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THE SUSTAINABILITY OF TUNISIAN ARID FOOD SYSTEMS BETWEEN THE LIMITS OF ENVIRONMENTAL SUPPLY AND THE CHALLENGES OF FOOD SECURITY FOR RURAL POPULATIONS: CASE OF CEREAL FARMING

Ali Hanafi

Biogeographer, Ph.D., « Geomatics and Geosystems » Laboratory - LR19ES07, FLAHM, Univ. of Manouba, Tunisia.

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ABSTRACT

Cereal farming plays a key role in food security for all countries since it is cultivated over large areas and the crops are often stored for later use, which allows meeting the food demand even during periods of shortage or economic instability. By promoting the production and storage of cereals, cereal farming helps reduce the risks of famine and food insecurity, particularly among the most vulnerable farming communities. In Tunisia's arid region, this strategy of managing uncertainty has characterized traditional food systems, allowing them to become sustainable and rural communities to limit the effects of climate and economic hazards. Based mainly on barley and durum wheat, cereal farming has in the past been able to meet the food needs of people and their livestock thanks to a resource management and food system adapted to the fragility of agroecosystems. However, the increase in population numbers and changes in land use and feeding patterns, with a clear trend towards consumption of soft wheat, which is barely produced in the country, have led to an increase in demand for this product. However, neither the very irregular climatic conditions nor the national and international political instability have made it possible to meet these growing food needs. In the arid region of Tunisia, cereal farming is increasingly marginalized since its problems related to the weakness and fluctuation of production and yields have persisted in addition to the pressure that this activity is subjected to by other agricultural activities, considered more profitable, such as olive farming and greenhouse farming. Furthermore, the transformations of eating habits have led, in southern Tunisia, to a gradual abandonment of culinary traditions and know-how. Today, the sustainability of these food systems is deeply compromised, and the disruption of its equilibrium has reached an almost irreversible threshold.

Keywords: Sustainable Food Systems, Cereal Farming, Arid, Food Security, Southern Tunisia.

INTRODUCTION

Food security is a global issue that poses to all countries multiple challenges requiring international cooperation to overcome them. These challenges are even more complex as the world's population continues to grow to nearly 8 billion by 2023, driving up demand for food. Climate change, including global warming, extreme weather events, soil degradation, dwindling water resources and biodiversity loss, are all challenges that threaten food security in many parts of the world. In addition, conflicts, wars, and humanitarian crises can also have dramatic consequences on food security, limiting access to food for the most vulnerable populations (FAO *et al*. 2022, HLPE 2022, Lopes Morey *et al*. 2022, Solidarités International 2022, UN 2022). According to the World Food Program, more than 270 million inhabitants are estimated to be experiencing "acute food insecurity" in 2021 (WFP, 2021). With the outbreak of war in Ukraine since February 2022, this number is likely to increase as several countries have been affected by food insecurity, particularly those whose food supply is usually dependent on Ukrainian grain imports. According to the IMF, the global economic outlook is increasingly uncertain, especially in a context of financial sector disruptions, high inflation, the effects of Russia's invasion of Ukraine, and the legacy of the three-year COVID-19 pandemic.

In the Mediterranean, food security is a major challenge due to difficult climatic conditions, pressure on natural resources and conflicts affecting the region. These conflicts are particularly affecting food systems by limiting access to food, disrupting supply chains, and degrading agricultural infrastructure. According to FAO, about 8.3% of the population in the Mediterranean region in 2021 is affected by hunger, or about 25 million people (FAO 2022). Child malnutrition rates are also high in some countries of the region, reaching up to 14 per cent in some areas. The Mediterranean countries are also facing challenges, such as land degradation due to over-farming, water scarcity due to population growth and climate change, and threats posed by crop diseases and pests.

The MENA region, and particularly Tunisia, is where these constraints are felt the most, not only because of the restrictive environmental conditions (aridity), but also because of the economic crisis that the region has been plunged into since 2011, when the "Arab Spring" broke out (Boubabkri 2011, Daoud 2011, Gana 2011, 2013, World Bank 2012, 2016, Ayeb 2013, Elloumi 2013, Ben Jelloul 2014, Elfatih A. 2015, Mushtaq & Afzal 2017). This crisis has led to a sometimes-chaotic economic situation which has manifested itself, in the case of Tunisia, by the

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over-indebtedness of the state and its inability to maintain the pace of imports of several necessities, mainly food[1].

It is in this region that food insecurity is most pronounced, since it is naturally arid and presents many obstacles for agricultural activities to ensure food for the population, especially those in rural areas. One of these activities is cereal farming, which is often characterized here by significant fluctuations in yields and quantities produced. According to FAO data, cereal production in North Africa and the Middle East, two regions with arid conditions, grew at an average annual rate of 1.7% between 2000 and 2019. However, this growth has been uneven from year to year due to a variety of factors such as changing weather conditions, armed conflicts, and crop diseases.

The manifestations of these fluctuations are manifold and affect the environment, the economy and society. Environmentally, unstable cereal production can put increased pressure on natural resources, such as water and soil, due to the need to irrigate crops and maintain soil fertility. Fluctuations in production can also have significant economic consequences for farmers and rural communities, who often depend on the income from selling crops for their livelihoods. Fluctuations in production can also affect people's food security, especially in regions where cereal crops are an important source of staple foods. In this arid region, where climate conditions are difficult and water resources are limited, food security challenges are even more complex and require innovative and sustainable solutions to ensure food availability and accessibility for local populations (Hanafi 2022a).

The arid region of Tunisia is a typical example of this complexity, which is dominated by a peasant population consisting essentially of a category of agro-breeders with small farms with very few tools and means of production that do not allow them to achieve convincing results in terms of production (Sfia 2018). Although they are an important element in the agricultural landscape of Tunisia's arid region, this category of small-scale farmers most often faces financial, technological, and social difficulties that hinder their ability to produce enough food to meet the needs of rural communities (Elloumi 2006, Dhaher 2010, Ben Said *et al.* 2011, Fautras 2015, Jouili *et al.* 2017, Chebbi 2019, Frija *et al.* 2021).

In addition to the problems common to peasant agriculture in the Mediterranean region, agriculture in southern Tunisia is particularly confronted with difficulties linked to water scarcity, land fragmentation, poor access to finance and production technologies, and competition from

[1]According to IMF estimates in 2020, the total external debt of Tunisia's public sector (government, state-owned enterprises, and the Central Bank for the balance of payments) and private sector increased from 84.6 percent of GDP in 2017 to 94.7 percent in 2020. It was estimated that it would exceed 100% of GDP by 2022 and gradually fall to 95.7% in 2025. It is also considered unsustainable without a structural reform program (source: The debt crisis in Tunisia in an acute pandemic context (aa.com.tr))

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imports. Indeed, small family farms in the South are struggling to compete with cheap imports, which can make their production less profitable and reduce their ability to meet local food needs. The COVID-19 pandemic has also exacerbated the region's food security challenges, having a significant impact on the regularity of food supply chains, and reducing farmers' incomes.

Cereal crops are becoming important for small farmers in the South and Tunisian farmers in general, as they play a significant role in feeding the population. Cereal crops, especially durum wheat and barley, and secondly soft wheat, have always been dependent on rainfall conditions and have always fluctuated in the annual sown areas, the harvested areas, the quantities of production and the yields per hectare. This fluctuation has a direct impact on the food security of Tunisians as well as on the country's economy. Despite the annual imports of soft wheat by the State, the food supply of the rural population in Tunisia's arid region has been disrupted, particularly during the last two years, with the observation of several cases of shortage of cereal products. It is in this context that we will attempt in this work to study the importance of cereal farming in the equilibrium of food systems in the Tunisian arid region and to analyze its problems related to the fluctuation of its production and its yield and to examine, finally, the key factors that threaten the sustainability of these systems as well as the traditional food autonomy that characterized this region.

STUDY AREA

The south of Tunisia is a large region comprising an uninhabited Saharan part at the southern and southwestern end of the country and an arid part that stretches over the east bordered by the Mediterranean Sea and the north bordered by the High Steppes. The arid region, object of this work, concerns this last part of the South concerned and extends over about 40,000 km². It has a variety of natural landscapes with small mountain ranges, cramped foothills, vast plains and spreading areas in the form of *sebkhas*[2] and *garâas*[3]. All these landscapes are characterized by the arid bioclimatic stage with its two lower and upper sub-stages. Administratively it is a vast territory that is part of the governorates of Gabes, Medenine, Tataouine, Kebili, Tozeur and Gafsa with a small part of the governorate of Sfax. This vast arid region often faces agricultural challenges due to its constraining climate, fragile soil, and scarce water resources.

[2] Sebkha: a closed salt-water depression
[3] Garâa: a closed depression with fresh water

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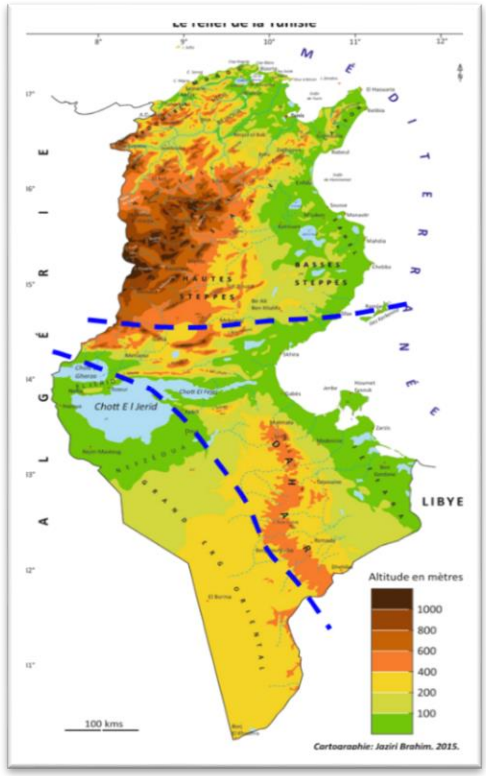

Fig. 1: Location of the Tunisian arid region

I. AN ARID ENVIRONMENT WITH LIMITED POTENTIAL

1. The Aridity: a constraint on the balance of agroecosystems and the development of cereal farming

As mentioned in the introduction, arid regions occupy a large part of the land surface and are populated by one third of the world's population (Le Floc'h *et al.* 1992, Chakrabarti 2016). Ai defines all the climatic factors that characterize a region: temperature, precipitation, air humidity, insolation, etc. It is different from drought, which is caused by an accidental phenomenon of variable duration and periodicity, and which is marked by an acute water deficit (Toupet 1984, Pelissier 1989). Furthermore, disturbances in arid regions most often lead to malfunctioning of agroecosystems affecting both natural components (steppes, soils, etc.) and human components (agropastoral production systems). Chronic scarcity of precipitation, the intensity of evaporation, the precariousness of water resources characteristic of arid regions results in widespread erosion, overexploitation of naturally fragile ecological systems, irreversible changes, and degradation of production potentials (Le Floc'h *et al.* 1992). These harsh environmental conditions are most often an obstacle to the development of these regions, especially rural ones.

