to adapt to current and future climate variability.

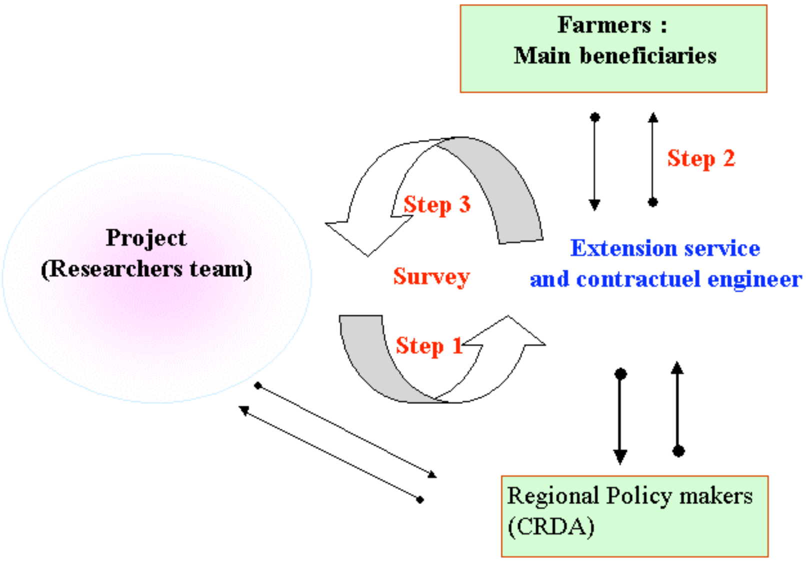


Fig. 94: Method of survey development in Tunisia.

A- Survey sampling Methods and analysis

According to the statistics of the regional centre for agricultural development (CRDA, Centre Regional de Development Agricole) there were 3500 farmers that produce cereals in the region of Kairouan but in recent years 1500 of them have changed their production system to market gardening and currently only about 2000 farmers represent cereal production. In theory, a significant sample must contain at least 5% of the total population that is 100 farmers. In our study, we limited the survey to 58 farmers that represented 3 percent of the total population due to budget and time limitations. The sampling method was "random sampling" to avoid problems such as farmer absenteeism, difficulty to access the farm due to the state of the roads.

The apparently low percentage of schooling (55.17 %) was obvious since the average age of the farmers was 58 years. The farm size was relatively large (29.8 ha). The participation of the family members in agricultural activities was high; as 62 % of the farms family members participate in the activities.

In the Kairouan region the value of the rainfed agricultural land is 100 Tunisians Dinars. This high price discourages farmers to continue the agricultural activities, since the opportunity cost for them is not interesting because the average cereal yield during the last two decades has been 6.9 quintals/ha.

Surface ploughing is adopted by almost all farmers since this type of labour it is relatively cheap. Only 29.3 % of the farmers' practiceed crop rotation, the given reason was the several difficulties in doing so. In rainfed agriculture, 82.75 % of the farmers were not use fertilizers, and 17.25 % of the farmers used fertilizers only during the favourable climatic years. 39.65 % of farmers were not use commercial selected seeds, but they used their own-produced seeds or seeds bought from other farmers.

Supplemental irrigation was used by 25.86 % of the farmers. Irrigation is applied mainly to fodder crops for livestock. The irrigated surface represents only 3.26 % of the total cultivated area because of the small amount of water available and the financial constraints to purchase irrigation materials. All farmers that used supplemental irrigation were conscious of the advantages of fertilization and its management (date and quantities). It is important to notice that rainfed cereals were the principal activity even for the farmers who have access to water.

Ovine production is a vital activity among farmers. Indeed animal production gives added value to fodder resources. The data of survey showed that 72.4 % of the target farmers practise especially the ovine production. After 2002, 27.8 % of them were obliged to liquidate their herds because of the previous drought years (1997-2002).

The animal production activity was considered as financial refuge for the majority of farmers because of the facility to liquidate the animals if necessary, the facility of animals' substitution and the possibility for increasing livestock number during the “good year”, and the high rate of sheep reproduction.

Cereal yields fluctuated in the surveyed farms, especially for rainfed cereals. This was due primarily to severe climatic conditions, which were mainly characterised by the intra-annual and inter annual drought. Average of cereal yield during the two last decades was 6.9 quintals/ha in the region of Kairouan. The National average is 13 quintals/ha. Cereal yields in the northern region of the country were larger since the precipitation was larger in that region, for example in Béja average cereal yields was 20.09 quintals/ha. It is important to notice that irrigated cereals yields can reach 80 quintals/ha in other areas of Tunisia. It is evident that this cereal yields in Kairouan are unprofitable, especially for farmers who have a small farm size.

Table (80) shows the average yields of rainfed and irrigated durum wheat and barley in the region of Kairouan. The values showed that rainfed yields were smaller than irrigated yields because irrigation decreases the risk to farmers by increasing production. Indeed irrigated cereals yields provided a production profit of 40 % in relation to the average maximal yield in rainfed cereals. That was the reasone of farmers' orientation toward breeding to ensure a minimum incomes and the survival of their system.

The low yields produced from Kairouan farmers could be explained by:

- The low level of farmers schooling that constitutes a difficulty to understand the extension services advices;
- A difficulty for the extension services to change the farmers behaviours;
- A difficulty for the farmers to adopt new techniques even if they agree with them.

	Rainfed cereals		Irrigated cereals	
	Durum wheat	Barley	Durum wheat	Barley
Average maximal yield q/ha	32.77	39.61	46.66	54.16
Average minimal yield q/ha	0	0	24.16	37.91

Table 80: Average cereal yields in Kairouan region.

It arises from the survey analysis that only 20.7 % of the sample farmers adopted the advice of extension services. In addition, the extension services affirmed that near all farmers do not follow exactly the advice.

B- Farmers attitude toward climate

Most of farmers expressed their suffering from difficult climatic conditions. Indeed they suffered from long years of drought. Even during the rainy years, rainfall distribution may be inadequate for the crops. Dry conditions in March decrease cereal production and result in a loss of income for the farmer.

According to farmers' responses, 96.5 % of agricultural output was determined by climate. This perception resulted in a feeling of frustration. It was obvious that this behaviour is the result of the drought during the last years (1997 to 2002).

Only 12 % of the sample population know the possibility of adaptation methods to climatic change. In the other hand it was noted that 91.4 % of the farmers used their own methods of adaptation to current climate variability. 48.4 % of them have the will to build a well, but they found administrative, financial and land constraints.

The results of the survey show that farmers adopt currently several adaptation techniques during adverse climate conditions:

- Change of sowing date if the autumn is drier than normal;

- Storage of fodder to ensure the livestock food;

- Cactus cultivation for fodder in dry years;

- Changes in cultural techniques and management to ensure cost decrease, especially decreasing the number of labours and fertilization;

- Ovine breeding is considered as a valuable option and interesting adaptation strategy, because of the potential resistance of sheep to adverse conditions and their capacity for using a range of fodder resources. In addition, the possibility of using crops without alternative value, such as cactus, is an added value of sheep production.

The choice of crop varieties is not considered important and is not listed as an adaptation option by the majority of the farmers.

C- Discussion of the survey results

Previous analyses of drought management in Tunisia showed that variability in cereal production is explained by the variability of rainfall with a rate of: 78 % for the north; 50 % for the centre; and 40 % for the south. This is confirmed by our study that shows that in Kairouan region rainfall variability explains 56 % of the cereal yield variability.

In contrast, according to farmers' responses, 96.5 % of agricultural output is determined by climate. It is clear that the target farmers over-estimate the effect of climate variability. Consequently, it is necessary to know the other factors that have an effect on yield variability that are not considered by the farmers. Among these factors is the lack of recognition of farmers of the importance of farming techniques management. In addition, the possible investments by farmers may be not completely productive since the price increase for agricultural products is lower than for industrial products.

The survey results showed that only 20.7 % of farmers adopt the extension services advices. Indeed, it arises also from the investigation data that the extension services are efficient only in medium and large farms. This is confirmed by Chennoufi and Nefzaoui in 1996 who mention that "technologies generated appear to be more readily adopted by large-scale farmers, agricultural development agencies, rural development societies and cooperative farms, rather than by the majority of medium- and small-scale farmers". This behaviour is antagonistic with the strategies of rural development in Tunisia. In fact the strategies of rural development are directed towards a participative approach and a technical aid mainly for small farmers who represent about 80% of farmers in Tunisia.

6.2.2 Sfax case study

Sfax region characteristics

The choice of Sfax region is justified by the position of this region as the first producer and exporter of olive oil in Tunisia. Sfax represents 11% of the National olive oil revenues, 34% of the processing capacity, and contributes to 37% to the National production and 68% to the exports of olive oil. The region of Sfax is located in the Centre of the country. The region of Sfax is bordered from the north by Governorate of Mahdia and Kairouan, from the West by Sidi Bouzid and Gafsa, from the South by Gabès and the Mediterranean Sea, and from the East by the long Mediterranean coast of more than 120 km. The region is about 60 km wide.

Sfax climate is Mediterranean arid or semi arid, characterized by a long period of dry and warm spring and summer, followed by a low precipitation autumn and cool winter. The average rainfall recorded during the studied period is 192.4 mm/year. Rainfall is usually torrential and are characterized by great spatial-temporal variations and inter and intra annual variations also important (Figure 95). The frequent dry years (deficit > 50%) and drought persistence are more frequent in the south and the Centre than in the North (Figure 96).

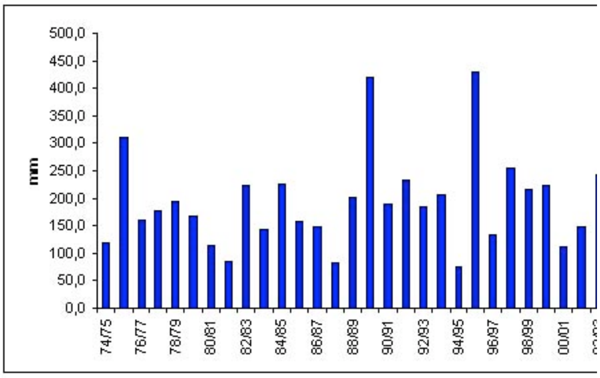


Fig. 95: Average annual rainfall (Sfax region).

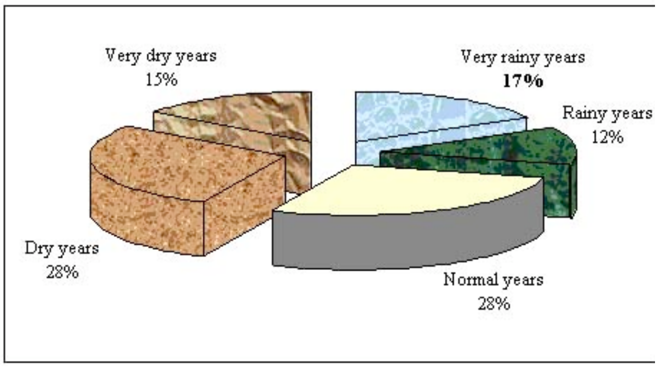


Fig. 96: Typology of rainfall in Sfax (1901-1990) (Bousnina. 1997)

Olive tree has a great adaptation capacity to different climates. Nevertheless, it remains sensible to water deficit. However, prolonged drought is damaging to this crop. The olive tree can support about 50% of yearly water deficit; if the deficit is maintained for a second year, the olive tree endures the drought essentially in marginal zones.

This climatic variability affects strongly the agricultural production of olives. (Figure 97) shows the large variability of olive production for the region of Sfax for the period 1974-2002. (Figure 82) also shows that although the large increase in production area, the production has not increased.

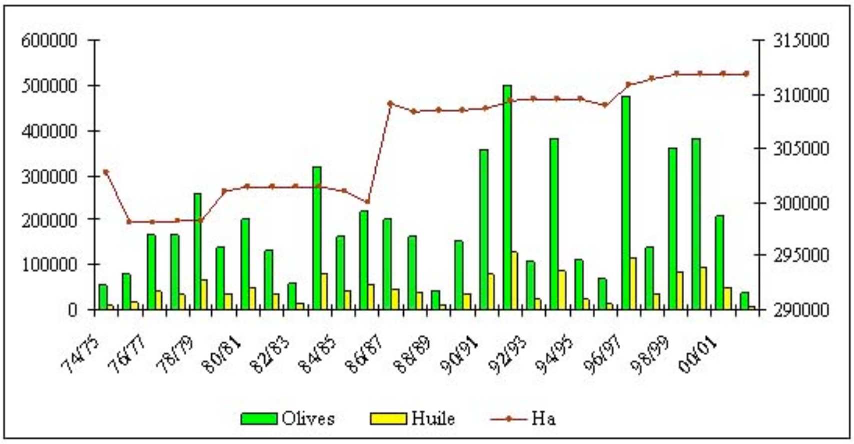


Fig. 97: Evolution of Olive trees production and harvested areas in Sfax region (1975-2002)

As it was done in Kairouan region, a farmers' survey had performed in the Sfax region. This survey aimed to help the researcher's team to:

- Evaluate qualitatively water deficit impact and high temperature impact on production.
- Identify the farmers strategies;
- Evaluate adaptive management options for better utilization of rainfall;

- Compare farmers strategies with strategies allowing the use of rainfall with a maximal water efficiency in order to secure a minimum production for the farmers;
- Identify the opportunities and difficulties in the actual policy making process.

Context of olive production in Sfax region

Olive production can be adapted to difficult climatic and edaphic conditions, but the olive is a species with alternating characteristics. This alternating phenomenon is more accentuated in semi-arid and arid regions due to the effect of low and irregular precipitation (torrential rains and drought periods) and due to the poor quality of the soils occupied by the crop in marginal areas that are not optimal for olive production. In summary, the characteristics of the olive trees, the climate, and the soils are the source of production variability that affects the performance of the overall production chain.

The olive producers have extensive experience, although most of them have also other occupations and they are relatively old, the tradition of olive production is inherited to their culture, and therefore the labour is greatly qualified. Nevertheless, the level of literacy and the technical qualifications are relatively low. The programs of formation of the Extension Agencies (l'Agence de la Vulgarisation et de la Formation Agricole) are directed to the younger producers and workers. In relation to the production techniques, the level of knowledge of olive producers is insured by the organization of a series of information activities related to the management practices. These extension programs aim to improve the cultural and management techniques of both the producers and the hired labour workers. In this respect the behaviour of the producers and the workers shows a large influence of the traditions. Their behaviour is not influenced by economic considerations for optimizing the production or the investments. The culture of olive oil production is considered little demanding and does not benefit in general of the technical advances in production management.

The social importance of the olive production has its origins in the long live of the olive trees. This has marked the history of Tunisia and has been the agricultural activity more important for generations. This tradition limits the potential for innovation techniques. The only innovation that has been introduced is the mechanization of work in the soil. The plantation density has remained low in the average, and the marginal lands have not been improved in terms of soil fertility and general conditions. The old plantations are a main focus of a program of tree removal and re-plantation, but some of the required operations for the success are sometimes not considered.

Socio-economic study: methods and objectives

Sfax region represents, since several years, the main olive-growing zone in Tunisia. The case study of this region assured in three steps corresponding each to an analysis ladder. The first step concerned the entire Sfax region. The average data related to the olives yield and the rainfall was used during the 1976-2002 period. The dependence relation between these two variables was measured. It is important to note that the olive yield is a complicated function that depends on many factors (conducting methods, soil nature, ages and structure of plantations…. and climate).

At the second step, It was preceded to an investigation close to a sample of 60 private olive-growing farms. It was as well as possible to collect information set relative to these determinants during three seasons. It's important to note that rainfall measurements were not available at the farms level; it's available at the meteorological stations.

All these factors appeared to have different impacts from region to region and from locality to another; consequently, it is difficult to define precisely the impact of each factors and of rainfall on olive yield basing on regional means data.

At the third stage level, to overcome the two difficulties, the field of investigating was limited to a public firm "Châal Domain". This limitation justifies itself by the availability of all necessary information to identify the effects on the olives yield of rainfall and all the others production parameters.

A- A regional study

Olive oil production constitutes the principal agricultural activity in the region. The agrocombinats of Chaal, Bouzouita, Essalama and Bir Ali of the Office des Terres Domaniales (OTD). Also, from 1995, there was a large and diverse range of private farms and a new category of farm and technical producers (46 lots). Oliviculture also maintains 372 oil production plants that have a capacity of trituration of 10,5 thousand tons per day and a stocking capacity of 100.7 thousand tons of olive oil.

The plantations of olive count for a total of 6.13 million of trees which means a surface of 312 thousand hectares (44% of the total agricultural surface and a 19% of the national olive production surface). These plantations were concentrated in the delegations of Manzel Chakeur (34%), Bir Ali (12.6%), Agareb (10,8%), Hencha (10,3%) et Mahres (10,1%). The other delegations (El Amra, Graiba, Djebéniana, Sfax Nord, Skhira, Sfax Sud et Kerkena), make up a total of 21.7%. The plantations was composed a 100% by the variety chemlali and they are planted with an average density of 20 trees/ha. 15.8% of these plantations were planted less than 20 years ago, 49.4% between 20 and 70 years old and a 348% are older than 70 years.

The agrocombinats leaded by the Office of Communal Lands represent 13% of the olive production surface (40.6 thousand ha) and 12% of the plantations (755.9 thousand ha) from which 71% are older than 70 years.

Data related to the olive production in the region of Sfax have been available at the level of the Commissariat Regional of Agricultural Development (the districts of the statistics and of the vegetal production, the coordination centre of the extension activities, the territorial centres of extension and the centres of agricultural education), and of the services of management of agro-climatology of Châal, Bouzouita, Essalama et la ferme de Bir Ali.

In the other hand, the micro-economic data related to the management and performance of the olive production, were not available. In order to provide data, surveys were conducted in 60 private production farms and one collective production farm (agrocombinat Châal).

The survey grouped in quantitative and qualitative variables and divided into the following chapters (demographic, historical, structure of production, investments, production factors, investments, credits, productions, intermediate consumers, reporting to the Organizations, multi-activities, external resources, and additional information).

The sample of the olive farms accounts 61 private farms and one collective farm (agrocombinat of Châal). The selection of the private farms made with the collaboration of the heads of the territorial extension agencies that represents the regional stakeholders.

A.1- Survey analysis

The analysis was based on an econometric linear regression model that links the production of a particular year (n) with the precipitation of the same year (n) and the precedent years (n-1 and n-2). We have analyzed the principal factors that determine the production in the collective farm of Châal (agrocombinat Châal) and in the private production farms. The variables considered refer to the structure of the plantations, the rainfall, the management practices, and the final yield. These variables evaluated by means of a factorial analysis of principal components (Analyse factorielle en Composantes Principales, ACP) in order to identify the main factors that determine the yield of olives.

A.2- Olive production in the region of Sfax

Olive is an alternating species in the region of Sfax. This alternation is translated into one year of good olive production preceded by two of low production or one year of low production and an average one. The region generally registers 4 good harvests out of 10, 2 average and 4 low harvests. Between 1974 and 2002 the olive production varied between a minimum of 35 thousand tons in 2001/02 and a maximum of 500 thousand tons in 1991/92 (Figure 98) with an annual average of 200 thousand tons.

The characteristic year-to-year variation in olive production were incremented by the rainfall variability and the poor quality of the soils devoted to olive production, due to the fact that olive production takes place in marginal areas.