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Although inherited for hundreds of years, scientists agree that aridity is a phenomenon that has been accelerated and aggravated by humans. On the occasion of a synthesis on the drylands of Morocco, Ionesco (1965, cited by Floret and Pontanier 1984) notes that climate effects can be masked or aggravated by human activity. Deforestation, fire, overgrazing, erosion... all contribute to increased climate aridity. These phenomena of woody trees clearing, and eradication have been mentioned in the arid region of Tunisia by several authors, which has certainly accelerated the process of aridification of the environment (Le Houérou 1959, 1969, Floret *et al.* 1978, etc.). For Floret and Pontanier (1982), land cover degradation leads to an increase in air and soil temperature, which results in a decrease in water storage capacity.

This is the case of the Tunisian arid region, subject of this synthesis, where imbalances have been observed in several economic sectors and ecological environments, and where development encounters difficulties, particularly in its rural part (natural resources, agropastoral production systems, strategies of peasant societies, etc.). To evaluate these difficulties, it is important to analyze this aridity in its both climatic and edaphic aspects (precipitation, temperature, evapotranspiration, quantities of water available for living beings, physico-chemical characteristics of the soil) (Floret and Pontanier 1984, Le Floc'h *et al.* 1992).

1.1. Climate aridity

Climate aridity is a natural phenomenon but also a climate concept that refers to a given region (Floret and Pontanier 1984)[4]. This aridity is an essential feature of the study area. The latter is part of the Mediterranean isoclimatic area and is defined as a transition climate between temperate and tropical climates. This explains the South's submission to the two climate action centers: one, located in the South-West, is the site of a dry and hot sub-tropical Saharan climate, the other, located in the East in the Gulf of Gabes, is under the influence of a temperate Mediterranean climate (Ferchichi 1996). This climate is characterized by seasonal and daily photoperiodism, and rainfall concentrated in the relatively cool winter season. Summer is a hot and dry season. Most precipitation originates either in the Gulf of Gabes (autumn and early winter rains) or in the western Mediterranean basin (spring and winter rains) and rarely in the Atlantic (Floret and Pontanier, 1982). It is through these main characteristics that we present this aridity in the study area.

[4]Aridity should not be confused with drought, which is a temporal meteorological situation characterized by lack of precipitation during time-limited episodes (Arar 2016). Unlike aridity, drought reflects a temporary water deficit and is not related to the climate of the area where it occurs. It affects soil structure and causes changes in vegetation. Specialists distinguish between several types of drought such as (i) agricultural drought which manifests itself in a decrease in soil moisture which prevents plants and crops from growing and (ii) edaphic drought which causes a decrease in water infiltration and consequently the water reserve of the soil, and finally (iii) agroclimatic or bioclimatic drought which is recorded following a decrease in the water available to plants (Floret and Pontanier 1982, 1984, Arar 2016).

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1.1.1. Low and highly variable precipitation

The numerous studies conducted on the Tunisian arid region agreed on the low and high variability of precipitation (Le Houérou 1959, 1969, Floret *et al.* 1978, Floret and Pontanier 1982, 1984, Ferchichi 1996). Although only an indicative value, the average annual rainfall presented in the table below is low for all southern stations ranging from 87.8 mm for Kebili to 161 mm for Gabes. It is essentially its regularity or rather its variability that characterizes the climate. The coefficient of variation is around 50%, except for Gafsa where it is about 39%. The ratio of absolute maximum rainfall to absolute minimum rainfall varies from 11 times for Gafsa to 22 times for Kebili, Tozeur and Tataouine. The annual number of rainy days for all stations is between 15 and 30 days. In Gabès this number is about 30.6, or about 1 day of rain out of 12. At this station, there are no more than 4 to 5 days of rain greater than 10mm in the year (Floret and Pontanier 1982). According to the same authors, the frequency of occurrence in the year of daily rainfall events greater than 100 mm is 0.0002 in Gabes and 0.0001 in Tataouine and Medenine, which represents respectively on average 1 day every 14 years in Gabes and every 26 years in Medenine and Tataouine.

Tab. 1: Variability in average annual precipitation at some stations in the Tunisian arid region

	Pmm	Variation Coeff %
Gafsa	156.8	39
Gabes	161	52
Tozeur	96.9	46
Kebili	87.8	54
Medenine	152.8	57
Tataouine	118.4	53

Pmm: average interannual rain in mm

Sources: Floret and Pontanier 1984, Ferchichi 1996.

The stormy nature of the rain means that they very often have exceedingly high intensities, with a maximum that can exceed 100 mm/h in 5 minutes causing very violent floods. In Gabès, the return period of a rainy event with an intensity of at least 100 mm/h for 5 minutes is 25 years, whereas in one year out of 5, this intensity will be 30 mm/h (Ferchichi 1996). The variability of rainfall is even greater at the level of daily rainfall since, according to Ferchichi (1996), it is not unusual to observe in 24 hours more than 50% of the rainfall of the year and more than 100% of the interannual average. According to Floret and Pontanier (1984), on December 12, 1973, it fell

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256mm in the sector of Menzel Habib - Segui, 70% of the total of this year (371mm), and 159% of the interannual average in Gabès (161mm).

On a monthly scale, rainfall is very unevenly distributed across seasons and months. The rain shows a peak between November and February, and a trough between July and August. It should be noted, however, that the average monthly rainfall is not as representative in rainfall-differentiated climates such as the Mediterranean climate and especially its arid stage. This average is only an arithmetic value that considers exceptionally dry or wet months that are sometimes very abnormal or questionable.

Using a frequency analysis, Ferchichi (1996) notes that for all stations, the median monthly precipitation, that is, that reached or exceeded every other year, is low (generally less than 20 mm) and has absolute maxima in winter for Tataouine, Tozeur and Medenine, in autumn for Gabes and in late winter in early spring for Gafsa and Kebili. The values of the first quartile, i.e., the frequency of the quantities precipitated one year out of four, show that, except for summer, a period with low or no rainfall, each of the months of the year could be sufficiently rainy (> 20 mm) one year out of four. The values of the third quartile, i.e., the frequency of the quantities precipitated three out of four years, show that these precipitations are very low (<5 mm). Apart from the dry summer period when the variability is in the order of 300% and can reach extreme values of 700%, this value fluctuates between 120 and 150% for the rest of the months of the year.

Tab. 2: Average monthly rain in some Tunisian arid stations (in mm)

	S	O	N	D	J	F	M	A	M	J	J	A
Gafsa	15.1	17.2	17.6	17.5	15.6	15.1	22	15.2	11.4	5.8	1.7	4.5
Gabes	17.5	34.8	30.3	19.6	21.3	17.4	21.1	13.4	8.6	1.6	0.4	1.1
Tozeur	8.4	13.1	12.7	10.8	11.2	8.1	12.8	10.1	5.8	1.1	0.2	1.2
Kebili	6.5	12.3	12.5	12.8	10.9	8.2	15.3	8.4	5.5	1.3	0.3	0.2
Medenine	10.8	23.6	18.5	17.2	17.2	17.7	24.3	13.3	6.4	1.4	0.2	1.1
Tataouine	7.7	10.3	13.8	14.7	16.8	14.3	19.6	11.2	6.4	1.3	0.1	1.6

Sources : Ferchichi 1996, N.I.M.[5]*2018*

Drawing on the work of Le Houérou (1969) and to have an idea of the level of availability of this precipitation for natural and agricultural vegetation, Ferchichi (1996) identified a set of criteria for establishing a classification of rainy years. According to this author, a favorable year is

[5]N.I.M.: Tunisian National Institute of Meteorology

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considered when the amount and distribution of rainfall have sufficient moisture at the soil level to ensure the germination of seeds, the growth of young plants and the regular growth of adult plants until the completion of their reproductive cycles. Based on this definition, he accepted that a year is favorable if:

- Rainfall is greater than or equal to the inter-annual average,
- Rainfall peaks occur in autumn and spring,
- The amount precipitated is spread over an extended period of the year. The distribution of precipitation is here more interesting to consider than its quantity.

For Le Houérou (1969), early fall rain favors seedling germination and the start of the growing cycle after a summer rest period. Similarly, late spring rains allow new seedlings to enter the summer dry spell in a state of self-defense. To be able to make a quantitative estimation of a favorable year, Le Houérou (1969) introduced the notion of effective rain. This concept provides information on the first autumn rain necessary and sufficient to activate vegetative start-up and makes it possible to specify the minimum daily rain threshold above which rainfall is effective for vegetation. Admitting that rainfall below 10mm in 24 hours is not highly effective, because this water is quickly taken up by evaporation, he concludes that in southern Tunisia, the rainfall efficiency is less than 50% in the upper arid bioclimatic stage and less than 40% in the lower one. Moreover, for all the main stations in the South, the years favorable to vegetation do not exceed 30% and fall to only 14% and 15% in Kebili and Tozeur, respectively.

However, several natural plants can start their cycle independently of autumn rainfall, and this is done by deferring moisture from the previous year in the case of *Ziziphus lotus, Erodium glaucophyllum, Peganum harmala* (Ferchichi *et al.* 1991). Other species more demanding for a larger quantity of water are only able to start their cycles from a rain of 20 mm, the case of *Periploca laevigata*, *Atriplex halimus* and *Stipa lagascae* (Visser *et al.* 2002, Chaieb *et al.* 2004). The beginning of the rainy period can, therefore, be defined as the first autumn daily rain at least equal to 20 mm. The effectiveness of rainfall below 20mm depends on its situation in relation to all rainfall events of the year. This threshold is also valid for most cultivated species, except barley which has a capacity to trigger its cycle with an amount of rain around 10mm.

According to Floret and Pontanier (1982), only two out of five years are wet and are favorable to plant activity. In the arid region of Tunisia, on an annual scale, it is exceedingly difficult to obtain this period, but if it takes place, it corresponds to about one month in autumn (from mid-October to mid-November) and one month in spring (from mid-February to mid-March). Overall, in arid bioclimate vegetation benefits from only 20 to 35% favorable years compared with 15 to 20% dry years and 30 to 50% normal years.

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Tab. 3: Number of dry[6] years and years favorable to agriculture in some study area stations.

	% very dry years	% of years favorable to vegetation
Gafsa	18	28
Gabes	17	26
Tozeur	19	15
Kebili	24	14
Medenine	19	21
Tataouine	18	16

Source : Le Houérou 1969, Floret et Pontanier 1984, Ferchichi 1996

1.1.2. The Aridity is accentuated by hot temperature

Temperature exerts a crucial influence on the behavior of organisms through its control over all vital processes. Plants' growth, activity and reproduction are heavily dependent on temperature. According to Floret and Pontanier (1982), the influence of temperature on plants is exerted first at the level of the rate of chemical reactions which changes with temperature, at the level of the activity of enzymes which also usually increases with temperature, then at the level of the influence that the latter exerts on the physical phenomena of solubility and viscosity of liquids, permeability of cytoplasm and consequently on the speed of internal exchanges and with the environment, and finally at the level of physical and mechanical alterations of plants under the effect of low or high temperatures. Plant species are more sensitive to the minimum temperatures of the cold season and to the maximum temperatures of the hot season and consequently to the amplitude of their oscillations. Moreover, it is these elements that best characterize the thermal regime in a given place.