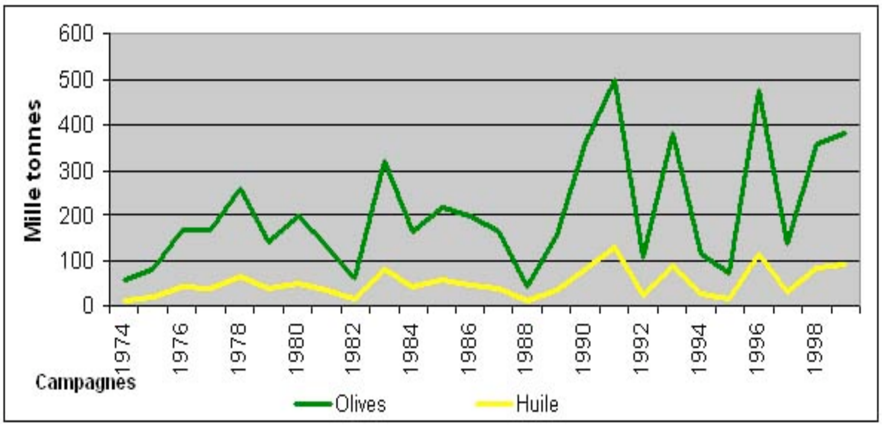


Fig. 98: Olive production and olive oil production in the region of Sfax

Olive production changed from 179 thousand tons in the period 1977-81, to 193 thousand tons in the period 1982-86, to 243 thousand tons in the period 1987-91. In the period 1992-97 olive production raised to 229 thousand tons. After that, olive production increased steadily. It is important to notice that the olive production shown greater variability in the last period. The coefficient of variation are ranging from a maximum of 0.809 during the period 1992-96 and a minimum of 0.29 during the 1977-81 period (Table 81).

The increase in the production explained essentially by the increment in yield. The effective area devoted to olive production had increased slightly.

Periods	Olives production (tonnes)	Coefficient of variation	Number of trees	Yield (kg/tree)	Relative production increase (%)	Relative trees number increase (%)	Relative increase of the yield (%)
1977-81	179400	0,29	6102295	29,4			
1982-86	192600	0,489	6113122	31,5	1,430	0,035	1,394
1987-91	242840	0,755	6070768	40,0	4,745	-0,139	4,891
1992-96	229330	0,809	6084404	37,7	-1,138	0,045	-1,183
1997-01	241700	0,619	6131501	39,4	1,056	0,154	0,901

Source : CRDA Sfax

Table 81: Production, area, and yield of olives in the region of Sfax (1977-2001)

This small evolution is explained by limited efforts to expansion of the olive plantations. The changes included trees removal (237,2 thousand trees), re-planting (161,4 thousand trees) and creation of new plantations (205,7 thousand trees), that taken place since 1977. These facts resulted in a slight increase of olive trees (129,9 thousand trees) (Table 82). By contrast to the changes in the surface and number of trees, the yield increased. In the past, the yield was more than 37 kg/tree during the period 1987-01, and was less than 32 kg/tree during the period 1977-86. The average for the period 1977-01 was 37 kg/tree (726 kg/ha). We have to notice that the annual yield is very variable ranging from a minimum of 6 kg/tree (112 kg/ha) in 2000/01 to a maximum of 82 kg/tree (1617 kg/ha) in 1991/92. The olives yield increase was partially explained by the management improving (regeneration and re-juvenation) of the plantations that have been made in the period 19882-91 and in the climatic conditions of the years 1989 and 1995.

Unit: trees

Period	Regeneration*	Improvement in the old Plantations**	Removal	Re-plantation (same areas)	New Plantation	Balance***
1977-81	1608	0	57403	57403	19085	19085
1982-86	46055	1190000	80072	79905	32740	32573
1987-91	44273	1227240	63856	13588	59920	9652
1992-96	8729	182380	29975	8416	65747	44188
1997-01	1897	2740	5879	2100	28170	24391
Total	102562	2602360	237185	161412	205662	129889

Source: CRDA Sfax , and our calculations

Table 82: Change in the plantations of olive trees (1977-2001)

* Natural reconstitution of the trees by “recépage”.

** Improved management (“taille de renovation”) with the objective of making the plantation progressively young. *** Balance = New plantations + Re-plantation – Removal.

A.3- Effect of rainfall on the production of olives in the Sfax region

To evaluate the effect of annual rainfall on olive production, The correlation among the olive yield of the year (n) and the rainfall of the same year and the previous years (n, n - 1, and n - 2) was evaluated.

Dependent Variable: Yield per tree

Method: Least Squares

Sample (adjusted): 1976 - 2002

Included observations: 27 after adjusting endpoints

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	-16.09311	11.31308	-1.422522	0.1677
PLUV(-1)	0.179476	0.036139	4.966243	0.0000
PLUV(-2)	0.082164	0.035824	2.293504	0.0309

R-squared	0.519782	Mean dependent var	34.38516
Adjusted R-squared	0.479763	S.D. dependent var	21.53644
S.E. of regression	15.53368	Akaike info criterion	8.428338
Sum squared resid	5791.087	Schwarz criterion	8.572319
Log likelihood	-110.7826	F-statistic	12.98863
Durbin-Watson stat	2.754889	Prob (F-statistic)	0.000150

Table 83: Effect of rainfall in olive production in the Sfax region.

The time series of olive production of year n was analyzed in terms of the relationship to the annual precipitation of the same n year, and the two preceding years (n-1 and n-2). (Figure 99) shows that olives production seems not to be greatly influenced by the annual precipitation of the same year of production. It was also shown that olive production (year n) seems to be influenced by the precipitation of the previous year (year n-1) (Figure100). (Figure 101) shows that olive production (year n) seems not to be very influenced by the precipitation of the previous to the last year (year n-2).

In conclusion, the annual precipitation of the previous year to the production seems to be the best indicator of the probability distribution of olive production. This result should be confirmed by further analysis.

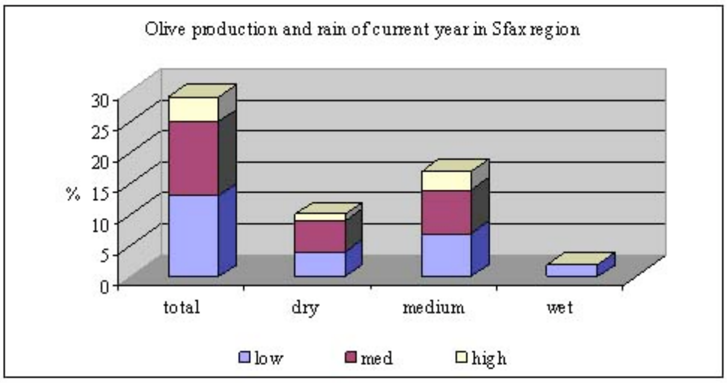


Fig. 99: Frequency distribution of olive production as influenced by the precipitation of the year of production

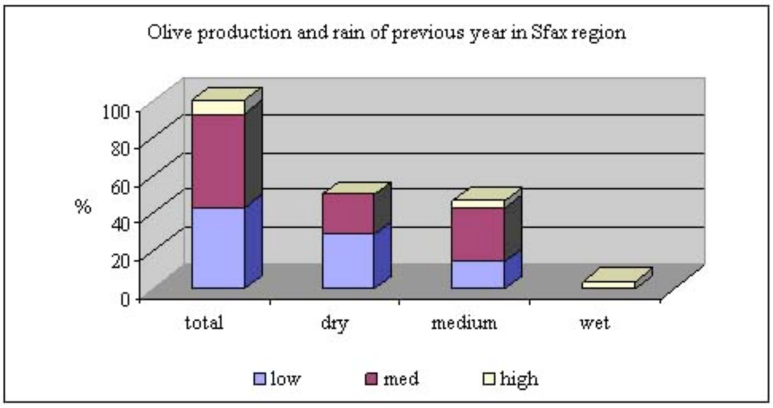


Fig. 100: Frequency distribution of olive production (year n) as influenced by the precipitation of the previous year (year n-1)

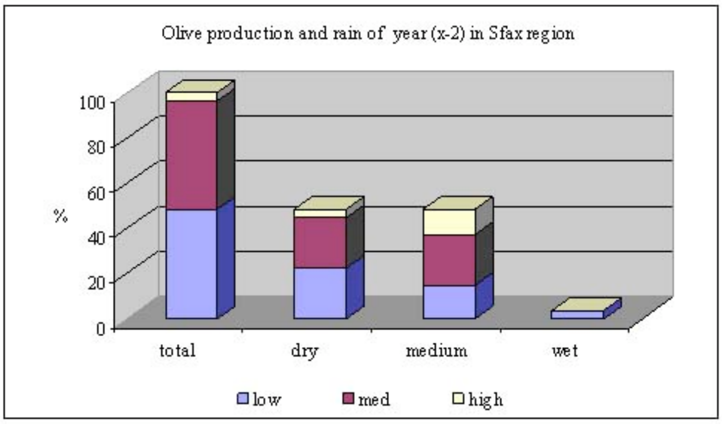


Fig. 101: Frequency distribution of olive production (year n) as influenced by the precipitation of the previous to the last year (year n-2)

B- A local study

B.1- Rainfall impacts on olive production in Châal Domain (Sfax region).

B.1.1- Châal Domain characteristics

The "Châal Domain" belongs to the state domain (Office des terres domaniales OTD). It is located at 62 km in the Southwest of Sfax's governorate and it represents the greatest farm specialized in the olives and olive oil production in Tunisia. It contains 20 farms and covers a total surface of 31936 ha (29165 ha of cultivated lands).

The climate is dry upper strongly influenced by the sea. The rainfalls are characterized by the irregularity in time and space. The average rainfall during 1974-2002 period is equal to 195,6 mm, it varies from a minimum of 68 mm (year 1994) and a maximum of 581,8 mm (year 1989 (Figure 102). The Châal region is generally overdrawn with a succession of dry years.

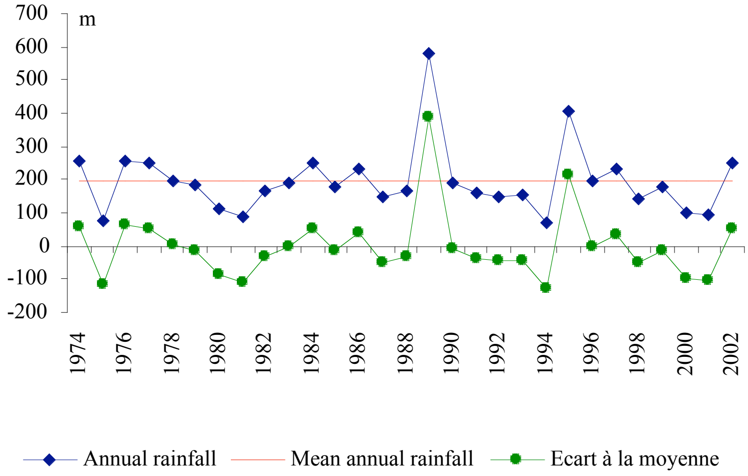


Fig .102: Annual rainfall evolution (Sfax. Châal Domain. 1990-2003)

The analysis of the rains seasonal distribution during 1990-2002 period, shows their abundance during autumn and winter and their scarcity during the summer.