The table below summarizes, for some stations, the information concerning the average of the maxima of the hottest month (M), the average of the minima of the coldest month (m) and the thermal amplitude (M-m). The values in this table show that:

- Although not very significant, the average annual temperature exceeds 20°C for all stations except Gabès and Gafsa,

[6] A year is classified as dry when the rainfall of the year does not exceed 50% of the average inter-annual quantity. If it exceeds this rate, then the year is considered wet (Floret and Pontanier 1982, Ferchichi 1996).

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- On the coast, the average minimum of the coldest month is generally high exceeding 5.8°C (with a maximum of 6°C in Medenine). Indoors, the temperature drops to around 3-5°C. It is the lowest in Tozeur with 3.1°C,
- The average maximum of the hottest month exceeds 40°C in the sub-desert stations (42.2°C in Kebili and 40.5°C in Tozeur). On the coast, it is about 34°C. It is between 35° and 38° C. over the rest of the territory,
- The thermal amplitude is generally high for all the stations studied. But it is the lowest on the coast with 28.9°C in Gabes and it is because of the moderating influence of the sea. On the contrary, the continental zone has excessively high maximum amplitudes, above 34° C. with a maximum of 39.1° C. in Kebili.

Tab. 4: General temperature characteristics at some stations in the study area

	T	M	m	M-m
Gafsa	19.6	38.3	3.9	34.4
Gabes	19.3	34.8	5.9	28.9
Tozeur	21.6	40.5	5.3	35.2
Kebili	21.2	42.2	3.1	39.1
Medenine	20.7	36.9	6.0	30.9
Tataouine	20.6	37.9	4.8	33.1

***T**: Mean annual temperature in °C, **M**: Mean of the maxima of the warmest month in °C, **m**: mean of the minima of the coldest month in °C, **M-m**: annual thermal amplitude in °C.*

Source: Floret and Pontanier 1982, Ferchichi 1996

1.1.3. Evapotranspiration and overall water balance

The first type of evapotranspiration that will be presented here concerns potential evapotranspiration (PET). This is a fundamental characteristic of the climate and represents the accumulation of soil evaporation and plant transpiration. This concept helps to better interpret the impact of drought on crop production (Floret and Pontanier 1984). Although evapotranspiration is closely related to climate factors (solar radiation, temperature, wind, etc.), it also depends on the natural environment of the area studied, the plant species concerned and the soil properties. Several authors have developed indices and formulae which make it possible to characterize this PET (*Thornthwaite, Penman, Turk*, etc.). Hammami (1990) compared the application of these different formulas in the Mediterranean climate. For this author, the PET is the maximum water consumption of an active, dense and extended vegetation covering a large

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area and well supplied with water and corresponds to the maximum of the evaporating power of the air.

In arid Tunisia, the PET calculations, evaluated by three different formulae, show that the annual evapotranspiration is extremely high for all stations and exceeds 990mm in Gabes according to the *Thornthwaite* formula. For this station with the lowest PET, it increases according to the *Penman* and *Turkish* formulae to 1255mm and 1408mm, respectively. The PET is highest at the stations of Tozeur and Kebili, whatever the formula applied. On a monthly scale, Ferchichi (1996) found that the minimum PET value usually occurs in December and the maximum is reached in July. The gap between the summer maximum and the winter minimum ranges from 215mm in Gafsa to 141mm in Gabès. The rainfall exceeds the PET only in rare exceptions (October for Sfax, October and December for Gabes and December for Medenine). These high PET values have a direct impact on the annual water balance, which is highly deficient for all stations ranging from -849 mm/year at the coastal station of Gabès to -1116 mm/year at the subdesert station of Tozeur.

Tab. 5: Potential evapotranspiration and water deficit at some sites in the study area

Station	PET (mm)			P - PET
	Turkish	*Thornth.*	*Penman*	(mm)
Gafsa	1417	1042	1318	-876
Gabes	1408	996	1255	-849
Tozeur	1459	1171	1450	-1116
Kebili	1433	1158	-	-1102
Medenine	1401	1096	1322	-978
Tataouine	1416	1085	-	-989

Sources: Floret and Pontanier 1982, 1984; Ferchichi 1996

The second type of evapotranspiration is real evapotranspiration (RET). Its value depends on the amount of water available for plants. When the soil is saturated with water and this water is available, the RET can reach the PET values. According to Gerbier and Brochet (1975 cited by Ferchichi 1996), the RET/PET ratio is presented as a climate index that tends towards unity in the equatorial zone and towards zero in the desert dry zone.

According to Floret and Pontanier (1982) and Ferchichi (1996), the water cycle in arid Tunisia develops in three periods. During the first period soil reserves (SR) begin to build up as soon as the first autumn rains. The start of vegetation depends on how quickly the reserves build up. During this phase, which extends from the first autumn rains until February-March, the RET = P

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+ SR. Due to irregularities in precipitation, some months of this period may be in surplus, and the RET is then equal to the PET. Consequently, the production of green matter, not being limited by the water deficit, is at its maximum. The second period is a post-wet period where soil reserves are beginning to run out. During this period, stomatal regulation occurs, which reduces the production of green matter. The RET is then equal to the rainfall (RET=P). The last period corresponds to the period of summer drought during which rainfall is zero and the climate balance is largely in deficit. As a result, plants reduce their exchange areas and close their stomata. The production of green matter becomes zero and the ETR, which equals rainfall, is canceled out.

The statistical expression of the humidity and aridity levels established by several specialists (Thornthwaite, Lang, Auberville, Gaussen and Bagnouls, Emberger, etc.) consisted in establishing a balance of water brought to the ground by precipitation and water likely to be lost by evaporation and transpiration (Ferchichi 1996). By applying Emberger's Q2 index for the climate data of arid Tunisia, Le Houérou (1959, 1969), was able theoretically to distinguish two bioclimatic sub-stages (upper and lower Arid) and two winter variants (fresh and mild). The values of some indices of quantification of climate aridity, applied to the climatic data of some southern stations confirm the great aridity of this region. The cross-referencing of the various indices shows that the number of dry days is exceedingly high for all stations, exceeding 266 days in Gabes and reaching 336 days in Tozeur. For dry months, the various calculations made show that their numbers exceed 11 months for all stations.

Tab. 6: Some indices of climate aridity in the study area

Station	Clues				Average annual dry months		
	P/PET (Penman, UNESCO)	P/T (Lang)	Q2 (Emberger)	Ix = number of dry days (Gaussen & Bagnouls)	Thornth. (P<= PET)	Gaussen & Bagnouls (P<=2T)	Auberville (P<30mm)
Gafsa	0.12	8.7	15.8	298	11	12	12
Gabes	0.15	9.7	23.8	266	11	12	10
Tozeur	0.08	4.2	8.4	336	12	12	12
Kebili	-	4.2	7.2	-	12	12	12
Medenine	-	7.1	16	-	12	12	12
Tataouine	-	6.3	13	-	12	12	12

Sources: Floret and Pontanier 1984, Hammami 1990, Ferchichi 1996.

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Overall, RET analysis in the study area shows that plant growth is discontinuous and the influence of irregular and sporadic precipitation on cereal production is very pronounced. Frequency analysis of years favorable to vegetation has also shown that the annual precipitation regime in arid bioclimatic stages is not favorable to the regeneration of plant species and groups. Although the annual amount of rain is low to extremely low for all stations, more account should be taken of its distribution and in particular its occurrence during periods of plant activity. Moreover, it is not important for a cereal crop to receive any amount of rain per year if the distribution of this rainfall does not meet its seasonal requirements which are related to its life cycle.

1.2. Edaphic aridity

Edaphic aridity "*is a water stress that promotes the degradation of vegetation cover, and therefore the degradation of biodiversity*" (Arar 2016). This is common in dry areas where the vegetation cover does not exceed 40% and where the soil has characteristics that reduce its potential water storage capacity. For Le Goulven *et al.* (2009), according to the French dictionary of hydrology, "*aridity is manifested above all by its edaphic consequences (lack of vegetation and scarcity of living beings), hydrological consequences (weakness and irregularity of flows, degradation of networks) and geomorphological consequences (erosion processes, soil poverty)*". For Floret and Pontanier (1982), depending on the type of edaphic environment and its use by humans, climatic aridity can be either attenuated or, on the contrary, accentuated depending on the redistribution of water from precipitation. The soil therefore plays an all the more decisive role as water is scarce. Variations in soil water regime are the main limiting factor in the production of the arid agroecosystem, especially since this soil acts as (i) a temporary reservoir of infiltrated water, (ii) and as a regulator controlling the distribution of the different water flows: runoff, drainage, evaporation, and transpiration.

For Le Goulven *et al.* (2009), edaphic aridity can be quantified by empirical indices, most of which stem from simple hydrothermal relationships with a distinction between semi-arid regions where rainfall is sufficient to ensure a seasonal rhythm of vegetation and arid regions where rainfall is low, irregular, and grouped over a season with intermittent flows that are quite violent and disorganized. By measuring the water balance on a very shallow uncultivated loamy glacis, Floret and Pontanier (1982), established an index called the *rainfall efficiency coefficient ($Ke=Pe/P$)*, represented by the following equation:

$$Ke\ (\%) = 100 - (0.903\ I15 - 1.59\ SDC - 0.11\ IR + 6.5)$$

With: Ke: Rain efficiency coefficient; I15: maximum intensity in 15' (0.1mm/h); SDC: deficit in relation to the field capacity of the first 20cm of the soil (0.1 mm); IR: vegetation cover index in

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%. The result gives 3 classes: Ke < 50%: low efficiency, Ke: 50-70%: medium efficiency, Ke > 70%: high efficiency.

The results of this calculation, presented in the table below, show that if infiltrated rain is considered, soil aridity increases with rainfall intensity, which increases runoff and, consequently, water outflow from the region. It also grows with the decrease of the plant cover which, by its absence, promotes runoff. This coefficient is also dependent on the form and intensity of land use. For this reason, it is lowest in highly degraded and eroded steppes, while it is highest in healthy and uneroded steppes and those protected by crops. Moreover, a rainstorm will not have the same effect on the recharge of water reserves, depending on the type of soil, its physical-water characteristics, its water state at the time of rain, the state of its surface, the topography, the land use, and the vegetation cover level.