The spatial distribution of the rainfall shows a big variation, it vary from a minimum of 130 mm at the firm Hicha and a maximum of 210 mm at the farm Hajeb. This spatial variability lets the farm management difficult.

The information relative to olive-growing surface, olive-growing strength, plantations structure, ground nature, conduct mode and maintenance, management operations, plantation age structure, rainfall and yield by hectare at the level of the domain as a whole, were collected.

In Châal domain, as in all Sfax region, the production of oil olives was rather fluctuating and varied between a minimum of 323 tons in 1995 and a maximum of 36196 tons in 1991 with a coefficient of variation of 0,88 (Figure 103).

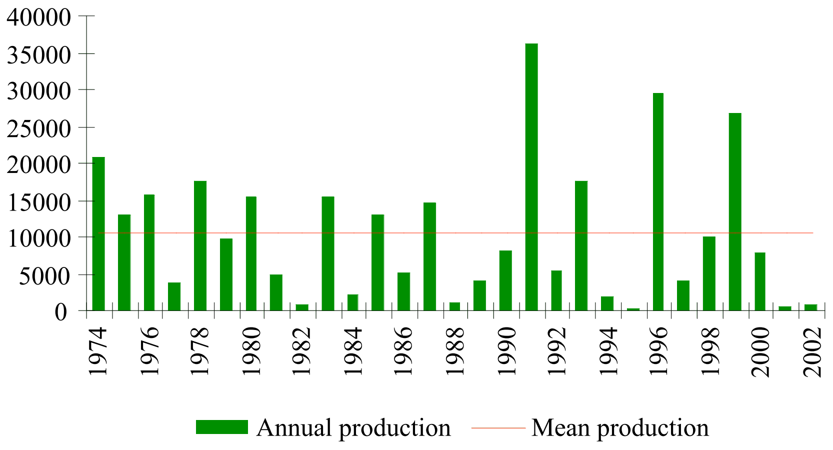


Fig. 103: Olive production (Oil. Sfax. Châal Domain. 1974-2002

B.1.2- Used methods

A period of 28 years (1974 to 2002) was considered for the data related to the entire Chaal domain and the period from 1996 to 2002 for the data related to the 209 field distributed on the 20 farms in the same domain. All these data were used for 2 main components analyses: ACP (Analyse en composantes principales).

For the first ACP we used the 209 parcels and 12 variable (olive-growing surface conducted in dry expressed on % of the olive-growing surface total, average rainfall during the period 1996-02, plantations density, plantations aged of less than 20 years, between 20 and 80 years and more than 80 year proportions, olive-growing surface conducted in full expressed on % of the olive-growing total surface, surface treated against the couch-grass proportion, pruning plantation proportion, regenerate plantation proportion and means olives yield during the period 1996-02 by hectare and by tree.

For the second ACP the same variables were used. The olives yield by hectare and by tree kept corresponds to the weak production season (2001/02).

B.1.3- Results analysis

The analyse of the results shows a big sensitivity to water deficit of olive plantations aged more than 80 years, essentially those growing in marginal areas.

It was highly the difficulty to dissociate the rainfall effect on olive production from the effects of the others productions parameters. This could be possible by experiment fields that are not part of the objectives of AIACC, AF 90 project.

It was also shown that it is necessary to implement an awareness campaign toward the olive growers in order to respect cultural operation and to engage, when it is necessary, the rejuvenation and replantation.

2.2.4- Stakeholder analysis

The analysis included the evaluation of the answers to the questionnaire provided in the Third Technical Report. Figure 1 shows the results to the question “Have you noticed a change in the weather or climate in the last 10-20 years?” The (figure 104) shows that farmers in Kairouan and Sfax have different perceptions about current climate change. In Kairouan, the main production system in Dryland cereal production that is greatly affected by year-to-year climate variations and therefore more farmers has the perception of climate change. In contrast, Sfax farmers are often olive producers, and the influence of climate in the olive trees is more complex. (Figure 105) shows the farmers' response to the question “Did you notice decrease of production due to climate? In this case all farmers responded unanimously that the influence of climate in their production was very clear.

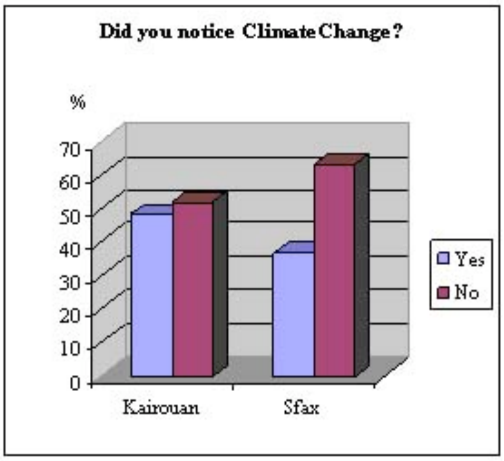


Fig. 104: Response of the farmers to Question 1.

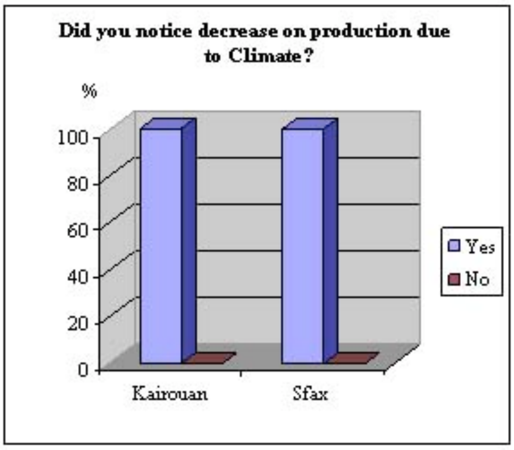


Fig. 105: Response of the farmers to Question 2.

6.2.3 Hendi Zitoun case study

The Hendi Zitoun is located in the center region and is most vulnerable to climate variability and predicted climate change. The region is among upon arid climate.

<u>*The climate in Hendi Zitoun region*</u>

Hendi Zitoun region is characterized by a moderate temperature (mean annual temperature: 19.2 °C); however, hot temperatures are frequent in the summer period. The average maximum temperature in August is about 38°C and a maximum temperature have reached 50°C (August 1993). In addition to the hot temperature, the high evaporation rate (mean annual evapotranspiration: 1665 mm) and the low rainfall (mean annual rainfall: 313 mm) can affect the rainfed agricultural production (Table 84).

Month	Max.temp.(°C)	Min.temp. (°C)	Global radiation	Wind speed (m/s)	Relative humid. (%)	Rainfall (1962-2002)
January	16.2	4.9	5.1	1.9	72	29.0
February	17.6	5.6	5.8	1.9	66	29.1
March	20.4	7.6	6.6	2.1	66	33.7
April	23.4	9.5	7.2	2.2	65	28.4
May	28.2	13.4	8.5	2.4	62	19.9
June	33.1	17.2	9.2	2.0	59	12.7
July	36.6	19.8	10.1	2.1	56	6.4
August	36.7	20.8	9.2	1.7	58	16.7
September	32.5	18.4	7.6	1.5	64	41.8
October	27.1	15.0	5.9	1.4	69	55.9
November	21.6	10.5	5.4	1.5	69	30.4
December	17.7	6.5	4.8	1.6	75	25.5

Table 84: Climate characteristics in Hendi Zitoun region (1981-2002)

A- Temperature evolution in Hendi Zitoun station

The mean annual temperature evolution for the 21 year period, from 1981 to 2002, shows a big variation regarding to the mean values; we can see (Figure 106) an increase temperature trend from the last 10 years.

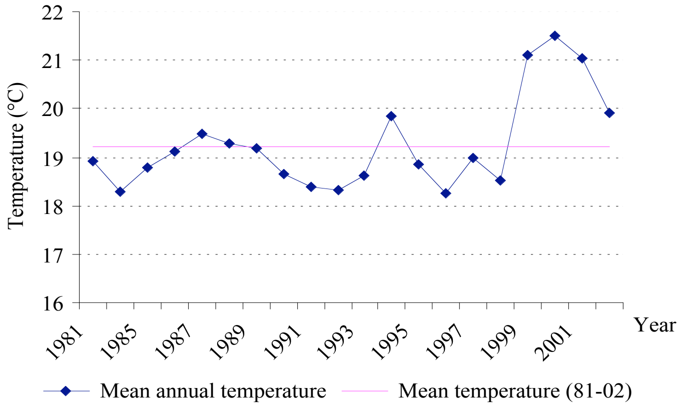


Fig. 106: Mean annual temperature evolution. Hendi Zitoun station (1981-2001)

B- Rainfall evolution in Hendi Zitoun station

In this region, water deficit and drought represent a permanent risk for rainfed agriculture.

Rainfall is characterized by a very important year to year variability (Figure 107) and by its scarcity; consequently, production is variable. As for Kairouan, the severely dry years and drought persistence are more frequent in the region

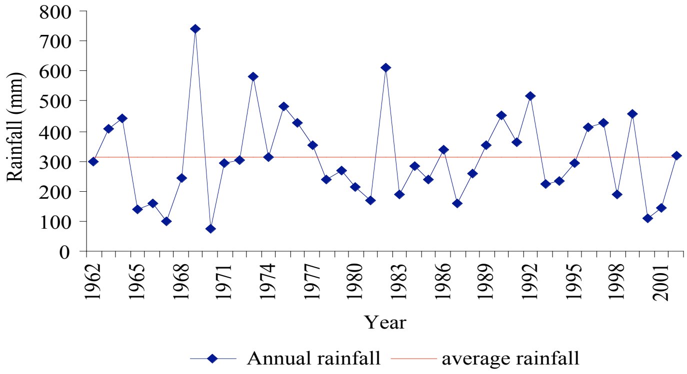


Fig. 107: Annual rainfall evolution. Hendi Zitoun station

Climatic characterization of Hendi Zitoun region

A- Climatic index evaluation

For the agroclimatic characterization in actual conditions and in climate change conditions, the actual and the predicted climatic index were compared. Climate index are used to establish criteria to compare between and to classify climate. They were used to classify climates according to their aridity.