To show how the Emberger rain quotient (Q2) can be modulated according to the main types of environments, Floret and Pontanier (1982) conducted measurements in the Menzel Habib-Segui region, considering not the rain falling on a given environment, but the quantity that infiltrates there. First, an average value of Q2 obtained in the order of 21.4 is representative of environments where there is no water supply or deficit following runoff. Only the deep sandy environments would have the ecological zonality that is attributed to the general bioclimatic classifications, that of Emberger. Elsewhere, the authors found that:

- The sloping glacis covered with calcareous crust have, considering that infiltrated rain, Q2 is between 12 and 14, whereas on the gypsum crust glacis with very sparse vegetation, Q2 is between 13 and 15. As a result, the glacis are close to the Saharan level,
- The loamy environments, often devoid of vegetation and having a Storm threshing film on the soil surface, have, despite their slight slope, a poor surface porosity. Q2 on their extension areas is between 15 and 16,
- Wadi-beds may have Q2 values ranging from 28 to 35 or more, depending on the topographical situation, due to water inflows. As a result, they are close to the upper arid and even the semi-arid floor.

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Tab. 7: Variation of rainfall efficiency by type of environment in study area

Type of steppe	Degradation level	Land use	Vegetation Cover %	Rainfall efficiency ratio %
Sandy steppe	In good condition	Grazing	40	84
	Medium, swinging surface	Grazing	20	65
	Very degraded, eroded and beating soil	Grazing	10	55
	Cleared, slightly truncated soil	Cereal Farming	5	74
Loamy steppe	Medium condition, swinging surface	Grazing	20	82
	Very degraded, eroded and beating soil	Grazing	5	78
	Cleared, eroded soil	Cereal Farming	5	62
Wadi bedssteppe	In good condition, slightly swinging surface	Grazing	40	86
	In good condition	Cereal Farming	10	95
Gypseous steppe	In good condition, slight swinging cover	Grazing	15	66
	Very degraded, flush crust	Grazing	5	55
Calcareous steppe	In good condition, slight overlap	Grazing	20	72
	Very degraded, flush crust	Grazing	10	44

Source: Floret and Pontanier 1982, adapted

This analysis shows that, apart from the amount of rainfall and its intensity, it is the soil characteristics that most determine the infiltration efficiency and, consequently, the edaphic aridity degree. According to Floret and Pontanier (1982), for an identical distribution of rainfall during the year and for the same annual height of precipitation efficiency, diverse types of soil do not show the same responses to climatic aridity. Thus, some soils allow the plant to have a longer vegetation cycle and this only according to the physical and water characteristics of their horizons. To characterize edaphic aridity, Floret and Pontanier (1982, 1984) admitted that:

- A dry month (SP) if it receives less than 10mm from June to October inclusive, and less than 5mm from November to May inclusive,
- Theoretical climate drought (SC) if (*Pe - Penman PET< 0*),
- Dry soil (Se) for plants occurs when the plants can no longer sweat, i.e., when there is no more water available in the soil.
- That the absolute soil drought (SE) is represented by the water state of the soil (number of edaphically dry months).

Tab. 8: Average duration of soil aridity according to soil type in the Menzel Habib-Segui region for the period 1971-1977.

Type of steppe	Subscript	Number of months sec/year	Average rain
Sandy soil	SP	6.1	213
	SC	11.3	
	SE	3.3	
	Se	4.8	
Loamy soil	SP	6.4	227
	SC	11	
	SE	4.4	
	Se	7.8	
Gypseous soil	SP	6	212
	SC	11.4	
	SE	4.3	
	Se	4.7	
Calcareous soil	SP	6.3	221
	SC	11.1	
	SE	3.9	
	Se	7.2	

SP: rainfall-related drought (P<=10 mm in summer; P<=5 mm in winter); SC: theoretical climatic drought if Pe <PET Penman in the

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month; SE: absolute edaphic drought when the soil water supply is at So (permanent state of drying); Se: edaphic drought for plants; the whole profile is at a water state below the wilt point (pF 4.2). N.B.: the month is considered dry if the drought lasts at least 3 weeks; the climatic year ranges from 1/09 to 31/08.

Source: Floret and Pontanier 1982, adapted

Table 8 shows that absolute edaphic drought (SE), and for almost comparable rainfall amounts, is the highest in the loamy steppes of those gypseous where it lasts 4.4 and 4.3 months, respectively. This could be explained by the heavy texture of these soil types compared to sandy soils, which are lighter and therefore more porous, thus favoring more infiltration for water. For gypseous soils, their absolute soil aridity remains lower than that of loamy soils because of their characteristic absorbency of gypsum crystals, which plays a role in the storage of copious quantities of water during a long period of the year. The edaphic drought for plants (Se) is also highest in the loamy and calcareous steppes, with 7.8 and 7.2 dry months, respectively. The soil in these steppes is less water-filtering and more conducive to runoff. Paradoxically, sandy soils show less edaphic aridity than heavier textured or skeletal types. This finding may partly explain the interest of local populations in cultivating sandy land, even if the resulting wind erosion gradually reduces the water stock available for cultivation.

2. Limited and low-renewable water resources

Apart from its interest in the steppe, water is an essential factor for the human supply of drinking water and for the development of the agricultural, industrial and tourist sectors. Nationally, Tunisia receives an average annual volume of water of 36 billion m³ of precipitation but has only about 4.6 billion m³ of mobilizable water. As a result, each Tunisian has theoretically 450m³/year, a threshold below the global "water stress", commonly set at 500m³/year/inhabitant (Kochbati 2009). Of this 4.6 billion, approximately 2.73 billion m³ flow at the surface and only 1.870 billion m³ is used to supply groundwater aquifers that then constitute the renewable resources (Hbaieb and Albergel 2001, MARHP[7] 2020).

These waters are very poorly distributed, with 80% of them in the north of the country, while 70% of groundwater is in the south. In 2015, surface water was mobilized by 33 large dams, 253 hill dams and approximately 902 hill lakes. Groundwater is mobilized by 111,431 groundwater wells and 21,675 deep drillings, 11,102 of which are illegal. The deep aquifers, which are located in the south and shared with Libya and Algeria, contain 610 Mm³ of non-renewable water. Moreover, the maintenance of economic growth remains dependent on this resource, which is a limiting and limited factor in the arid region of Tunisia (Hbaieb and Albergel, 2001). This region

[7] M.A.R.H.P.: Tunisian Ministry of Agriculture, Water Resources and Fisheries

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is characterized by the scarcity of water resources because of climatic and edaphic aridity which, firstly, does not encourage the accumulation of surface water and, secondly, makes it difficult to supply groundwater.

Tab. 9: Distribution of water resources in southern Tunisia in 2017

	Potential in Mm³
Surface water	190
Groundwater	124
Deep tablecloths	785
Total	1099

Source: Gafrej, 2017

However, the confrontation between resources and needs, which increase from one year to the next, reveals a chronic deficit, despite the State's efforts to fill it with unconventional water resources (reuse of wastewater and treated water, reuse of drainage water, development of techniques for saving drinking water and irrigation, transfer of water between regions, etc.) (Gafrej 2016, 2017). From the point of view of their chemical quality, about 72% of the country's surface water potential has a salinity of less than 1.5g/l (82% of the northern waters, 48% of the central waters and only 3% of the southern waters). At groundwater level, only 3.8% of resources have salinity levels not exceeding 1.5g/l (Gafrej 2016). According to Ben Alaya *et al.* (2014), water salinity in the South is high around 4g/l. In some coastal areas such as Zarzis, it reaches 6 g/l and is even higher at the edges of the sebkhas. This mediocre quality of water in the region has not prevented the great increase in irrigated areas from only 18860 ha in 1975 to 78490 ha in 2015 (Baduel 1980, Kassah 2002, Gafrej 2017).

This increase in irrigated areas, particularly in oases, has been accompanied by over-exploitation of water resources. In 2015, the average groundwater exploitation rate was 114% and that of deep water was 120%. This rate reaches alarming levels of 216% in Kebili, and 212% in Chott El Fedjej and Djerid (Gafrej 2017, MARHP 2020, ODS[8] 2020). This overexploitation is explained by the feeding of irrigated agriculture, which is sometimes intensive in oases, but also by the drinking water supply to growing urban centers. According to the MARHP report (2020), the agricultural sector consumes 79.1% of the water in the deep water, compared to 18.5% for drinking water and 2.4% for industry and tourism. 82% of the groundwater is also exploited in the agricultural sector because of its high salinity.

[8]O.D.S.: Tunisian Southern Development Office

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Tab. 10: Intensive change in irrigated areas (ha) by main forms of irrigation in the South in 2015

	Deep drilling	Surface Well	Treated wastewater	Other sources	Total
Gafsa	6560	12290	-	-	18850
Gabes	12240	4920	-	-	17,160
Medenine	580	-	1920	-	2500
Tozeur	7720	470	-	180	8370
Kebili	23930	-	-	-	23930
Tataouine	3530	4150	-	-	7680
Total	54560	21830	1920	180	78490

Source: Gafrej, 2017

In 2015, irrigable perimeters were assessed at 92568 ha, of which 88.6% are private perimeters and 11.4% are public perimeters. Only 84.4% of these areas are irrigated (78490 ha) with an average intensification rate of 92% (Gafrej 2016, 2017). The decline in this rate is due to land fragmentation, land degradation (salinization and hydromorphy) and the decline in water quantity and quality in some regions. Table 10 also shows that 54560 ha (69.5%) of the perimeters are irrigated by deep drillings, meaning that they draw their water from the deep-water aquifers. As mentioned above, these aquifers are exploited through a remarkably high number of illegal drillings, particularly in the governorates of Kebili and Tozeur (Mekki *et al.* 2021). Annual exploitation by authorized water points reached a volume of 924 Mm³, representing an imaginary continuous flow of 23015 l/s. The illicit annual exploitation was estimated in 2020 at 319 Mm³, which is equivalent to a fictitious continuous flow rate of 9426 l/s. Overall, the south of Tunisia totals 11,788 water points, 81.5% of which are illegal, putting a heavy strain on water resources.

In short, water resources in the South are non-renewable due to the aridity of the environment. Despite this situation, they are subject to increasing human pressure and numerous socio-economic challenges (increasing demand for drinking water, demand for the agricultural and tourism sectors, etc.). The situation of uncontrolled overexploitation of several aquifers has led, in coastal regions, to an excessive drop in their piezometric levels and to water salinization following the intrusion of marine waters, thus altering their chemical quality (Romagny *et al.* 2004, Gafrej 2016, MARHP 2020).

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Tab. 11: Deep-water exploitation in southern Tunisia in 2020

	Total volume (Mm³)	Exploitedvolume (Mm³)	%	Distribution of holdings by governorates (%)					
				Kebili	Tozeur	Gabes	Gafsa	Medenine	Tataouine
TC	368.6	587.5	159	104	53	-	2	-	-
IC	117.7	136.9	122	58	20	34	-	-	10
JT	217	177	82	-	-	54	-	18	10

Ground waters names: TC: Terminal Complex, IC: Intercalary Continental, JT: Jeffara's aquifer, Source: MARHP 2020

II. CEREAL FARMING IN TUNISIAN ARID REGION, A CHALLENGING AND RISKY UNDERTAKING

1. Agropastoral production systems unfavorable to cereal farming

An examination of the agropastoral production systems in the study area in terms of their structure and technical characteristics shows that they are not very favorable to large-scale cereal crops like the North of the country (Hanafi 2000, 2010, 2022a, 2022b, Hanafi and Naoui 2022, Khebour *et al.* 2021). In fact, the synthesis of the forms of use of resources in the South reveals three main systems of peasant production which have a set of characteristics common to the different regions:

- Food farmers
- Small, Precarious Farmers
- Medium-sized farmers in productive expansion

Although they are different in economic terms, the first two forms of exploitation are united in the dominance of the small-scale peasantry, with all its characteristics relating to structures, tools and means of production as well as income. Indeed, agriculture is characterized in the arid region of Tunisia by the dominance of small farms (<5 ha) exceeding half in most of the sites studied and reaching about 96% in Kerkennah.

In addition, a peasant farm is characterized by the possession of about 20-50 feet of olive trees, about 20 other fruit trees, 1-2 ha of irrigated crops and 1-3 ha of dry crops (with very few inputs) and the ownership of a sedentary herd of about 20 heads dominated by sheep. The number of farm workers, often family and female, is around 2-4 persons per household (Hanafi, 2010, 2022, Hanafi and Naoui 2022). Except for oases, traditional food farms are technically and economically the most stable. Whether in the mountains, in the foothills (Bhayra, Limaoua, Sidi Aich, Segui, etc.) or in the plains (Ferch, Gordhab, etc.), the owners of these farms (generally

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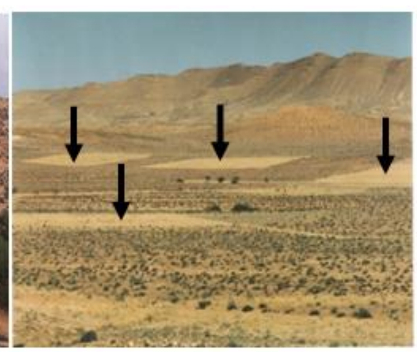
professional farmers and not converted nomads) have, throughout history, been able to make the most of their agricultural know-how, which has enabled them to set up a production system based on self-sufficiency with a functioning that minimizes the risks associated with natural and economic hazards.

Tab. 12: Characteristics of the main agropastoral production systems in Jeffara.

	Group 1	Group 2	Group 3
Farm area	--	--	=
Breeding	-	0	-
Arboriculture	++	++	++
Irrigated	--	0	++
Family assets	+-	-	+-
Age of head of household	=	-	--
Farm income	--	--	+
External activity	++	++	++
Total income	-	--	+

Group 1: Small agropastoralists; Group 2: Small precarious farmers; Group 3: Young agropastoralists in agricultural expansion. Relative importance of variables in each group: -- very low; -: low; +: high; ++: very high; =: medium; 0: zero; Source: Hanafi 2010, updated

A: Mountain arboriculture behind the jessour[9]



B: Rainy cereal farming in the plain

Fig. 2: Spatial organization of agricultural land in the Tunisian arid region (Photos: A. Hanafi 2004, 2018)

[9] *Jessour* (singular *jesser*) is a local name in southern Tunisia traditional water and soil harvesting technique built by earthen or dry stone along intermittent mountain streams to accumulate fertility (water, organic materials) and use it for a variety of agriculture (Bonvallot 1986).

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As for precarious farmers, they are often a part of the oasis population, or that of small villages with little means to work the land, or those where a good part of the family members has gone to work elsewhere and who, therefore, have abandoned the farms. In oases, for example, agricultural work is most often entrusted to a sharecropper (*khammes*). In other cases, women and older people are doing most of the work (Hanafi and Naoui 2022).

Tab. 13: Size of agricultural farms in some studied sites in the Tunisian arid region.

Site name	Studied area in ha	Farms area	Farms number	%
Jeffara	150,000	<5ha	326	54
		5-20ha	205	34
		>20ha	69	12
Menzel Habib	80,000	<5ha	198	57
		5-20ha	101	29
		>20ha	51	15
Kerkennah	145,000	<5ha	212	96
		5-20ha	9	4
		>20ha	0	0
Skhira	100000	<5ha	68	58
		5-20ha	33	28
		>20ha	16	14

Sources : personal Survey, 2000, 2001, 2020, Khebour et al. 2021

In terms of numbers, and whatever their level of technical stability and economic viability, it is the production systems characterizing small farms that are dominant in the arid region of Tunisia. Comparing the number of smallholder farms in the country, Jouili (2016) found this importance, as the number of small farms in the South is more than four times that of small farms in the North, hence the importance of small-scale farmers in the region.

Tab. 14: Number of farmers in two regions of Tunisia in 2014

	Storm farms	Mixed farms	Irrigated farms	Total
South	182946	21725	14,893	219564
North	40053	6481	3925	50459

Source: Jouili 2016

In 2014, there were 219,564 farms in southern Tunisia, representing almost 72% of the total number of farms. As for their area, they were spread over approximately 940000 ha, which shows their importance not only in relation to other regions of the country, but also in relation to large farms. According to Jouili (2016), 59% of this area is allocated to arboriculture, 33% to

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cereals, 1.9% to fodder, 2.2% to market gardening and 3.9% to legumes. Irrigated areas account for 6.3% of the cultivated area. Traditionally, farmers in the study area have maintained a strong capacity to manage environmental uncertainty (drought, soil fragility, scarcity of rainwater) by rotating between dry cropland and fallow cropland for livestock. The possession of several parcels scattered between the different territories (Jeffara, Dhahar, Oasis, etc.) allowed farmers to transplant with their herds and cultivate the cereals where the rain falls. Their task was easy, since keeping a large part of the land divided was an asset for these farmers. Thus, these agricultural rotations were also part of wider rotations with the steppes in order to maintain sufficient feed for the herds. This was one of the most effective strategies, inherited and passed down between generations, and which maintained the equilibria of existing agropastoral production systems, fragile steppe ecosystems and feeding systems for humans and their herds (Cialdella 2006, Genin *et al.* 2006). In this spatial organization and strategy, cereal farming, together with arboriculture and livestock farming, was a key element in the way of life and land management, since it enabled land to be exploited on an ad hoc basis, the soil to be developed rationally, the steppe and water resources to be conserved and the human and herd populations to be fed in a satisfactory manner.

In the 1st plan: a fallow of about 5 years used as a run by a sheep herd, in the 2nd plan: a bowl plot grown in barley, in the 3rd plan: a calcareous-limestone steppe run.

Fig. 3: Agropastoral land management of in the arid region of Tunisia (photo: A. Hanafi, 2018)

Contrary to these small farms and the traditional system, the continued privatization of several collective lands since the 1990s has allowed the emergence of a category of young farmers in

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Kerkennah, Skhira, Jeffara, Zanouch, Mareth, etc. who have engaged in a much more market-oriented and larger (>5ha) agricultural activity. For this reason, the operators of this system tended to specialize in a single activity while intensifying working methods (irrigated olive cultivation, above-ground breeding, irrigated vegetable crops, etc.). This has led to an increased dependence of production systems on factors of production and has sometimes been hampered by a problem of the marketing of products, especially since this new production system has shown its limitations in the face of a highly competitive national and international market (Hanafi 2022b). In addition, these farmers have gradually neglected dry cereal farming since it is a risky activity for them. The consequence was then observed in the level of production, which remained not only low but also fluctuating very well.

2. Marginalized cereal farming activity

At the national level, cereal production is highly irregular, with a gap of 1 to 10 between a dry year and a year of abundance (Khaldi and Saaidia 2018). This is the case, for example, in 1988, when the country recorded only 2.9 million quintals (qs), while in 2003 it recorded the exceptional quantity of 29 million qs. However, technical progress has not succeeded in stabilizing the sector’s output but has at least enabled it to increase significantly. Indeed, the ten-year average almost doubled between the decade 1970-1979, when it was around 9.5 million qs, and the decade 2000-2009, when it reached 17.6 million qs. But at the annual level, output gaps remained extremely high across the country, but the fluctuation was even greater in arid regions.

2.1. Large fluctuation in cereal areas

Because of its aridity, and although several cereals have always been cultivated there, southern Tunisia is not a cereal region par excellence. It should first be noted that the cereal year starts in the South a little later than in the North of the country. This is a delay of about 15-20 days starting in late November and early December, when the occurrence of autumn-winter rains is high. This season ends between the end of May and June, which is the harvesting period after the seeds in their ears have completely dried out. In this “crop year,” seed success is highly dependent on the first rain, which must be “significant” for farmers to plow land and cultivate grain in possession. It should be recalled here that significant rain in the agricultural sense and according to the results mentioned above, must be around the averages of November and December, i.e., about 10 to 20 mm.

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Tab. 15: Evolution of cereal farming area in the Tunisian arid region between 1980 and 2020

Year		1980	1990	2000	2010	2020
Sown area (1000ha)	The South	112	205	169	37	59
	Total Country	1375	1590	1583	1380	1044
	%	8.1	12.9	10.7	2.6	5.7
Harvested area (1000ha)	The South	95	138	67	4	44
	Total Country	1301	1392	1090	1328	828
	%	7.3	9.9	6.2	0.3	5.4

Source: O.C., 2021

Moreover, the success of harvests also depends on spring rain (between the end of February and March) which must be well distributed even if quantities are limited (around 5 minutes per episode). It is usually this rain that determines the quantity and quality of the crops. By reaching the last two months without problems, the cultivated cereals usually complete their cycle by producing the cobs with seeds. During the month of April, mature plants need little moisture (sometimes from morning dew) to 'fatten' the seeds and multiply the foliage. Thus, and given its rainy nature, this activity can always be called into question if, unfortunately, the autumn or spring rains are not there. In the first case, farmers do not plow, and in the second, the harvest is most often delivered to the livestock.

The observation of the data on the sown areas and harvested areas shows the low share of cereal cultivation land in Tunisian arid region compared to the rest of the country. This share is less than 10%; only in 1990 did it reach almost 13%. This was the case in 1980, when the area planted reached 205000 ha, while it was reduced to only 37000 ha in 2010, i.e., 2.6% of the national area (Slim *et al.* 1984, Romagny and Hajji 2006, Khaldi and Saaidia 2018). The situation is even worse for areas harvested annually and whose share was still below 10% or even zero in 2010 (0.3%). A slight increase was, however, recorded during the 1990s, explained by the cultivation of several lands after the waves of privatization experienced in the region, particularly in Jeffara and Menzel Habib - Seguisites, and the concern of new owners to assert their property rights (Abaab 1986, Hanafi 2000, Guillaume 2009, Guillaume *et al.* 2003, Elloumi 2015).