For our application we have used: aridity index of Martonne the Emberger coefficient and the ombrothermic index of Gaussen (1952). The same scenarios have been implemented for Kairouan and Hendi Zitoun regions.

A.1- Aridity index of Martonne

The application of GIEC scenarios to calculate the Martonne aridity index showed a trend from the semi-arid to arid (tab 3a, 3b) as well for Hendi Zitoun than Kairouan (Table 85).

Aridity index of Martone	Temperature increase (°c)				
	Mean temperature	**+ 1.3°C**	**+ 2 °C**	**+2.5°C**	**4°C**
Mean actuel rainfall	10	10	10	10	9 arid
Rainfall (–5%)	10	10	10	9 arid	9 arid
Rainfall (–20%)	9 arid	8 arid	8 arid	8 arid	8 arid

Table 85: Aridity index of Martone evolution in climate change conditions : Hendi Zitoun region

A.2- Pluviothermical quotient of Emberger :

The same climatic trend that for Kairouan (semi-arid towards arid) was confirmed by the pluviométric quotient of Emberger (Table 86), as well as the quotient "pluvio-évapotranspiratoire" for Kairouan and Hendi Zitoun regions.

Pluviothermical quotient of Emberger	Temperature increase				
	Mean Temperature	+ 1.3°C	+ 2 °C	+2.5°C	+ 4°C
Mean actual rainfall	33 Semi-arid	33 Semi-arid	33 Semi-arid	33 Semi-arid	33 Semi-arid
Rainfall decrease (- 5%)	33 Semi-arid	32 arid	32 arid	32 arid	31 arid
Rainfall decrease (-20%)	27 arid	27 arid	27 arid	27 arid	26 arid

Table 86: Emberger index variation according to climate scenarios. Hendi Zitoun.

A.3- Indice ombrothermique de Gaussen (1952)

The Ombrothermic Diagram for Hendi Zitoun station and for the period ranging from 1962 to 2002 shows a dry period from 15 March to 15 Septembre (Figure 108).

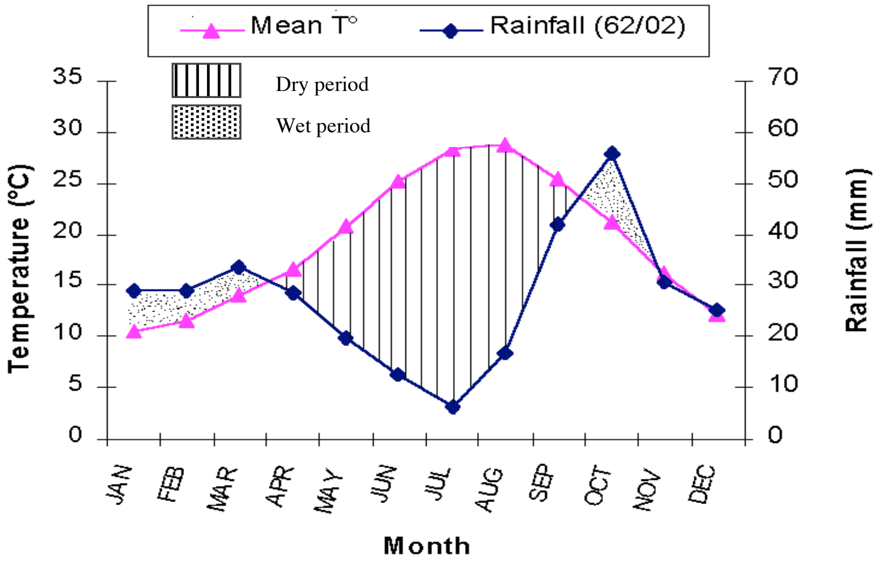


Fig. 108: Ombrothermic Diagram in actual conditions. Hendi Zitoun

In climate change conditions (temperature increase and rainfall decrease), the Ombrothermic Diagram for Hendi Zitoun station showed a lengthening of the dry period duration. As for Kairouan region, when the pessimistic scenarios (all temperature increase scenario with 20% decrease on rainfall) were considered, the dry period spreads out over all year (Figure 109).

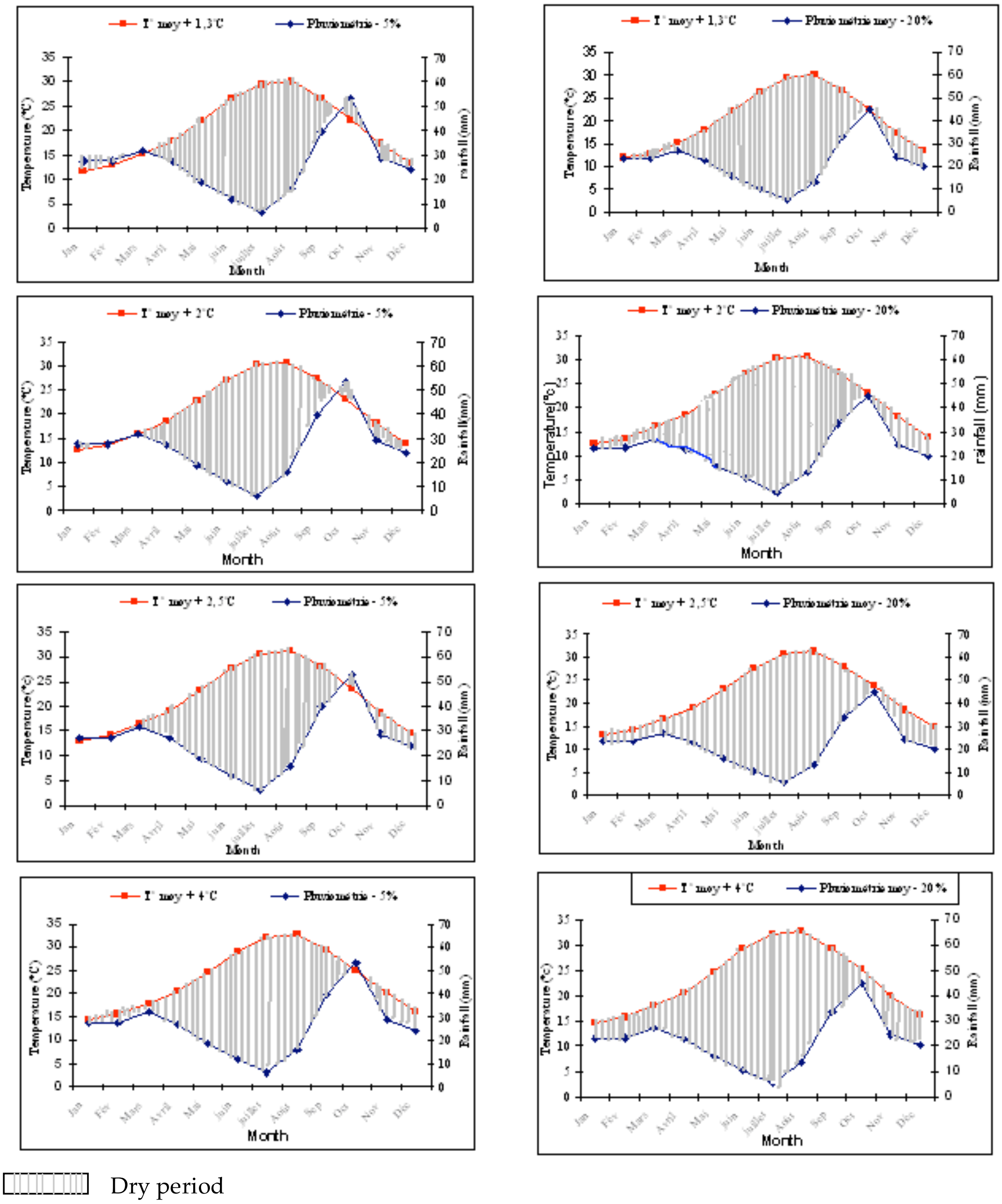


Fig. 109: Ombrothermic Diagram in climate change conditions. Hendi Zitoun

B- Reference evapotranspiration (ET_0) in climate change conditions

Using daily data (1990-2002), Monthly reference evapotranspiration for Hendi Zitoun was evaluated in actual and temperature increase conditions, in order to evaluate the climate change impacts on evapotranspiration.

Penman Monteith formula (FAO Irrigation and drainage paper 56) was used to calculate the reference evapotranspiration (RET), and the evapotranspiration increase was evaluated in climate change conditions (Figure 110).

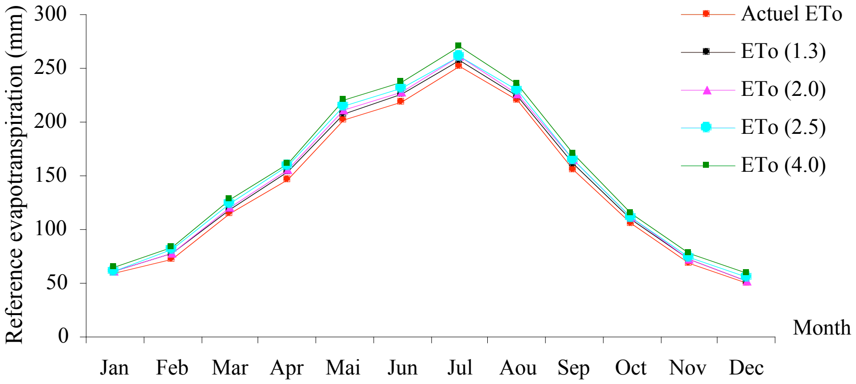


Fig. 110: Reference evapotranspiration evolution in actual and climate change conditions (Hendi Zitoun)

In climate change conditions, the rates of RET increase by year 2100 compared to actual ²values (1665.1mm), are equal to 3.3% for the optimistic scenario (+1.3°C) and 9.5 % for the pessimistic scenarios (+ 4°C).

To show the climate change impacts on water availability, the RET increases was compared to the mean total annual rainfall in the Hendi Zitoun region (334.9mm). Also the rate of RET increase was compared, to the water demand projections for agriculture in the Centre region up to 2030 (3435 m^3/ha).