Although the sown areas and the harvested areas in the Tunisian arid region are small, it should be noted that the correspondence between some of their points on the curves in Figure 5 as for the years 1980, 1985, 2015 and even 2020, suggests that the bet of the farmers who cultivated

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their land during these years was raised since the areas of the harvested land were very close to those sown in the autumn. This situation also shows that rain has been present during the two main periods necessary for plant growth. Consequently, and in this series of nine observation dates (1980-2020), the success share of the agricultural year was around 45%, which can be considered as good risk-taking on the part of farmers if this activity is still included in its traditional general framework of complementarity between activities and territories, considering the very random nature of the rain.

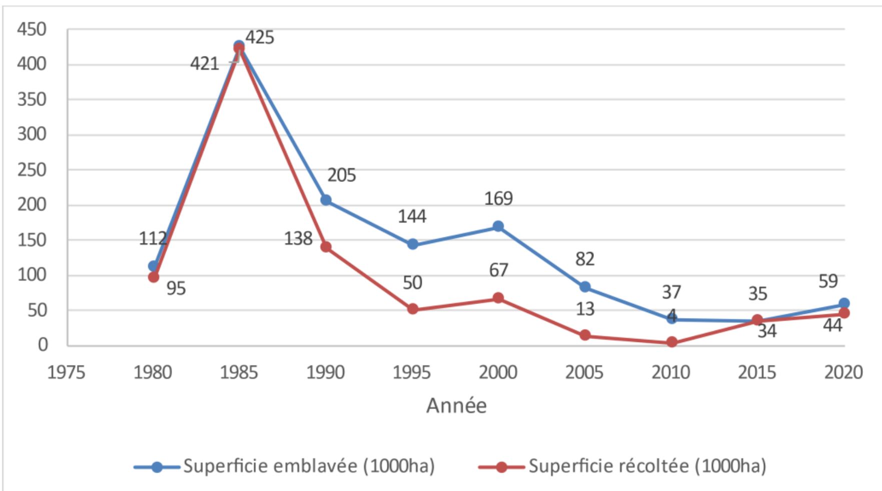

Fig. 4: Variability of cereal farming area in the study area between 1980 and 2020 (Source: O.C., 2021)

But, whatever the outcome, climatic conditions will still have a major impact on decisions about land use, particularly for a group of farmers who are increasingly lured into agricultural speculation and are unwilling to bet their money and time. But in addition to the climatic conditions that explain the small areas, we must emphasize the changes that the Tunisian arid region has experienced in terms of agricultural production systems, with a focus on “more profitable” activities such as olive, almond and pistachio plantations in Sfax, Gabes, Gafsa and Medenine; and vegetable crops under greenhouses in Skhira, Zanouch, Segui, El Ferch, Kettana and Mareth (Ben Saad and Elloumi 2015). These changes have put pressure on the traditional cereal plains, most of which have been privatized and sold to speculators.

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Fig. 5: Decrepit field a barley under weed and greenhouse pressure in Menzel Habib (photo A. Hanafi, 2020).

2.2 Greater fluctuation in the amount of grain produced

2.2.1 The fluctuation of total quantities

Dryland cereal production in arid environments is a difficult and risky business. As a result, cereal production is often characterized by large fluctuations in terms of quantities produced. Examination of the statistical data presented in Table 16 shows, like the areas, a great weakness in the quantities of cereals produced in the Tunisian arid region since 1980. In fact, the share of cereal production has never exceeded 5%, with a maximum quantity of 684000 qs harvested in 1990, or 4.3% of the national quantity. But, in most years of observation, this share is usually around 1%, which is almost insignificant and could not meet the food needs of the inhabitants and their livestock.

Tab. 16: Evolution of total cereal production in the study area (in 1000 qs)

Year	1980	1985	1990	1995	2000	2005	2010	2015	2020
Southern Tunisia	174	1676	684	180	159.1	55.1	77	152.2	205.3
Total Country	11663	20662	15993	6107	10831	20919	25,086	24430	10303
%	1.5	3.3	4.3	3	1.5	0.3	0.3	0.6	2

Source: O.C., 2021

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And even in these small quantities, it is especially important to note their very fluctuating nature, up to almost 30 times when comparing, for example, the year 2005 (with 55100 qs) with that of 1985 (with 1676000 qs). The cases of the 1985s and 1990s show how productive these lands can be when conditions meet, despite their natural fragility. The multitude of vestiges of granaries known locally as '*Ksour*', built for millennia on this land by local populations, is a testimony to the importance in terms of cereal production in these regions. It could also reflect the climate change that has occurred in the region, as most of these granaries are now neglected or in ruins.

Moreover, this wide fluctuation in figures does not allow a clear trend to be established regarding this production and confirms the risky nature of this activity. The causes of these fluctuations are multiple and vary according to the context. Weather conditions are key factors, as hot temperatures and erratic rainfall can affect the growth and yield of cereal crops. In addition, extreme weather events, such as intense and frequent droughts, can also have significant effects on cereal production in Tunisia's arid environment. Similarly, the increasing pressure on land and the low use of inputs to fertilize the soil are all factors that accentuate these fluctuations in cereal production.

2.2.2. Fluctuation of quantities produced by governorate

At the governorate level, the picture of fluctuating cereal production is the same. A first horizontal reading of the data presented in Table 17, making it possible to compare the evolution of production between the years, confirms this observation as well as that of the absence of a clear trend regarding the evolution of cereal production in the region.

Tab. 17: Evolution of cereal production by governorate between 1980 and 2020 (in 1000 qs)

Governorate	1980	1985	1990	1995	2000	2005	2010	2015	2020
Sfax	32	524.1	224	5.6	70	34.5	4.3	2.7	10.2
Gafsa	90	475.5	272	4.8	10.4	14.6	55.2	74.8	46
Gabes	27	267.8	106	74.2	4.5	1.4	9.8	0.8	48.5
Medenine	25	193.8	46	85	69.3	3.8	6.2	44.8	97.8
Tataouine	0	214.6	36	10.8	4.9	0.9	1.5	29	2.9

Source: O.C., 2021

The example of the Sfax governorate production is glaring, since the rate of the large harvests could not be maintained for two years in a row. However, when it comes to small quantities, it has been easier to follow one year after another, in the case of the years 2010, 2015 and 2020. It should also be noted that for all the governorates, of the nine years set aside for observation, only

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two years can be considered good in terms of production, which represents the very low share of around 22%.

As for the vertical reading of these data, which makes it possible to compare the production of each governorate, it clearly shows a decreasing production gradient from the governorates furthest to the north of the study area, i.e., the most "humid", i.e., Sfax and Gafsa, to the governorates furthest to the south, and consequently the most arid, i.e., Medenine and Tataouine. This moisture factor is more important in explaining the differences between the quantities of cereals produced each year in each governorate than data on the extent of arable land or the tools and means of production used by farmers. For the governorates of Tataouine and Medenine, for example, and despite the extensive sandy and sandy-loamy plains, the harsh weather conditions, including annual rainfall averages of less than 150 mm with the recurrence of dry years, make it very difficult to grow cereals and obtain large harvests. For this reason, cereal production in Tataouine did not exceed 10000 qs in more than 65% of cases. The quantities produced in Medenine and Gabes are much larger since the cultivated fields can benefit from the freshness and humidity coming from the coast.

However, whatever the variation in production between the governorates, it is important to note that the often-stormy nature of the rain in these regions is most often the cause of very local showers that sometimes extend over only a few square kilometers, which could also explain a difference in cereal production between two sectors that are geographically close. Moreover, the pace of land privatization, which is quite different between some governorates, could play a role in these quantities, since it is more the private land that is cultivated when it comes to asserting its ownership.

2.2.3. Fluctuation of quantities produced by type of cereal.

On the scale of cereal types and crop varieties, several authors agree that, given the harsh climate, the lack of rainwater resources and the fragility of the soil, it is the cereal species most suited to these conditions that are most often cultivated in southern Tunisia and top of the list is barley and then durum wheat (Ben Salem *et al.* 1995, El Felah 1998, Slama *et al.* 2005, Deghais *et al.* 2007, Gharbi & El Felah 2013, El Felah, Gharbi 2014, Babay *et al.* 2014, Khaldi & Saaidia 2018). An examination of the data presented in Figure 7 shows that the areas under barley are more than double the areas under durum wheat and more than triple the areas under soft wheat. In the South, barley is grown wherever land permits. It can be found, for example, in the mountains behind the *jessour* of Matmata, on the sandy-loamy foothills of the jebels Tebaga, Chereb, Bou Hedma and Orbata, and on the plains of the Southern Lowlands, the Jeffara and the oases of Tozeur and Kebili. In addition to its rustic character adapted to drought, it is a crop of great food interest for humans and livestock (Medimagh al. 2006).

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Fig. 7: Extension of *Ardhaoui* barley in the Menzel Habib region (Photo: A. Hanafi 2021)

As for the types of barley most cultivated, farmers have always preserved the *Ardhaoui* variety well known in southern Tunisia and whose characteristics of adaptation to the lack of water and the fragility of the soil have been demonstrated (El Felah 2011, El Felah & Medimagh 2005). Durum wheat also has, where conditions allow, significant quantities. This was the case in the years 1985 and 1990 when production reached 920000 qs and 340000 qs, respectively. In years when the crop is awfully bad, production is not completely lost because it is delivered to the herd, which is, in a way, a form of economic gain for the farmer. As regards durum wheat, although it is not important in terms of area and production, it remains a very present activity in the region, despite climatic, water and soil constraints (Ben Salem *et al.* 1995, Deghaïs *et al.* 2007, Babay *et al.* 2014, Ben Krima *et al.* 2021).