The actual MET_W (618mm, calculated using the cultural coefficients in Zaîri 2003) was compared to the MET_W in climate change conditions.

The water deficit was calculated for the wheat growing period (405.9mm) and compared to the climate change conditions values.

Table 87 summarize the temperature increase impacts on evapotranspiration (RET and MET_W) and the impact of evaporation increase on water deficit for wheat crop.

	Temperature increase			
	+1.3 °C	+2.0 °C	+2.5 °C	+4.0°C
Annual RET increase	3,3	4,7	6,2	9,5
Annual RET increase / Mean annual rainfall	16,3	23,6	30,8	47,2
Annual RET/ Water demand projection	15,9	23,0	30,0	46,0
MET_W increase (wheat growing season)	3,8	5,0	7,3	10,2
Water deficit (wheat growing season) increase	6,6	8,7	12,6	17,7

Table 87: Rate of RET, METw and wheat water deficit increase (%) in climate change conditions (Hendi Zitoun)

6.3 Adaptation of Agriculture to Climate Change in Tunisia

In Tunisia rainfed production is characterized by very low and very variable productivity. Irrigated production is characterized by the high water consumption. Water demand for irrigation is expected to increase in all countries of North Africa and it is important to define adaptation strategies that take into account the possible deficit of water for irrigation in the future (Eid et al., 1997; Strzepek et al., 1995; Iglesias et al., 2003).

In Tunisia, irrigated areas are expected to rise to nearly 400.000 ha by 2010, with a consequent increase in irrigation demand to a total of 2140 Mm3 (Lebdi, 2002).

The expected climatic changes, especially precipitation decreases, increases in variability and an increase in drought episodes in addition to population increase, urbanization and industrial development as well as the intensification of irrigation increase water demand and agricultural production variability and consequently the country vulnerability. It is also evident that in Tunisia the socio-economic and agricultural systems make difficult the adoption of new adaptation strategies.

6.3.1 Adaptation strategies of the farmers in the framework of the project

To avoid the negative impacts of actual climate variability and climate change, it is necessary to undertake new adaptation methods and to enhance the know-how of the farmers in order to augment their adaptation capacity.

In Tunisia, the project focuses in rainfed agriculture in the Centre Region. A survey to evaluate the capability of the farmers to adapt to climate change and to adopt new techniques has been conducted wheat production (in Kairouan).

The survey analysis has several objectives. The determination of the farmers behaviour toward the climate variability effect on agricultural production, the analyze of their capability to adapt to climate variability, to enumerate the adaptation methods already used in the farms and to specify the reason that prevent the farmers to adapt to use new adaptation methods.

6.3.2 Research orientation

During the last ten years, the agronomic search programs in Tunisia are mainly focussed to the assessment of the drought impact on agricultural production and consequently their results can constitute an “adaptation method” to actual climate variability and to predicted climate change.

At present, the National Commissions for Research Planning is the main Institution that defines the research programs. The Commissions define the research priorities, evaluate the research program and they include researchers, professors from agricultural academic institutions and agronomists from various development sectors.

The assessments of the climate impact and drought effects on the agriculture are constantly taken into account since over a decade. A great national effort is made to reduce these effects and several research programs are focused toward this theme.

At present the research sector have 10 research programs. The Cereals Research Program and the Water Research Program constitute first priorities.

Among the research themes that provide results constituting directly adaptation methods are:

- Increasing of agricultural areas;
- Management of water resources;
- Improvement and the genetic selection of cultivars;
- Improvement of techniques already used and use of new techniques (fertilization, irrigation, etc.) that are allow minimizing the negative effect of climate variability and climate.

Linkages among research and development

As important adaptation strategies are the relationships established among research and development sectors. These collaborations are at different levels:

- Short training,
- Field days,
- Common research programs,
- Common use of databases,
- Laboratories and research stations, and

- Common publications and reports.

In addition, seven "Regional Poles for Research" (Pôle Régional de Recherche) are located in the agro ecological zones. Those regional development Poles improve the collaboration between research and development fields. They offer a collaboration framework with all partners: researchers at the central and regional level, technical staff also at central and regional level, extensions services, and farmers.

The involvement of the rural population concerned to attain the objective remains essential. That is why nowadays the participative approach is necessary for the use of new technology. The approach objective is to develop technologies adapted to the ecological and socio economic conditions. We can attend these objectives by research development programs realized taking into account the farmer's strategies.

6.4 Recommendations

The study realized within the framework of the AIACC AF 90 project allows bringing some evident recommendations:

- A better coordination between institutions and an improvement in the communication will reduce the climate change risks.
- Federating "the experimental field "to facilitate the use of decision support systems models (DSSAT).
- Optimization of the meteorological network. The meteorological network has to be as efficient as possible.
- Sociological studies are needed to evaluate the adaptation capacity.
- Integration for the political and economical decisions the climatic changes impact at means and long-term.
- To considerate the climates change in an integrated way in order to demonstrate the relationship between this phenomenon and others socio-economic phenomena.
- The support of small farmers, who are the most vulnerable to climatic changes and the first beneficiaries of the results. The improvement of their know-how guarantee for them a minimal income and the survival of their system therefore avoid a drift away from the land.
- The necessity of the rural population involvement to reduce the vulnerability of Tunisian farming in climatic changes. This would be possible by the participant approach in every thing which is undertaken.
- Due to the difficulties to dissociate between the effects of the rainfall on the olive production and the effects of others factors, only a consistent experiment would put into evidence the rainfall impacts.
- The old olive trees plantations (ages more than 80 years) are sensitive to hydrous deficiency and consequently more vulnerable to climatic changes.
- A management and rejuvenating program for the old plantations would be considered as a method of adaptation among others for the improvement of the olive production and could prevent the predicted climatic changes.

6.5 Conclusion

For Tunisia, vulnerable country, to minimize or ovoid climate change impacts on agriculture sector, it is necessary to proceed step by step:

- In a first step, to assess the present vulnerability in order to identify the actual and future adaptation options to climate variability.

- In a second step, to assess the vulnerability to climate change and to identify the adaptation options.

For the two steps the vulnerability assessment has to be done at regional scale because of the high social and agricultural systems variability in Tunisia. The efforts must be focussed on highly vulnerable groups and sectors.

- In a third step, it is necessary to set up a national adaptation plan to face several challenges to adapt to climate change. For the adaptation plan, we have to take into account the available adaptations methods already used and easily adopted by the farmers because the "technologies generated appear to be more readily adopted by large-scale farmers, agricultural development agencies, rural development societies and cooperative farms, rather than by the majority of medium- and small-scale farmers" (Chennoufi and Nefzaoui.1996).

7. Conclusion

Climate is perceived by North African farmers as one of the major risks of agricultural production, but the magnitude of the risk is perceived as higher than the risk derived from empirical knowledge. Farmers do not recognise the importance of farming techniques for adaptive management and therefore their investments may not be completely productive.

There is a range of adaptation measures but the have varying levels of effectiveness, feasibility of adoption at the farmers' level, and social and environmental consequences. Changes in crop variety, crop calendar, and irrigation amount and nitrogen fertilization were the main options produced through the analysis steps. A combination between the three options were produced and tested too. Promoting education programs on water-saving practices and changes in crop choices was the fifth adaptation option resulted from the project investigation.

Only a limited number of farmers follow the advice of the extension services that seems to be the key adaptation measure. The study concludes that the involvement of the rural population and extension services in capacity building programs is an essential adaptation measure, with information flows among and between these two groups of stakeholders.

8. Capacity Building Outcomes and Remaining Needs

8.1 Workshops

Investigators and Students participated in AIACC workshops and several other meetings in order to gain more knowledge and experience. Following is the list of meetings attended:

- Training course for Vulnerability and adaptation assessment methods, AIACC, Trieste, Italy, 3-14 June 2002. (M. Medany Prticipation).
- AIACC Africa Regional Open Meeting and Workshop. March 10-13, 2003. artebeespoortdam, South Africa.
- R.Mougou and A.Iglesias Participated in Tunisia Project Meeting, July 8-13, 2003.INRGREF, Tunis.
- Second AIACC Regional Workshop for Africa and Indian Ocean Islands. Dakar, Senegal. 2004. (R. Mougou Participation)
- Project Internal Meeting: Cairo, 4-9 Dec 2004. Raoudha Mougou, Mohsen Mansour and the Egyptian project team. Development of technical and financial final report of AIACC AF90 Project, and attend the project training program entitled "Utilization of DSSAT software and Development of Climate Change Scenarios".
- Project Internal Meeting: Cairo, 18-22 Feb 2005. Ana Iglesias and the Egyptian project team. Development of methods for vulnerability analysis in the context of the North Africa climate change project, and Development of technical final report of AIACC AF90 Project.
- Project Internal Meeting: Cairo, 20-22 June 2005. Ana Iglesias and the Tunisian project team. Development of technical and financial final report of AIACC AF90 Project.
- AIACC Adaptation Synthesis workshop, 13-17 September 2005, Kenya.

8.2 Other Training Activities Supported by the Project

- M. Medany participated in the following international activities related to the project:
    - Training course for Development and application of scenarios in impact, adaptation and vulnerability assessment, Tyndall center for climate change research, school of environmental science, University of East Anglia, Norwikch, UK, 15-26 April 2002.
    - IPCC meeting of WG II contribution to the fourth assessment report, 14-17 March, Cairns, Austrlia.
    - IPCC Workshop on New Emission Scenarios, 29 June - 1 July 2005, Laxenburg, Austria.
- M. Mohsen participated in: «Les stratégies pour prévenir et atténuer les effets de la sécheresse dans la région Méditerranéenne». CIHEAM-IAMZ Title of presentation: *"Dryness isn't only climatic"*. Zaragoza, Espagne, 2004.
- R. Mougou participated in the following national and international activities related to the project:
    - International Workshop 'Les Mécanismes de Développement propre.Enjeux et barrière ',Tunis,décembre 2002
    - International seminar 'Le Climat de demain ',Institut National de la Météorologie de Tunisie,March 2003
    - National forum 'L 'évaluation et les perspectives en matière de changement climatique ', Ministry of Agriculture 'Environment and Hydraulic Resources. May 2003
    - First International Conference 'Les Changements Climatiques et le tourisme ',Oganisation Mondiale du Tourisme,April 2003.
    - The scientific day on "Le climat de la Tunisie et le changement climatique" organisée par l'Association Tunisienne des Changements Climatiques et du Développement Durable.

Tunis 2004.

- The information day on "La désertification et les changements climatiques : Impacts sur les écosystèmes" organized by: PANLCD-GTZ, l'ATSB et l'ATCCDD. Tunisia 2004.
- The Symposium organized in Beijing by the European Climate Forum (ECF) sur: "Key vulnerable regions and climate change". Paper presented: **"Vulnrability of** Maghreb countries to climate change. Case of Tunisia". Pékin 2004.

8.3 Courses

8.3.1 Course for students

- A course on "Climate change and Agriculture" was lectured at the University of Al Azhar, Faculty of Agriculture- department of ecology and bioagriclture, during 2003-2005, as a joint activity with AIACC Project. The course has credits for the under graduated students, and the post graduated students of M.Sc. and PhD. programs. The contents of the courses were focused in the following titles:
    - What is Climate change?
    - How the climate changes?
    - Climate change and climate variability.
    - Climate change impacts.
    - The vulnerability of the different sectors to climate change impacts.
    - The vulnerability of the water resources and agriculture sectors to climate change.
    - Climate change adaptation.
- The same course of "Climate change and Agriculture", with few changes, was lectured at Cairo University, Faculty of Science, during 2003-2005, as a joint activity with AIACC Project. The course has credits for the post graduated students of M.Sc. and PhD. programs.

8.3.2 Other courses on climate change

- A number of lectures and short courses were offered for Egyptian and Arabian agricultural researchers, in CLAC, through the period of the project.

- A special short courses were offered for Egyptian undergraduate students from faculty of agriculture and faculty of science, as a summer training courses, through the period of the project.

8.4 Students

- The Project supported the development of highly qualified students, who made their thesis in different aspect of it:
    - Mosaad Kotb Kotb Hassanein attained his Ph.D degree of Agronomy science, with a thesis on "Studies On Genetic Coefficients For Decision Support Models In Faba Bean (*Vicia faba* L.)"
    - Alaa Abd El-Raouf Mohamed Khalil. attained his M.Sc. degree of Agrometerology, with a thesis on "Effect of Climate Change on the Agriculture Map"
    - Heba Yahia Mohamed, attained her M. Sc. degree of Environmental of agriculture science, with a thesis on " the impact of geographical information systems on environmental development.
- Beside a number of a post graduated students, who registered in the following programs:
    - Mohamed A. Fahim, registered for Ph.D. degree of Plant disease, with a thesis on "Climate Change Impacts on Potato Blight Epidemiology and Prediction"
    - Mohey M. Kadah, registered for M. Sc. degree of Ecology , with a thesis on "Global Gas Emission impact on livestock production."

- Mona Mohamed Ahmed, registered for M. Sc. degree of Ecology-Botany , with a thesis on "Modeling of growth and geographical distribution of some crop plants in relation to expected climate change"
- Samar M. Attaher, registered for Ph.D. degree of Agriculture engineering , with a thesis on "Effect of climatic changes on Egyptian Irrigation system"
- Shaker M. Abou-Elmaty, registered for Ph.D. degree of Plant disease and environment , with a thesis on "Assessment of the Impact of climate change on some disease rust for wheat under Egyptian environmental conditions"

– The Spanish Ph.D. student Marta Moneo incorporated into the AIACC project team.

8.5 General Capacity Building Accomplishments

Since the Project integrate research from climate, agriculture, water resources, and social sciences, the project tram gained experience in multidisciplinary work and learned to synthesize results from different disciplines.

During the project, the participants developed some tools and learn to use other models and tools. These activities resulted in increased individual capacities in many techniques. As an example should be mentioned the use of DSSAT model to study the impacts of climate change on crops production, and working with GCM experiments results and utilizing this results under DSSAT. The other very important experience for most of the investigators of the Project was the work with stakeholder groups.

Institutional capacity building resulted from the strengthening of two groups for further investigations in climate change. One of these groups is the INRGREF institution (Institut National de Recherche en Génie Rural, Eaux et Forêts) in Tunisia, and the other is CLAC (central laboratory for agriculture climate) that related to Agriculture Research Center (ARC) in Egypt. In Addition to, increasing public awareness and understanding of climate change and related issues was one of the very important contributions of the project. This was obtained through workshops for stakeholders, conferences by the project team and numerous notes and interviews in the media.

9. National Communications, Science-Policy Linkages and Stakeholder Engagement

9.1 National and International Communication

Egypt:

- Prof. Abou-Hadid and Dr. Medany preparing to the 2nd National Communication in the field of agriculture under collaboration with Egyptian Environmental Affairs Agency (EEAA).
- The results of the AIACC North Africa Project will be included in the 2nd National Communications of Egypt. AF90 Egyptian team provides updated information to Ministry of State for Environmental Affairs, Environmental Research and Studies Institute, Ain-Shams University and Egyptian Meteorology Authority (EMA).

9.2 UNFCC:

Mahmod Medany was participating in Ozone Protocol annual meeting (**COP 9**), workshop, 2002 Montreal, Canada**,**

9.3 IPCC

Mahmod Medany is participating in the Fourth Assessment Report as lead author in the WG II, chapter 09; Africa.

9.4 Other Contribution

Tunisia:

- Dr. Raoudha Mougou participates in the European Union funded project: "Improved management tools for water-limited irrigation".

Spain:

- Dr. Ana Iglesias is involved in several projects related to climate change in North Africa, financed by the USA NOAA Office of Global Programs and the European Union. In particular, the EU project MEDROPLAN, that includes Spain, Morocco, Tunis, Greece, Cyprus, and Italy, has the objective of providing Guidelines for Drought Preparedness Plans in the Mediterranean countries.

9.5 National Policies

In Egypt and Tunisia there is no governmental plane or strategy towards climate change. But the results of the AIACC North Africa Project will be included in the 2nd National Communications of Egypt. AF90 Egyptian team provides updated information to Ministry of State for Environmental Affairs, Environmental Research and Studies Institute, Ain-Shams University and Egyptian Meteorology Authority (EMA). And the Egyptian project team is working now in developing a future agenda of climate change and agriculture based on the project results. This agenda will be presented to the policy makers in the Ministry of Agriculture, to study the availability of performing a future strategy for agriculture.

9.6 Stakeholder Engagement

The project was structured as an information exchange between the stakeholders and the scientific team. It based on the interaction between project team and stakeholders to set definitions of adaptation measures, and to increase the capacity of stakeholders to understand climate-agriculture relationships. The information was provided by the stakeholders, through interviews, surveys, and workshops participation. Feedback, Linkages and interactions are maintained throughout the analysis. Information is provided and interpreted according to the experience and technical expertise of each stakeholder group.

9.6.1 Stakeholder engagement in Egypt

A co-operation between the project Egyptian team and the Irrigation Improvement Project (IIP) team was performed to work with stakeholders in Damanhour area.

The IIP project is implemented by the Irrigation Improvement Sector, Ministry of Water Resources and Irrigation of Egypt, and is organized by the Soil, Water and Environment Research Institute (SWERI), Ministry of Agriculture and Land Reclamation in coordination with Agricultural Extension Services.

Through this co-operation, AF 90 project team achieved different activities; it can be summarized as follows:

Cropping systems investigation (Field study):

An investigation was held to study winter wheat and Egyptian clover cropping system and summer season cropping system, and the effect of land leveling in the crop production. This investigation implied on enhancing the participation of the extension service field staff as a conjuction between the project team and the farmers. A field manual for the demonstration application in Arabic and English languages has been prepared as a guide to all the agriculture extension field staff. Soil samples and field observation wells had been installed in each site to follow up the soil chemical properties and the water table fluctuation in each site. Water table samples were collected periodically to be analyzed for the total soluble salts. Daily field data was collected by extension service field staff.

On-farm training activities

An IIP on-farm and irrigation scheduling four training program was provided by the on-farm irrigation management consultant in Damanhour, Kafr El Shaik and Tanta to 170 trainees from both Damanhour and Kafr El Shaik areas at Damanhour training center. The training materials were covered different issues as soil-plant-water relationships, soil water movements, crop evapotranspiration, irrigation efficiencies, leaching requirements, irrigation water requirements and irrigation scheduling. Lectures hand out of 76 pages was given to each trainee, and color transparencies were used to illustrate different items. Field exercises and open discussions take a place in the training program schedule.

The on-farm water management component (SWERI) held two training programs. The first course was for land improvement of the project areas of Damanhour. Thirty one trainees attend the course for six days, 16 of them were from the Agricultural Extension Department and 15 of them were from IPP; IAS (Irrigation Authority Services). The second course was for integrated management and irrigation field efficiency. Thirty trainees attend the course for six days, 20 of them from the Agricultural Extension Department and 10 from IIP; IAS.

Another training program was provided by SWERI was held on the irrigation organization and/or irrigation scheduling on the improved mesqas. The main aim of that program was to give a hand to the IAS and the farmers at the mesqa level and teach them how they should efficiently irrigate and manage their crops at the farm level to increase water use efficiency for growing crops and to prevent the soil deterioration.

Meetings held through the period of demonstration

Different field visits and office meetings with stakeholders were held to discuss the different field demonstrations concerning problems facing the field staff and the summer work plan. These meetings were held at Damanhour IIP office, Abou Homos Agricultural Extension Office, and at the Agricultural Co-operation Office at Damanhour.

Other different meetings and/or field visits were paid to the demonstration sites and field staff office to flow up on the different activities and to discuss collected data insure its reliability and consistency.

Different meetings also were held with the communication consultants, to prepare an integrated work on-farm different activities for the selected sites. The main idea is to prepare wide spread media about what it is and what it should be throughout the different field demonstrations.

Other different activities

- Integrated work concerning communication and on-farm different activities was created to produce different leaflets to be distributed to the local leaders to illustrate to them the main objectives of the project. Four leaflets were suggested and prepared. The first was about the irrigation improvement project, the second was about the benefits of the irrigation improvement project, the third was about the raised mesqas and the fourth was about the pipe line mesqas. These leaflets helped the local leaders of the different mesqas to understand the different purposes of the project and its benefits.