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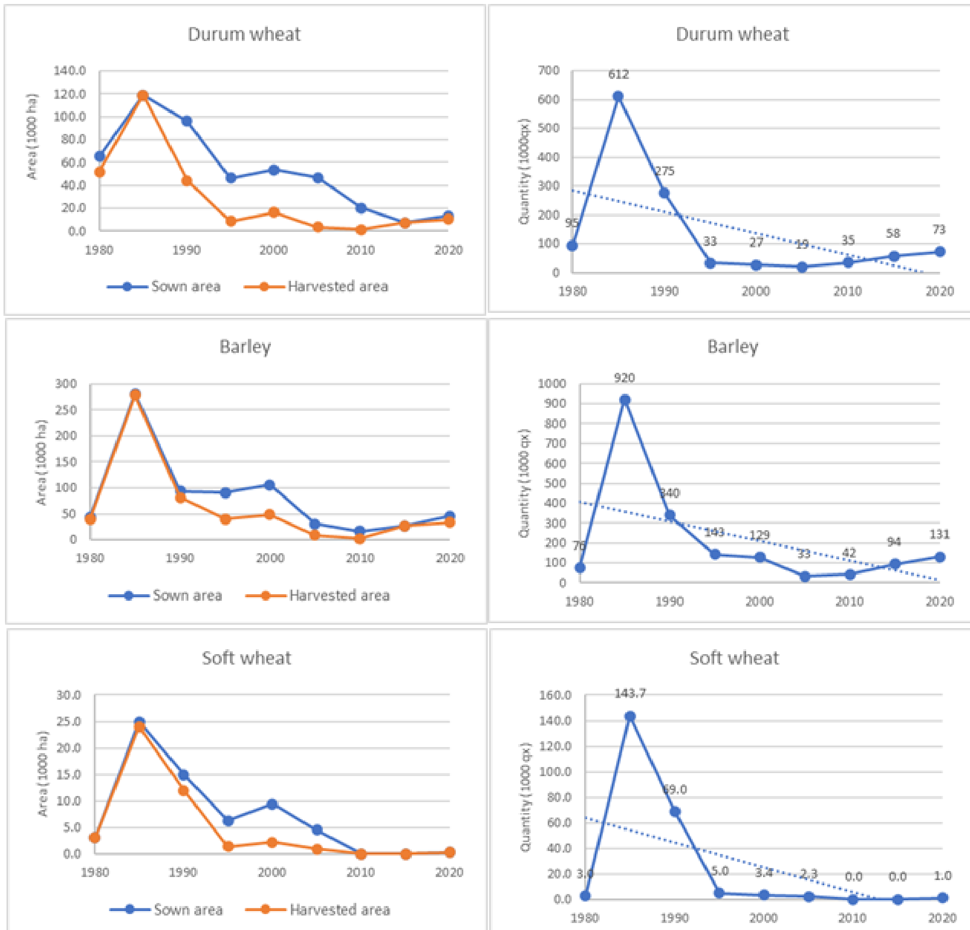

Fig. 8: Variation in area and production by type of cereal in the study area (source O.C., 2021)

Indeed, the observation of the data on durum wheat in Figure 7 shows that this type of cereal remains present in the agricultural landscape of the Tunisian arid region since it was cultivated in all the years of observation on areas, admittedly variable but with a substantial production, the case of 1985 during which the total production of the South reached 612000 qs and the year 1990 which recorded a production of 275000 qs. The main cultivated varieties are those that are local and most adapted to harsh climatic conditions, such as the *Karim* and *Mahmoudi* varieties. These crops extend on the northernmost fringe of the study area, namely the strip of plains that extend east – west between Gafsa and Sfax; as well as in the vicinity of Gabes.

The last type of cereal grown in the south to which we pay particular attention is soft wheat. Although this type of cereal is more demanding in terms of climatic conditions (more freshness), edaphic conditions (more soil moisture) and technical conditions (more agricultural inputs),

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some farmers have over the years succeeded in cultivating soft wheat, particularly in oases and in certain irrigated areas (Deghaïs 1996, Deghaïs *et al.* 2007). As a result, its areas are often reduced to no more than 25000 ha (in 1985) at best and harvests are often low to very low, with the cases of the years 2010, 2015 and 2020 during which southern Tunisia did not exceed 100 qs. The main varieties used are *Haidra*, *Salambo* and *Byrsa* grown in the oases of Tozeur and Gabès and in some irrigated areas in Sfax.

For these three main types of cereals grown, we note a downward trend in production, particularly in the last decade 2010-2020, despite the efforts made by the competent agricultural services as well as by farmers in terms of technical progress and greater use of agricultural inputs. It should be noted, however, that this decrease is due to the reluctance of young farmers to engage in this very risky agricultural activity.

III. CONSEQUENCES OF CEREAL PRODUCTION FLUCTUATION AND THE SUSTAINABILITY OF PRODUCTION SYSTEMS

1. Low yields of cereal production

Since independence, the State has implemented several agricultural policies at national level aimed at improving the yields per hectare of cereal production (Boughanmi 1995, El Heni 1997, Slama *et al.* 2005, Ammar *et al.* 2011, Bachta 2011, Ben Said *et al.* 2011, El Felah and Gharbi 2014, Elloumi 2015, Khaldi and Saaidia 2015 018). These policies have attempted to address all components of the production chain, from the promotion of research on seed improvement, to the optimization of techniques and means of harvesting and storing crops, to the improvement of means and agricultural practices, especially in the use of inputs. Despite these efforts, however, yields remained below the expectations of the competent services, in particular because of the inability to manage certain parameters such as rainfall spatiotemporal distribution, weed invasion or soil quality degradation. As a result, yields have always averaged around 12-15 qs / ha (World Bank 2022, ONAGRI 2022), while rising under similar bioclimatic conditions (semi-arid to arid) to an average of 20 qs / ha in China and above 25 qs / ha in the United States (Couturier & Doublet 2022).

In the Tunisian arid region, this situation is even more complicated since the figures obtained give an overall average for the three types of cereals studied and over the whole observation period 1980-2020 of only 6.4 qs / ha with, nevertheless, a slight upward trend, particularly during the last decade 2010-2020, during which the yield reached 9.3 qs / ha. It remained, however, fluctuating from year to year, falling from 17.9 qs in 2010 to 3.9 qs in 2015.According to Nasraoui (1996 cited by Slama *et al.* 2005), one of the first challenges for agricultural services in the 1990s was to improve cereal yields by favoring varieties that are highly adapted to adverse climatic conditions and provide a stable yield without necessarily being high. Thirty years later,

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despite tests on genetic improvements in cereal seed, yields have not been stable and weather conditions have always had a say in production. Moreover, these conditions have most often prevented farmers in Tunisia's arid region from investing in tillage, agricultural infrastructure, or the intensive use of productivity-enhancing agricultural inputs.

Tab. 18: Average cereal yields evolution in the study area between 1980 and 2020

	1980	1985	1990	1995	2000	2005	2010	2015	2020	Average
Southern Tunisia	1.8	3.9	4.6	5.5	2	11.3	17.9	3.9	6.3	6.4
Total Country	11	13	12	10	10	18	20	8	5	11.9

Source: O.C., 2021

Fig. 9: Poor yield of barley in Jeffara collected manually by women (Photo: H. Nouri 2002)

2. Greater economic and social precariousness

Although this is not common on farms in Tunisian arid region, fluctuations in cereal production can have effects on the environment due to increased pressure on natural resources such as water and soil to maintain their fertility and irrigate crops, especially in oases. According to Gafrej (2017), the MARHP (2020) and the ODS (2020), the over-exploitation of groundwater resources described above, reaching 216% in Kebili and 212% in Chott El Fedjej and Djerid, led to a decrease in the level of the water tables and a deterioration in the quality of the water. Although farmers in the South do not use water to irrigate large grain fields in Menzel Habib-Segui and Gafsa, for example, it is on small-scale farms in oases that this practice is conducted, especially below date palms. It most often leads to over-exploitation of soils and sometimes overuse of

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pesticides and chemical fertilizers, which affects the long-term resilience of soils and agroecosystems and calls into question their productive capacities.

From an economic point of view, weak and fluctuating cereal production can have important economic consequences for farmers, whose economies often depend on income from the sale of crops, the cases of small farmers in Gafsa and Menzel Habib - Segui who devote a large part of their land to this activity each year. This includes the significant financial losses caused by under harvesting, which may affect the ability of small farmers to invest in sustainable farming practices, extension of cereal land and improved yields in subsequent years. Furthermore, this situation may lead some of them to further impoverishment, in particular those whose incomes are dependent on cereal production, which puts them in a precarious economic situation and encourages the most discouraged among them to migrate in search of more economic opportunities.

Moreover, although this has not been demonstrated by previous studies in southern Tunisia, low and fluctuating cereal production is most often the cause of increased dependence on subsidies to cover the excessive expenses of farmers who find themselves forced to spend more to buy food and their herds and especially to buy cereal seeds for the following year. Examination of the data presented in Table 19 shows the increase in demand for barley distributed by the Cereals Board in three southern governorates from more than 947000 qs in 2018 to more than 1908000 qs in 2022, i.e., a 101% increase in five years; and it is the governorate of Tataouine which recorded the highest rate of increase with 188.9% for feeding the sheep after the three years of drought 2019-21.

Tab. 19: Evolution of demand for barley for livestock feed in some study area governorates between 2018 and 2022 (in 1000 qs)

Governorate	2018	2019	2020	2021	2022	Rate of increase 18-22
Gabes	225,254	294.69	327,069	354,711	382,123	69.6
Medenine	474,913	621,956	716,315	797,293	812,021	71.0
Tataouine	247,225	424,144	605,917	703,312	714,159	188.9
Total	947,392	1340.79	1649,301	1855,316	1908,303	101.4

Source: O.C., 2023

Moreover, in these "bad agricultural years," and with the decline in domestic cereal supplies, the government is forced to import copious quantities of cereals to meet domestic demand. This creates a dependency on international markets, which can make the country vulnerable to fluctuations in world grain prices. Moreover, the recent years, characterized by the Russian-

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Ukrainian war, have shown how fragile the Tunisian economy has been, since it has been hit hard by this war and the State has found great difficulties in maintaining the pace of cereal imports from these two countries, especially after the surge in prices on the international market. According to World Bank figures[10], the inflation rate for consumer products in Tunisia rose from 4.44% in 2015 (against a world average of 1.43% in the same year) to 8.31% in 2022 (against a world average of 8.27%). As a result, family economies have been hit in part because of their inability to balance their purchasing power in addition to the shortage of food on the market.

3. A finding of increased food dependency

In Tunisia, people's diets have traditionally been based on cereals. Although the quantities consumed have been steadily declining since the 1980s, the average per capita consumption of cereals remains extremely high and is estimated at 174.3 kg in 2015 (Khaldi and Saaidia 2018, Hanafi 2022a). In addition, because of changes in eating habits with the increase in consumption of soft wheat products, consumption of soft wheat has increased significantly, to the detriment of durum wheat and barley, from 72.2 kg/inhabitant/year in 1985 to 92.7 kg/inhabitant/year in 2015 (Chebbi *et al.* 2019).

Tab. 20: Evolution of the average consumption of some cereal products in Tunisia (kg/hab.) between 1995 and 2015

Product	1995	2005	2015
Industrial couscous	8.6	10.1	11.4
Pasta	12.3	11.9	15.4
Soft wheat flour powder	4.5	4.3	4.3
Bakery bread	65.7	69.8	73

Source: Khaldi and Saaidia 2018, Hanafi 2022a.

This table shows a slight increase in the consumption of durum wheat products, especially pasta, which increased from 12.3 kg/hab in 1995 to 15.4 kg/hab in 2015. However, the highest increase in consumption was recorded for bread made from soft wheat, whose consumption increased from 65.7 kg/hab in 1995 to 73 kg/hab in 2015. And when you consider that the country is not a major producer of soft wheat, let alone the arid region of Tunisia, you can imagine the extremely low level of food self-sufficiency in which the population finds itself. According to Khaldi and Saaidia (2018), the dependency in consumption on soft wheat is increasingly observed in rural

[10] Link: Inflation, consumer prices (% annual) - Tunisia | Data (banquemondiale.org)

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areas compared to urban areas, since the poverty level of the rural population often forces them to be content with a diet based on cheap products, including those based on soft wheat.