- A field day work was held with the communication for the TV shots for Ertwaa program to discuss problems facing the farmers and its solutions to overcome the different rumors they are facing towards the project.

- Another successful field day visit was paid to Kafr El Shaik, Agriculture Research Station, cotton-farms to explain to the farmers the benefits of zero and little slope leveled long furrows cultivated with cotton. Fifteen farmers from Bisintway and Abou Homos areas, Damanhour Agriculture Extension director, Bisintway Agriculture Extension director, Abou Homos Agriculture Extension director were attended that day.

9.6.2 Stakeholder engagement in Tunisia

A prototype survey was prepared by INRGREF (Institut National de Recherche en Génie Rural, Eaux et Forêts) team, and distributed to farmers in the Kairouan and Sfax. The farmers were selected conjointly by the regional technical staff taking into account their initial response and willingness to participate in the study. After that, farmers were questioned jointly by the research and extension teams. The survey general objectives were:

- Determine the rate of rainfed cereals in the farms;
- Define the farmers behaviour toward the effect to climate variability on agricultural production;
- Define the current and future vulnerability of rainfed cereals;
- Analyze the capability of the farmers to adapt to climate variability;
- Define the "know how" of the farmers in relation to predicted climate change;
- List the adaptation methods already used in the farms;
- Specify the reason that prevents the farmers to adapt to current and future climate variability.

The survey was limited to 100 farmers. The sampling method was "random sampling" to avoid problems such as farmer absenteeism, difficulty to access the farm due to the state of the roads.

Linkages among research and development

As important adaptation strategies are the relationships established among research and development sectors. These collaborations are at different levels:

- Short training,
- Field days,
- Common research programs,
- Common use of databases,
- Laboratories and research stations, and
- Common publications and reports.

In addition, seven "Regional Poles for Research" (Pôle Régional de Recherche) are located in the agro ecological zones. Those regional development Poles improve the collaboration between research and development fields. They offer a collaboration framework with all partners: researchers at the central and regional level, technical staff also at central and regional level, extensions services, and farmers.

10. Outputs of the Project

Until now, the outputs of the Project are mainly about specific aspects treated by only one discipline. More integrated products are expected for the next months,

10.1 Published in Peer-reviewed Journals

Abdel Hafez,S.A., Ainer, N.G. and Eid, H.M., 2003, Climate Change Impacts on Delta Crop Productivity, Water and Agricultural Land, J.Agric.Sci. of Mansoura Univ., Special Issue, Scientific Symposium on "Problems of Soils and Water in Dakahlia and Damietta Governorates", ISSN 1110-0346 Pp.15-26 March 18,2003.

Abou-Hadid, A. F., Iglesias, A., Medany, M., Mougou, R., 2004, Evaluation of Adaptation of Agriculture and Water Resources to Climate Change in North Africa. Submitted to Global Environmental Change.

Abou Hadid, A.F., Medany, M., El-Marsafawy, S. M., Ouda, S. A. and Eid, H. M., 2005, Assessment of Impacts, Vulnerability, and adaptation to Climate Change in Agriculture and Water Needs in Egypt, submitted in Egyptian Journal of Agricultural Research of ARC, Egypt (in press).

Garrido, A. and Iglesias. A., 2004, Institutional Framework to Cope with Drought Risks: A Comparison of Mediterranean Countries. Submitted to Water International.

Iglesias, A., 2003, Climate, Drought and Prediction in the Mediterranean: Opportunities for Agricultural Adaptation. Revista de Ingenieria Civil, 131, 25-31.

Iglesias, A. and Moneo. M., 2004, Drought Preparedness and Mitigation in the Mediterranean: Analysis of the Organizations and Institutions. Options Mediterranean. In press.

Iglesias, A., Ward, N.M., Menendez, M. and Rosenzweig, C., 2003, Water Availability for Agriculture: Understanding Adaptation Strategies to Climate in the Mediterranean. XI World Water Congress, WATER RESOURCES MANAGEMENT IN THE 21st CENTURY, 5-9 October 2003, Madrid.

Medany M., Attaher S. M., Abou-Hadid A. F., 2005, Socio-economical Analysis of Agricultural Stakeholders in Relation to Adapting Capacity to Climate Change in Egypt, to be submitted in Egyptian Journal of Agricultural Research of ARC, Egypt.

Mougou, R., Abou-Hadid, A. F., Iglesias, A., Medany, M., Chetali, R., Eid, H., 2005, Adaptation of Agriculture to Climate Change in North Africa: Evaluation of Proposed Stakeholder Measures", submitted to AIACC Adaptation Synthesis workshop, Kenia.

10.2 Other Outputs

Iglesias, A., Tsiourtis, N.X., Wilhite, D.A., Garrido, A., Garrote, L., Moneo, M., Gomez-Ramos, A. M., Hayes, J. and Knutson. C., 2004. Terms of Reference for Drought Risk Management: Drought Identification Studies, Drought Risk Analysis, and Best Practices. MEDROPLAN Working Paper.

Mougou,R. and Ben Slaem, M., 2003, Meteorological Conditions in Arid Regions and Effects of Climate Change in Dryland Crops, Training on Agricultural Techniques for Rainfed Agriculture and Communication to Farmers, Arab Center for Studies in Dryland Agriculture (ACSAD),Tunis.

An oral presentation of the project by A.Iglesias has been invited for the 2003 World Water Congress (October, Spain), the full text will be included in the Congress Proceedings.

An oral presentation was presented by R.Mougou, Le changement climatique et l 'agriculture. In: 'International seminar on *Le Climat de demain,* Institut National de la Météorologie de Tunisie, March 2003.

11. Policy Implications and Future Directions

The Northern African agriculture community is one of the good examples of the problems of poor irrigation management high agriculture system vulnerability to the current and the future demands. The agricultural production is highly influenced due to climate variability and change under rainfed agriculture system. Whereas the best water management and usage is the focal point under irrigated agriculture. The agriculture sector is expected to sustain from water shortage in North Africa countries in the next few years, due to population increase, water resources decrease, and cultivated areas increase due to the Government policy. Moreover, quality of water resources is affected by unsustainable agricultural practices, and improper irrigation management. The changes of rain amounts and patterns, and the increase in evapotranspiration are predicted to be intensified under climate change. This will worsen the water situation of the agriculture sector in the future.

In addition to, there is a big conflict in administration level to change water distribution sharing units between the different water usage sectors. The water share of agriculture sector is suggested to be reduced through the next years. This proposal of reduction is suggested according to the low water use efficiency of agriculture production comparing with industrial and tourism sectors, and to increase domestic water share to meet the continues increase of population. In the case of reducing the share of agriculture sector, the irrigated agriculture will be in critical situation.

In such case, the only available solutions for this situation are: i) to add new water resources, and ii) to improve the water management techniques in order to save any wasted water. Whereas, the second proposed solution is more applicable, that the highest percentage of water resources of North African countries is out-borders resources or extensively used.

The scientific community in is seeking always to find out an acceptable and efficient strategy to improve the relation between agricultural system and water resources, especially at the farm level. The overall objective of effective on– farm crops and irrigation management is to maximize crop yield per each unit of applied water. This target could be achieved through (i) determination of the accurate applied irrigation water; (ii) improving irrigation scheduling techniques; (iii) improving irrigation method; (vi) use of marginal waters; and (v) rising public awareness of irrigation management among irrigation stakeholders.

Through the project investigation and stakeholder engagment a number of adaptation options were produced by the farmers and evaluated by the simulation models. The details of the resulted adaptation measures are presented in Table (88)

Changes in crop variety, crop calendar, and irrigation amount and nitrogen fertilization were the main options produced through the analysis steps. A combination between the three options were produced and tested too. Promoting education programs on water-saving practices and changes in crop choices was the fifth adaptation option resulted from the project investigation. The potential value of each option was quantified by using agricultural models, and classified to two classes of "low" and "high". The feasibility for the farmer is evaluated by the extension service and it only reflects the adoption of the measure is the resources are in place, and it also classified according to the easiness of application and the required implementation cost. For example, to use additional irrigation water is extremely easy for a farmer that already irrigates crops, therefore the feasibility for the farmer is easy. Nevertheless, additional water for irrigation is almost unthinkable in most regions in North Africa unless new structures and rights are developed. In contrast, to change the crop calendar may be difficult, especially for a farmer that balances a multi-crop rotation. This measure may also have important consequences for markets and competitive advantages. For example, the additional value as export commodities of the North African crops relies on the time of production. Changes in the crop calendar, although may seem to be made at no additional cost, may be economically disruptive for the farmers. The changes in crop varieties are an ongoing trend in North African countries, limiting the local strategies for dealing with drought. Finally, education and capacity building appears to be the measure with most advantages at the farm level and with less social and environmental limitations.

The Egyptian project team is working now in shaping the AF 90 project-produced adaptation measures and its potentials in the form of a future agriculture adaptation plan or agenda to be linked with the long term strategy of Ministry of agriculture. This strategy is aiming to improve crops production, reduce insufficient-food gap, use natural resources in a sustainable way, and improve the rural society situation.

Adaptation measure	**Potential value for improving production under climate change**	**Feasibility of adoption for the farmer**	**Environmental or social limitations to measure**
Changes in crop variety	Low	Easy Low cost	Easy Low to high cost
Changes in crop calendar	Low	Easy Low to very high cost	Easy and without cost
Changes in irrigation amount	High	Easy	Easy
Changes in nitrogen fertilization	Low	Easy Medium cost	High
Changes in crop variety, calendar, irrigation amount and nitrogen fertilization	High	Difficult High cost	High
Education on water-saving practices and changes in crop choices	High	High	Low

Table 88: Evaluation of the adaptation measures proposed by stakeholders in Egypt

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AIACC Project Office
The International START Secretariat
2000 Florida Avenue, NW, Suite 200
Washington, DC 20009 USA Tel. +1 202 462 2213
Fax. +1 202 457 5859
Email: aiacc@agu.org
Or visit the AIACC website at:
www.aiaccproject.org