The fluctuation in domestic cereal production, which is unable to meet growing demand, particularly for soft wheat for bread, has led to a chronic dependence on imports (Chebbi *et al.*, 2019). In 2022, Tunisia imported about 42 million qs of food products with a total value of 6.9 billion dinars[11]. Among these imported products is soft wheat, which accounts for 18.7% of total imports, i.e., almost 13 million qs. The value of this soft wheat import increased from around 1.1 billion dinars in 2021 to over 1.6 billion dinars in 2022, despite a 1% decrease in imports between the two years. The explanation for this increase is simply due to the soaring prices recorded from 2022 because of the Russian-Ukrainian war since the price per kilo went from 0.85 dinars to 1.28 dinars, an increase of about 50.2%(ONAGRI 2023). Despite these imports, however, several deficiencies continue to be observed in the country, especially among the rural populations of the arid Tunisian region.

This is a population that has undergone a profound transformation of its food traditions, which used to be based on barley and durum wheat produced locally (*Couscous*, *Malthouth*, *Borghol*, *Bsissa*, *Mhamssa*...) as well as other local agricultural products such as dates and dried figs, and which made it possible to maintain an acceptable level of food autonomy. In addition, the gradual abandonment of these traditional dishes and the use of soft wheat food had an impact on the transmission of traditional culinary know-how in relation to barley and durum wheat. The gradual abandonment of barley and durum wheat crops has gradually led to a reduction in the use of the receipts and the techniques used to prepare them. This is the case, for example, with the manual technique used by rural women to prepare traditional couscous, which is now being used less and less in Tunisian arid region. The changes have also affected techniques for preserving cereal products, which are unfortunately being lost by rural populations. The tradition *of El Oula*[12], based on traditional techniques for collecting and storing food for humans and their livestock, was used to ensure a degree of household food self-sufficiency and limit the effects of climate and economic uncertainty. Today, the abandonment of this tradition has affected the food security of farmers and rural populations in general.

[11]In 2021, 1 dinar (TND had an average value of 0,372 USD. In 2022, this value decreased to around 0,332USD.

[12]*El Oula* is a term in the Tunisian dialect that designates "the food reserve". This is a tradition that dates to the Berbers and was widespread in North Africa and the Sahara. It consists of the storage by the families of the farmers, but not only, of food during periods of peace and/or of large production to consume during periods of war and/or famine. In the study area, this tradition was embodied, among other things, in the construction of the *Ksour* and cave-like granaries that were used to store cereals, olive oil, dates and any other food that could be preserved.

a: Storage of barley for livestock *b: Preparation of El Oula couscous*

Fig.10: Traditional methods of valorizing cereals in the arid region of Tunisia (photos: A. Hanafi 2022)

It should be noted, however, that rural populations did not have much choice in safeguarding their food traditions, since the increase in demand for food following the increase in population numbers accompanied by the weakness and instability of cereal production, especially in southern Tunisia, led the inhabitants and the State to resort to the consumption of imported soft wheat. The problem is that today the agro-breeders in the study area are suffering twice, as their cereal production is low, and imports are unable to meet their food needs.

4. How sustainable are the food systems in Tunisian arid region?

Sustainability is a concept that relates to "sustainable development". It has been developed since the late 1980s by the International Union for Conservation of Nature (IUCN) and the United Nations Environment Program (UNEP). It was a response to the introduction in the early 1970s and 1980s in developed countries of very liberal economic policy guidelines, and the application in several Third World countries of the "Structural Adjustment Programs" initiated by the World Bank and the IMF (Leroy & Lauriol 2011, Massin *et al.* 2016). In 1987, the United Nations report prepared by the World Commission on Environment and Development (WCED), known as the Brundtland Report, defined sustainable development as "*a mode of development that meets the needs of present generations without compromising the ability of future generations to meet their own needs*" (Brundtland 1987).

One of the main components of this economy, which is intended to be sustainable, is peasant agriculture, which must have a fundamental place in development projects and must be supported to maintain the economic and social equilibrium of rural populations. However, the

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current findings of this type of agriculture in the Tunisian arid region run counter to the definition of sustainable agriculture put forward by Landais (1997)[13] and suggest a more than mixed economic, social, and environmental record.

Indeed, on an economic scale, it should first be noted that the spatial dynamics that have occurred in the arid region of Tunisia, particularly since the 1990s, have seen an acceleration in the pace of olive plantations and vegetable crops, not only at the expense of the steppes but also at the expense of the land formerly used for episodic cereal cultivation in the plains (Guillaume *et al*. 2006, Romagny and Hajji 2006, Hanafi 2010, 2022a). As a result, farms, which are often small, are unable to produce enormous quantities of cereals. Recalling here that most traditional production systems in the Tunisian arid region were characterized by the valorization of a small area intended for cereal cultivation around 2 to 5 ha. Today, and with the strong control of tree-growing on these lands, this average has been revised downwards to no more than 3 ha for most farms (Hanafi 2010, 2022b). Near the oases of Gabes, Tozeur and Kebili, where agricultural ownership is reduced, the area for cereal cultivation on farms does not in most cases exceed 1 ha (Hanafi and Naoui 2022).

It is this small size of these cereal areas that is, moreover, one of the reasons why production and yields have remained low since small farmers are making less and less effort to engage in risky financial and logistical investments (purchase of excellent quality seeds, fertilizers, agricultural equipment, rental of tractors for plowing...). Interviews in 2021 with farmers in Skhira to find out their future agricultural orientations showed that most farmers are aware of the impact of climate change on cereal farming, with a strong recurrence of dry years, they said, making this activity “very risky and unprofitable”. They also stressed that if they found ways to invest, it would be in olive or greenhouse farming. Very few spoke of a desire to expand or even keep the grain acreage in possession. In addition, the difficulty of these farmers stems from the fact that the small size of their farms does not allow them to easily benefit from state subsidies and bank loans, especially since most of them do not have private property titles or have outstanding loans from previous years. But farmers’ weak commitment to investing in grain also comes from the “competition” that soft wheat offers to feed the locals. This competition, dating back to the first half of the 20th century (Hanafi 2022a), significantly altered food systems in southern Tunisia not only in terms of food production but also in terms of storage traditions and recipes used as well as in terms of culinary know-how that was in harmony with the environment and with available resources.

[13] Landais (1997) defines sustainable agriculture as "*a viable, livable, transmissible and reproducible agricultural enterprise*".

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CONCLUSION

Although cereal farming is not a flagship agricultural activity in Tunisian arid region, it has made us even more aware of the vulnerability of traditional agroecosystems and small farmers affected by the various crises that have hit the country since 2011 and who, as a result, have lost their means to maintain their balance. Despite its low production and fluctuating yields, cereal farming has previously played a key role in the sustainability of food systems in the South, through the implementation of agropastoral production systems favoring the application of rational practices and the intergenerational transmission of food know-how that made it possible to provide for families and limit the effects of hazards. Some 40 years after the beginning of an open and liberalizing economic policy (Jouili 2008), cereal farming in southern Tunisia has lost all its means and is no longer able to meet the food needs of the inhabitants of the region that even the State is unable to solve, as witnessed by the food crisis that the country has been plunged into since the outbreak of the Russian-Ukrainian war in 2022.

It also emerges from this analysis that cereal cultivation in southern Tunisia is a declining activity due to its inability to maintain interest among farmers in the region as well as its inability to meet the growing food needs of a rural population victim of a food policy that has long prioritized security (based on imports) rather than sovereignty (based on production). It is this policy that is probably at the origin of the timid attempts of the state to solve the problems of the cereal industry linked to the fluctuation of its production and its yields. Indeed, aside from government support for seeds and fertilizer, farmers must find the means to cultivate their land on their own.

In southern Tunisia, even these aids are not always accessible since the Cereals Office does not have seed storage silos in the southern governorates except Gafsa and Sfax. As a result, small farmers in Medenine and Tataouine, for example, if they want to have seeds, must keep them themselves from their farms or buy them in the nearest spontaneous souks without any guarantee as to the origin and quality of the product. Otherwise, they must make the long journey to Gafsa or Sfax to get state-controlled seeds. It should be noted, however, that it is these difficulties encountered by farmers that have enabled them, nevertheless, to preserve their peasant seeds (the case of *Ardhaoui* barley) and to avoid losing them in often unsuccessful exchanges and crosses. As regards the use of fertilizers, it should be noted that most farmers in the country where cereals are grown use little fertilizer. Even less so are farmers in southern Tunisia, except for a few farmers from Menzel Habib - Segui, Gafsa and a few small farmers from the oases.

As a result, crops based on barley and durum wheat are becoming less and less important for the region’s rural populations, not only because their production is fluctuating and not very guaranteed, but also because these products are no longer a priority for them in terms of food that

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is increasingly focused on imported soft wheat. This has led to a shift in agropastoral production systems towards ‘more profitable’ crops, as well as a transformation of food systems, with a gradual loss of traditional southern cuisine and all the know-how that went with it. Today, the sustainability of these food systems is deeply compromised, and its years-long disruption of balance has reached a near-irreversible threshold.

Today, in order to meet the challenge of regaining lost food sovereignty, it is important to include the cereal farming of the Tunisian arid region in a national project that must focus on the sustainability of food systems by favoring local products obtained from sustainable agriculture and not depredatory of water and soil resources. This is an agriculture that needs to find *in situ* solutions to fluctuations in cereal production and pressure on natural resources. This could include strengthening traditional agriculture, which is known in southern Tunisia for its strong resilience since it has withstood economic and natural hazards for millennia and strengthening traditional food systems. To this end, local culinary traditions should be preserved and enhanced, and the transmission of food know-how strengthened. This could include, for example, promoting the consumption of local and seasonal products, which could contribute to the diversification of food and the preservation of traditional dishes and recipes.

But to achieve these goals, we need to start with the farmer by building his capacity and knowledge about sustainable farming practices. This will improve agricultural production and strengthen farmers’ resilience to hazards. This can include training in soil conservation techniques and water resource management, crop rotation and the use of drought-resistant varieties, the use of modern agricultural technologies, crop diversification, improvement of agricultural infrastructure, access to food storage and conservation systems, and the promotion of agricultural policies that encourage investment in agriculture and protect the interests of small farmers.

All these actions must be accompanied at state level by the adoption of an integrated approach, involving local stakeholders and decision-makers to limit the risks of program failure and ensure the sustainability of the actions undertaken. Past experiences in southern Tunisia have shown that this integrated approach has often been lacking in the applied programs, resulting in their total or partial failure. Often conducted by actors outside the territory, these programs have most often neglected the fragility of agroecosystems, socio-economic dynamics, as well as local know-how in the management of natural resources. This has resulted in conflicts over access to resources and disruptions to agroecosystem imbalances that have also resulted in social exclusion and environmental degradation (Mzabi 1993, Ayeb 2013). That is why it is now important to use the country’s food economic crisis and the food systems in southern Tunisia to draw the right lessons and to think about putting in place a strategy that must place cereal farming in a national context of food self-sufficiency based on local resources and production and a return to food traditions that will preserve water and soil resources and limit the country's economic dependence on the outside world.

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